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AGS Machine Studies

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U.S. Department of Energy

USDOE Office of Science (SC)

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RHIC/AP/40
Oct. 5, 1994

AGS Machine Studies

Jie Wei, BNL, September 27, 1994

I. Introduction

II. Machine Study Summary

* transition crossing at slow ramp rate
  α_1 measurement, beam loss vs. $\dot{B}$, V_{rf}, etc.
* comparison with computer simulation
  cable loss and bandwidth limitation
* γ_t-jump study & α_1 measurement
* to meet RHIC proton specifications
* rf gymnastics for extraction to RHIC

III. Future Study Plan

* more studies on intensity dependence
* more studies on γ_t-jump
* intrabeam scattering study at AGS injection
* studies to achieve RHIC beams (proton, Au^{77+})

IV. Conclusions

Personnel:

AGS:

L. Ahrens
J.M. Brennan
K. Reece
T. Roser
W. Van Asselt

RHIC:

R. Connelly
D-P. Deng
W.W. Mackay
S. Peggs
A. Ratti
J. Rose
W.A. Ryan
C. Saltmarsh
T. Satogata
D. Trbojevic
A. Warner
J. Wei

Acknowledgements: AGS operation crew

I. Introduction

Goals:

1. To understand and verify accelerator physics issues pertaining to RHIC operation

   transition crossing; γ_t-jump; intrabeam scattering, etc.

2. To meet RHIC beam quality specifications

3. To meet RHIC injection conditions

   rf gymnastics, etc.

Study Time	Status	Run Date	Purpose
8 shifts	Au^{77+}	10/1993	slow-ramp transition crossing
			rf gymnastics J.M. Brennan MAC 94.1
2 hours	down	7/7/1994	cable loss and bandwidth measurements
4 hours	proton	7/21/1994	meet RHIC specifications
2 hours	proton	7/27/1994	γ_t crossing at various intensity
2 hours	proton	7/28/1994	α_1 measurement with γ_t-jump on
1 hour	Au^{77+}	9/27/1994	injection flattop study, IBS preparation

II. Machine Study Summary

Slow ramp rate transition crossing

* slow ramp, similar to RHIC transition crossing, (low intensity) chromatic nonlinear effect (α_1) is dominant;
* measure the rf phase switching time for minimum beam loss at different radial orbit, evaluate α_1 factor;
* measure beam loss versus rf voltage, ramp rate, and rf phase-switch timing;
* compare with computer simulation result from TIBETAN under the same conditions (measured V_{rf}, ramp rate, and emittance).

Single-particle effects

* Chromatic non-linearty (Jøhnsen effect)

* timing mismatch, non-linear bucket

  ⇒ longitudinal dipole-mode oscillation, beam loss

Multi-particle effects

* bunch-bucket mismatch due to self fields

  longitudinal quadrupole mode, beam loss

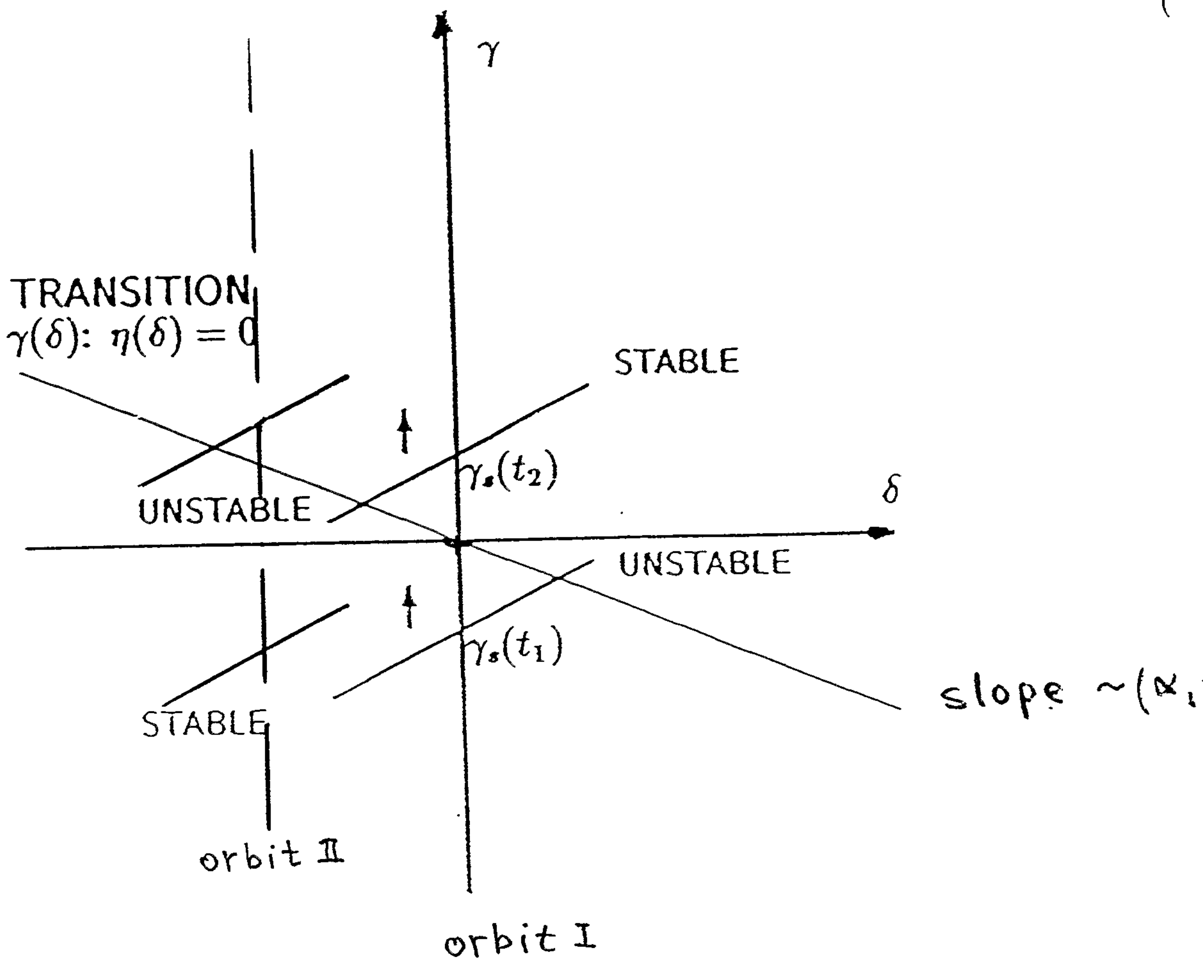
* combination of self fields and non-linearity

  high current, slow ramp, e.g. RHIC

* micro wave instability

  beam microwave signal, break up.

  secondary bunches



$$\frac{\Delta\gamma_T}{\gamma_{T0}} = \beta^2 \frac{\dot{B}}{B} \cdot \Delta t = -(\alpha_1 + \tfrac{3}{2}) \cdot \delta$$

particles of different momenta cross transition at different time transition energy : γ_T

$$\eta(\delta) = -\frac{d\omega/\omega}{d\delta} = 0 \qquad \delta \equiv \frac{\Delta p}{p}$$

$$\left(\alpha_0 - \frac{1}{\gamma_T^2}\right) + 2\left(\alpha_0 \alpha_1 + \frac{3}{2}\frac{\beta^2}{\gamma^2}\right)\delta = 0 \quad , \quad \alpha_0 \equiv \frac{1}{\gamma_{T0}^2}$$

$$\frac{\Delta \gamma_T}{\gamma_{T0}} = -\delta \cdot \left(\alpha_1 + \frac{3}{2}\right)$$

$$\boxed{\beta^2 \cdot \frac{\dot{B}}{B} \cdot \Delta t = -\delta \cdot \left(\alpha_1 + \frac{3}{2}\right)}$$

* vary δ by displace the radial orbit (V_{CMD})

1. from L. Ahrens, measure $\frac{\Delta\omega}{\omega}$ vs. ΔV_{CMD}

   $\Rightarrow$ $\frac{\Delta p}{p}$ vs. ΔV_{CMD}

2. from IPM centroid measurement , & dispers

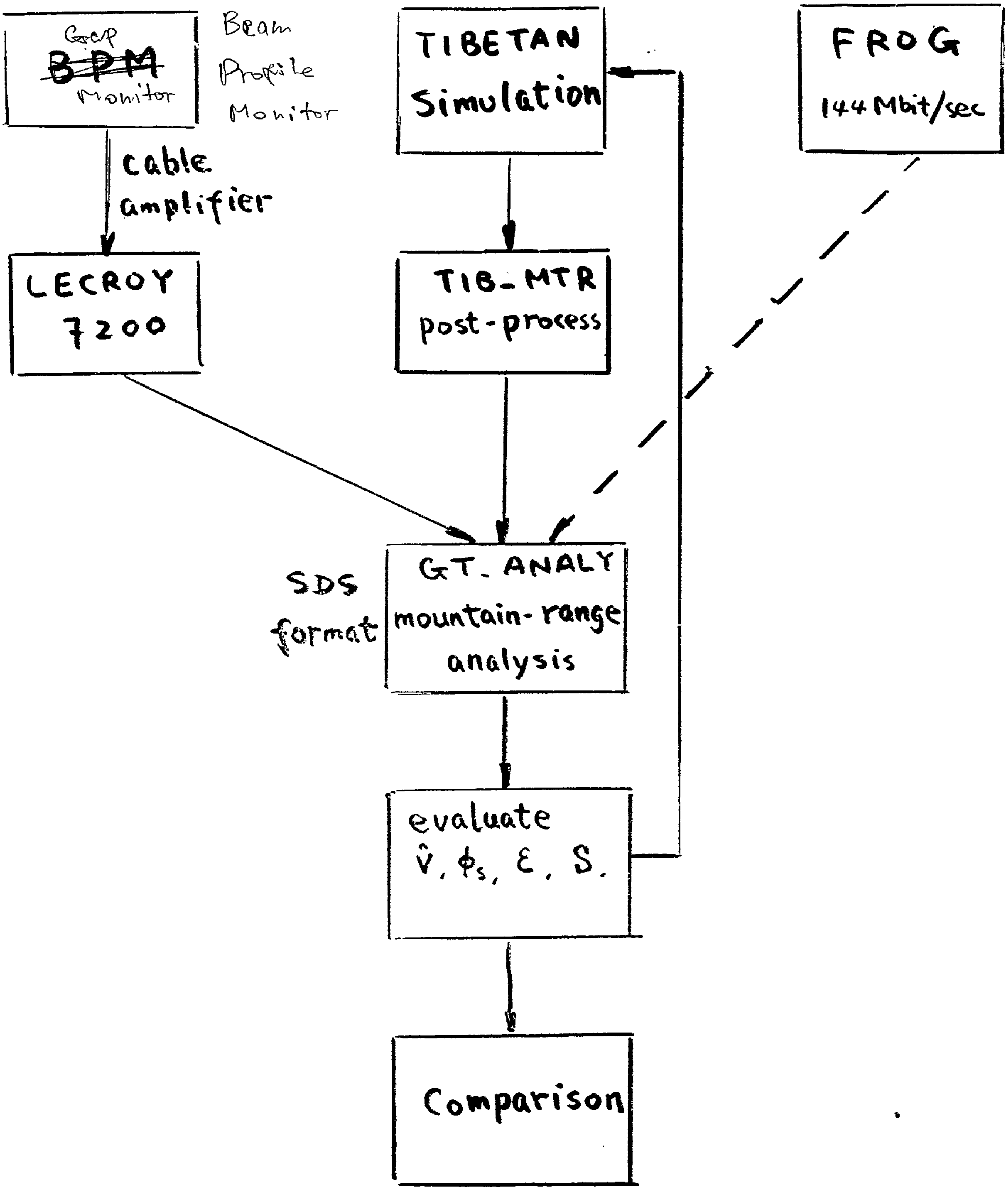
   $\Rightarrow$ $\frac{\Delta p}{p}$ vs. ΔV_{CMD}

* Δt : measure beam loss vs. delay time for phase switch-over

minimum beam loss $\Leftrightarrow$ transition energy

confirmed by simulation

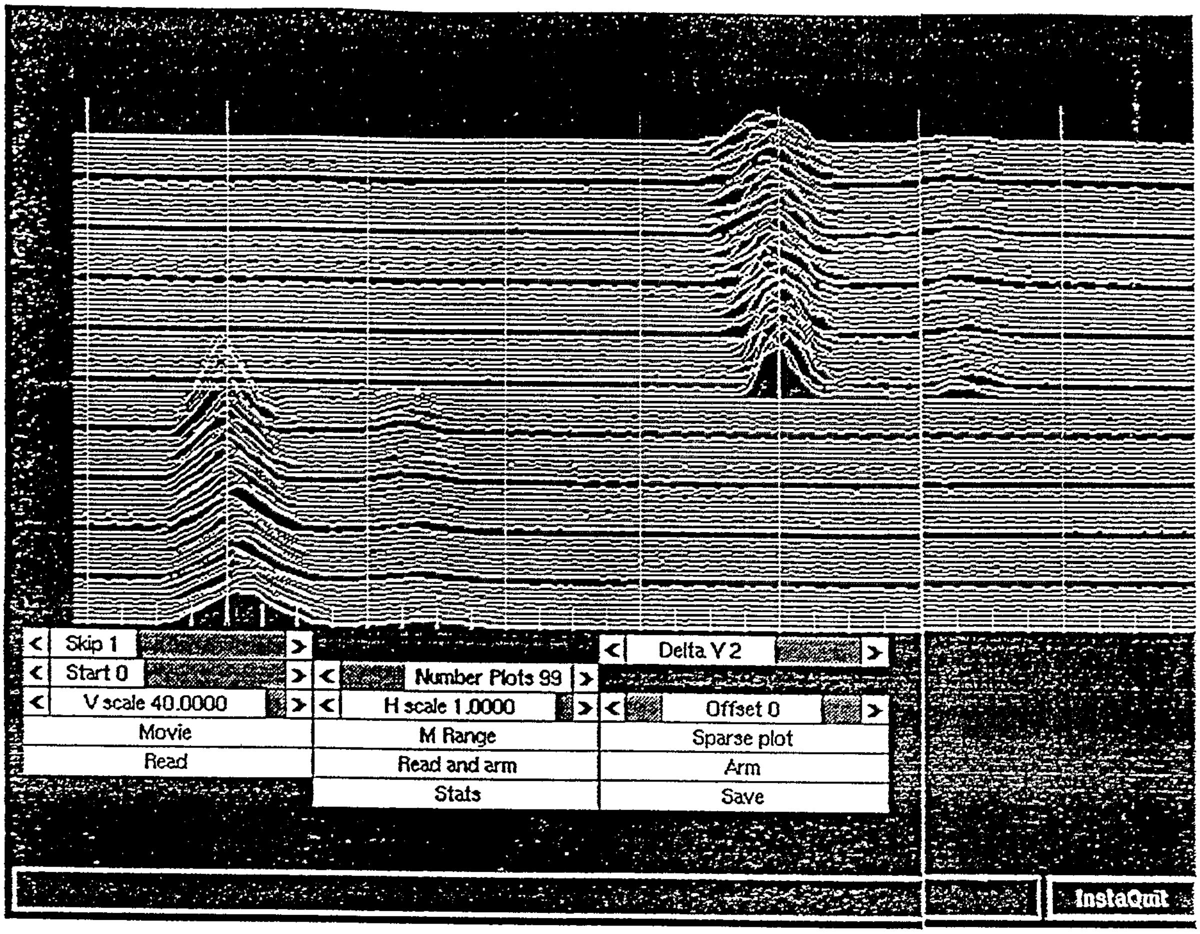
Experimental set-up & data reduction



LECROY 7200

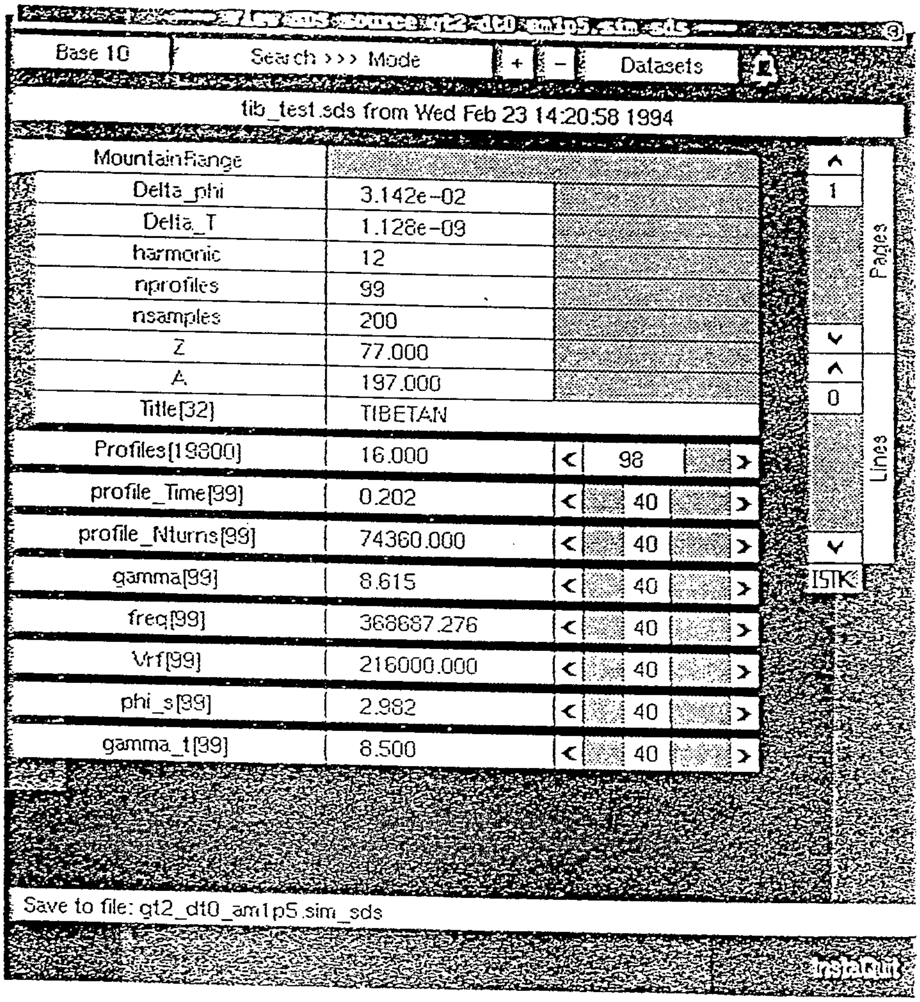
⇓

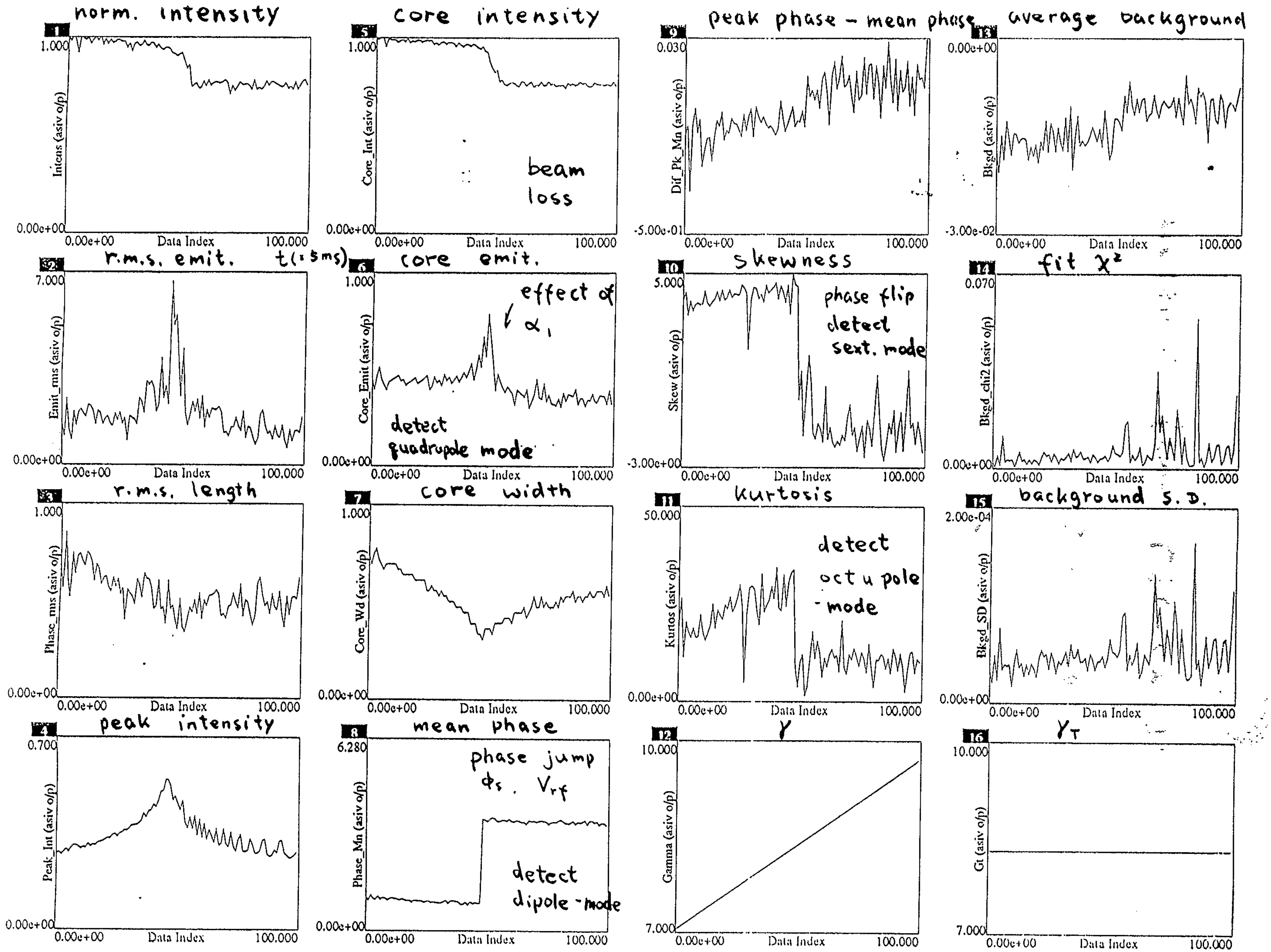
SDS



* Background subtraction
* Evaluation of intensity and r.m.s. bunch length
* Evaluation of bunch "core" intensity and widt
* Extraction of beam emittance (longitudinal)
* Evaluation of phase jump, rf voltage, peak intensity, skewness, kurtosis, etc.

SDS (Self-Describing Structure)





norm. intensity
1
1.000
0.00e+00
Intens (asiv o/p)
0.00e+00
Data Index
100.000
core intensity
5
1.000
0.00e+00
Core_Int (asiv o/p)
beam loss
peak phase – mean phase
9
0.030
-5.00e-01
Dif_Pk_Mn (asiv o/p)
average background
13
0.00e+00
-3.00e-02
Bkgd (asiv o/p)
r.m.s. emit.
t(×5ms)
2
7.000
Emit_rms (asiv o/p)
core emit.
6
effect of α_1
Core_Emit (asiv o/p)
detect quadrupole mode
skewness
10
5.000
-3.00e+00
Skew (asiv o/p)
phase flip
detect sext. mode
fit χ^2
14
0.070
Bkgd_chi2 (asiv o/p)
r.m.s. length
3
Phase_rms (asiv o/p)
core width
7
Core_Wd (asiv o/p)
kurtosis
11
50.000
Kurtos (asiv o/p)
detect octupole -mode
background S.D.
15
2.00e-04
Bkgd_SD (asiv o/p)
peak intensity
4
0.700
Peak_Int (asiv o/p)
mean phase
8
6.280
Phase_Mn (asiv o/p)
phase jump ϕ_s, V_{rf}
detect dipole-mode
γ
12
10.000
7.000
Gamma (asiv o/p)
γ_T
16
Gt (asiv o/p)

* Calibration of B field J.M. Brennan

Gauss clock reading calibrated by frequency measurement

* Calibration of rf voltage V_{rf}

evaluate ϕ_s from transition phase jump

calculate V_{rf} from ϕ_s and $\dot{B}$

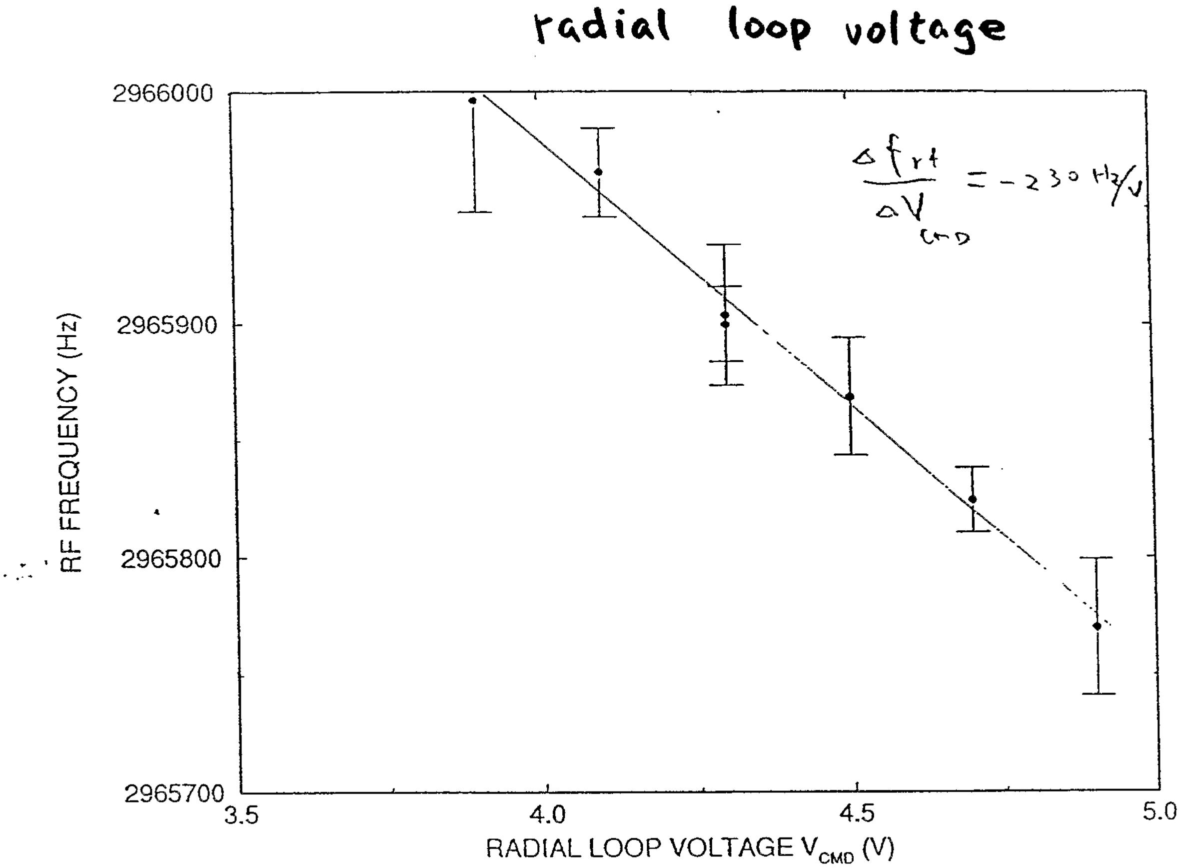
* calibration of bunch length

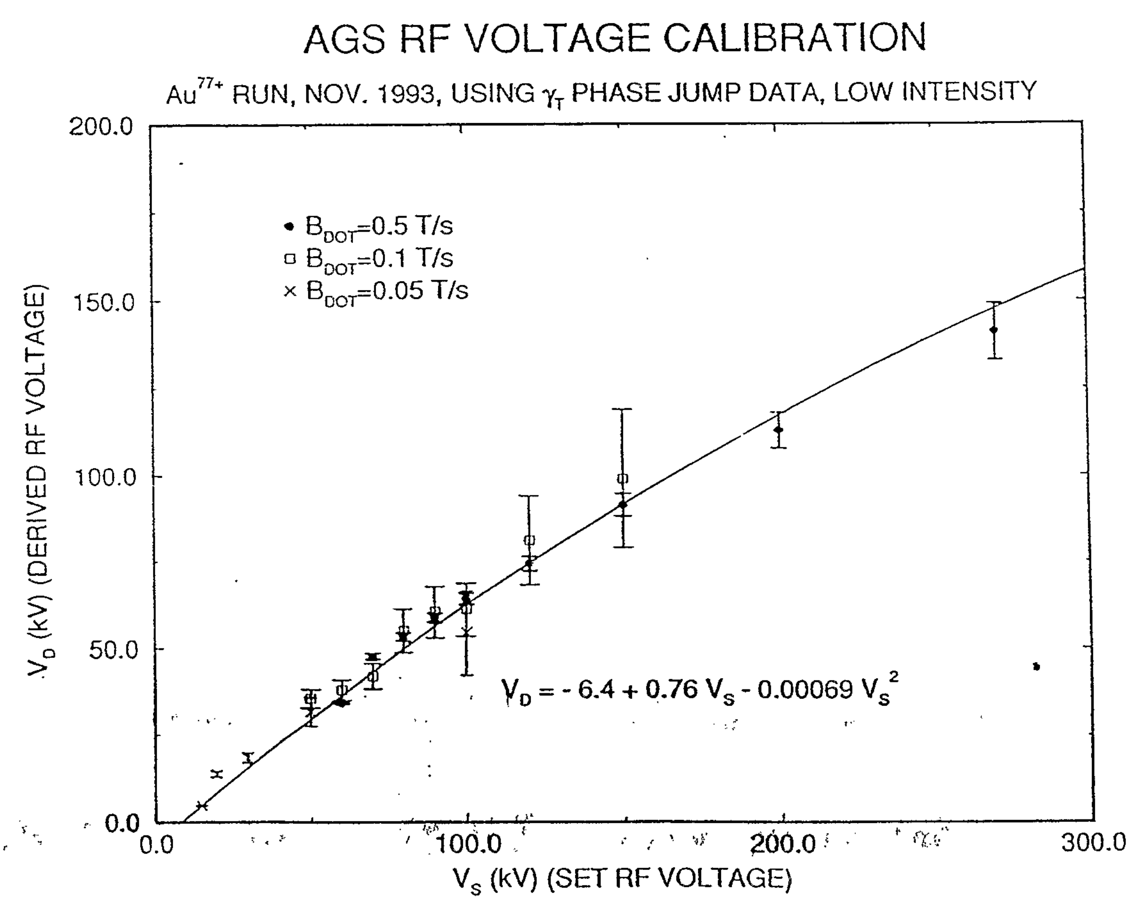
measure signal broadening due to cable attenuation and bandwidth limitation

(insert 1 ns ~ 15 ns signal at BPM

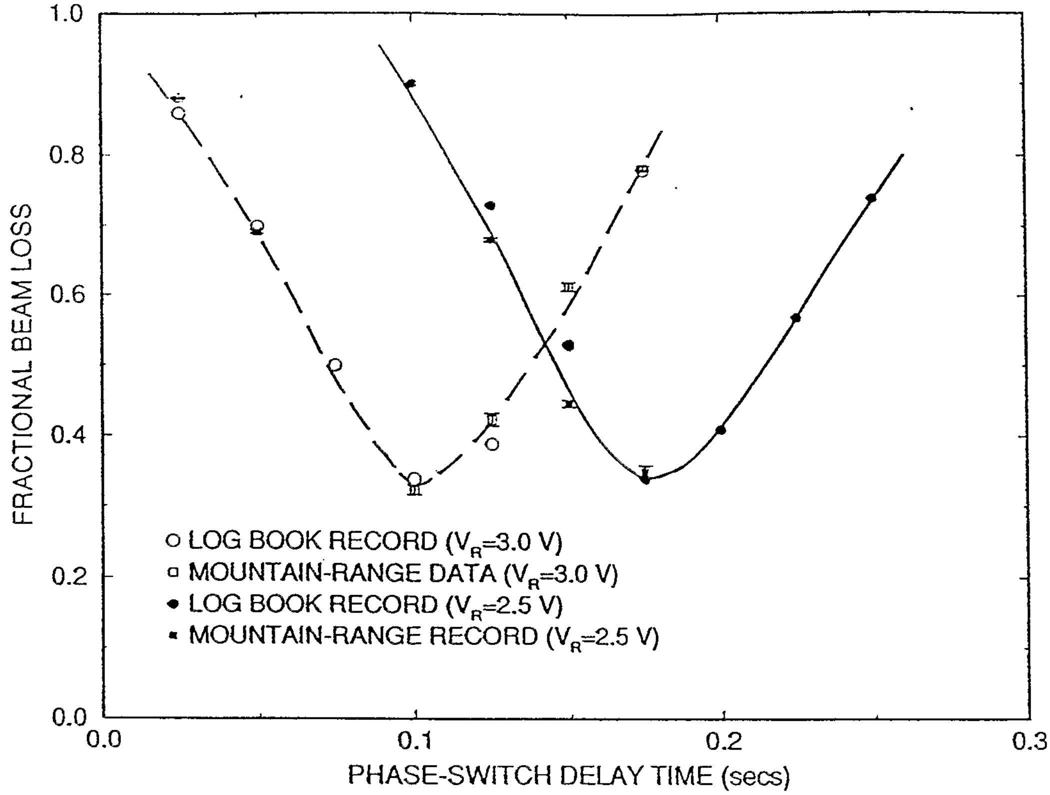
measure from LECROY 7200)

Calibrations





extraction of α_1 factor



$$\beta^2 \frac{\dot{B}}{B} \cdot \Delta t = -\delta \cdot (\alpha_1 + \tfrac{3}{2})$$

(I_H, I_V) (A)	(190, 0)	(0, 200)	(0, 0)
γ_{t0}	8.28	8.34	8.31
α_1	2.1±0.5	4.5±0.9	5.4±1.0

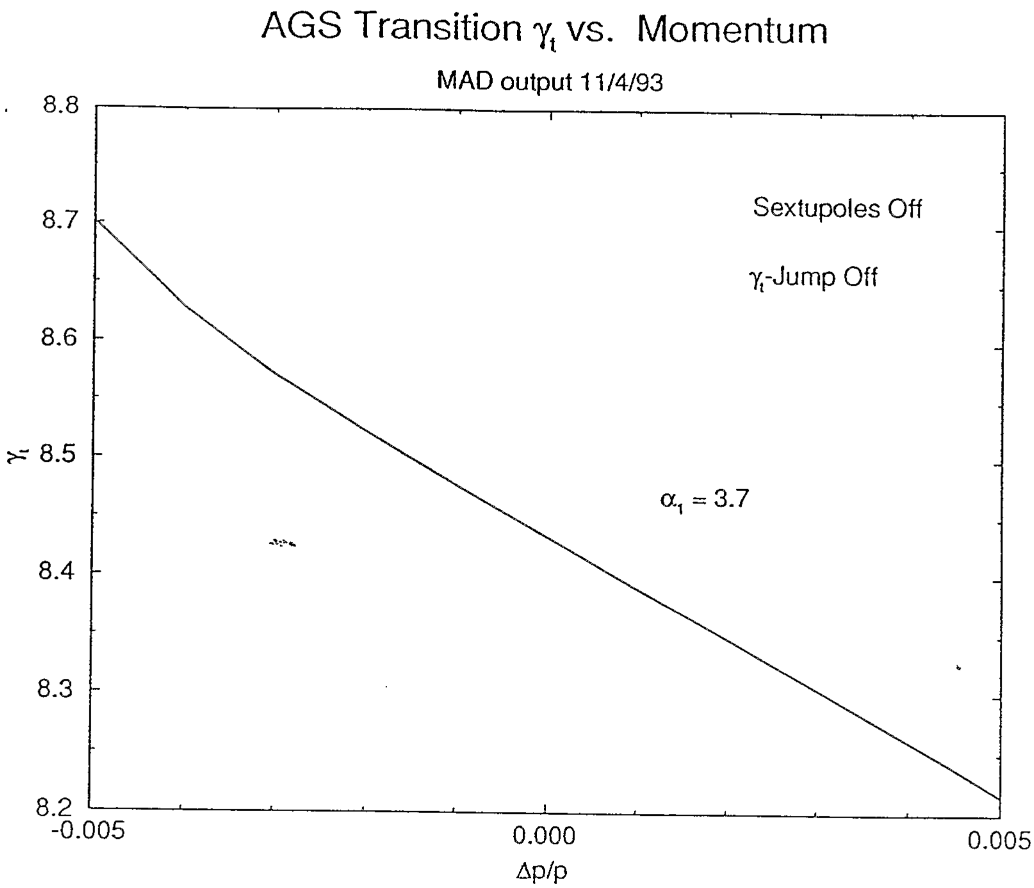
← sextupole currents

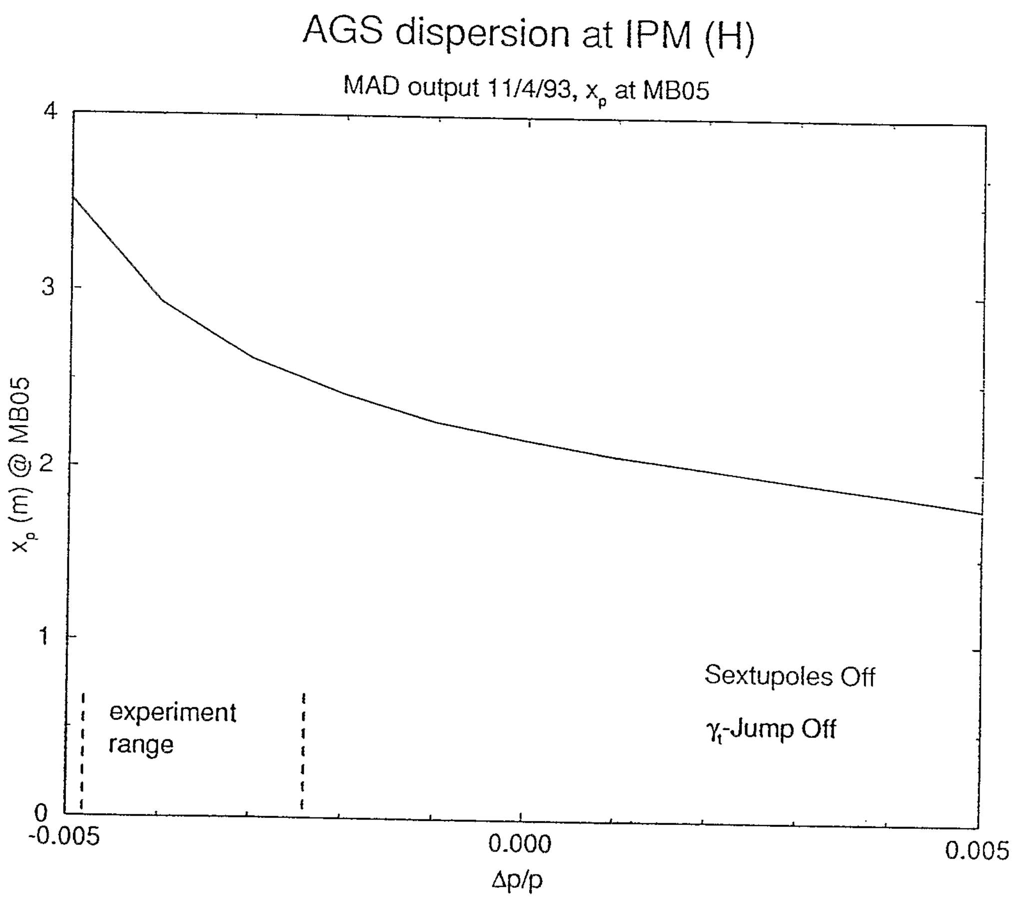
MAD α_1 : 3.7

SYNCH α_1 : 0.4 ?

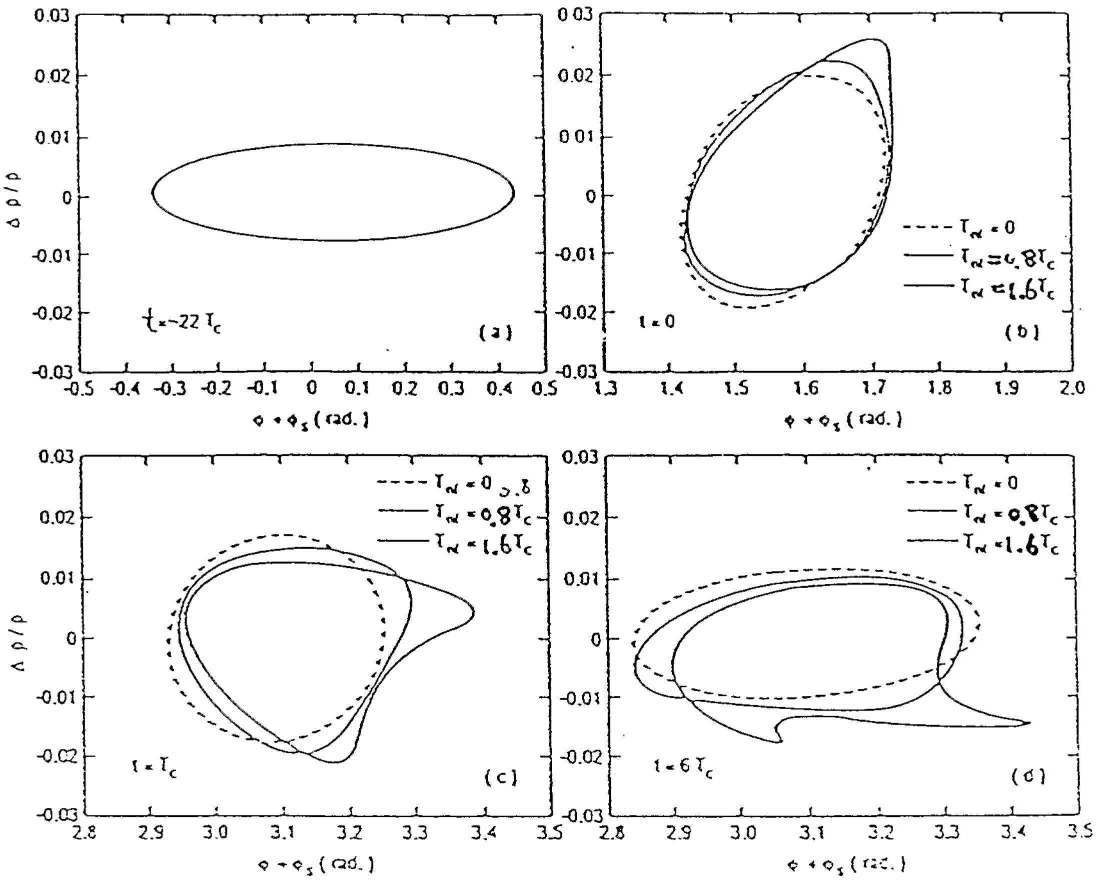
agrees with MAD calculation

consistent with IPM measurement (centroid)


AGS Transition γ_t vs. Momentum
MAD output 11/4/93
8.8
8.7
8.6
8.5
8.4
8.3
8.2
γ_t
-0.005
0.000
0.005
Δp/p
Sextupoles Off
γ_t-Jump Off
$\alpha_1 = 3.7$


AGS dispersion at IPM (H)
MAD output 11/4/93, x_p at MB05
4
3
2
1
0
x_p (m) @ MB05
-0.005
0.000
0.005
Δp/p
experiment
range
Sextupoles Off
γ_t-Jump Off

Jøhnsen effect



non-adiabatic time:

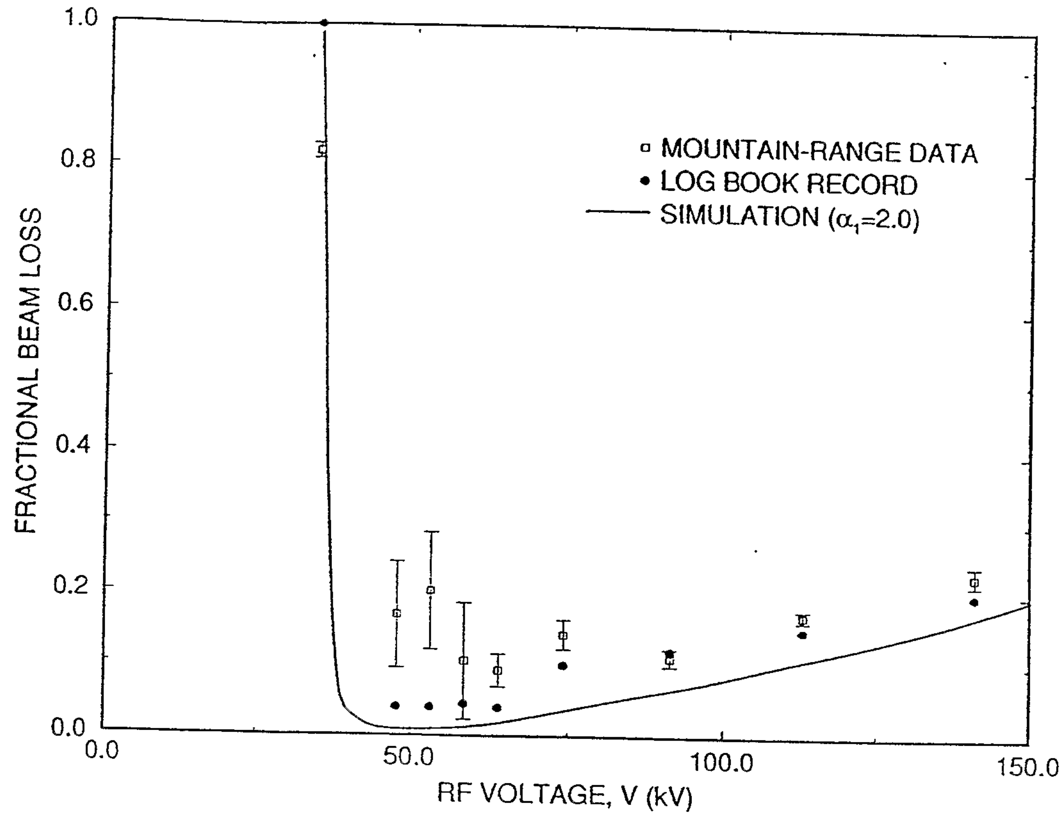
$$T_C = \left(\frac{\pi E \beta_s^2 \gamma_T^3}{qeV|\cos\phi_s|\dot{\gamma}_s h \omega_s^2} \right)^{\frac{1}{3}}$$

nonlinear time:

$$T_{nl} = \frac{\left|(\alpha_1 + \frac{3}{2}\beta_s^2)\right| \hat{\delta}(0)\ \gamma_{t0}}{\dot{\gamma}_s}$$

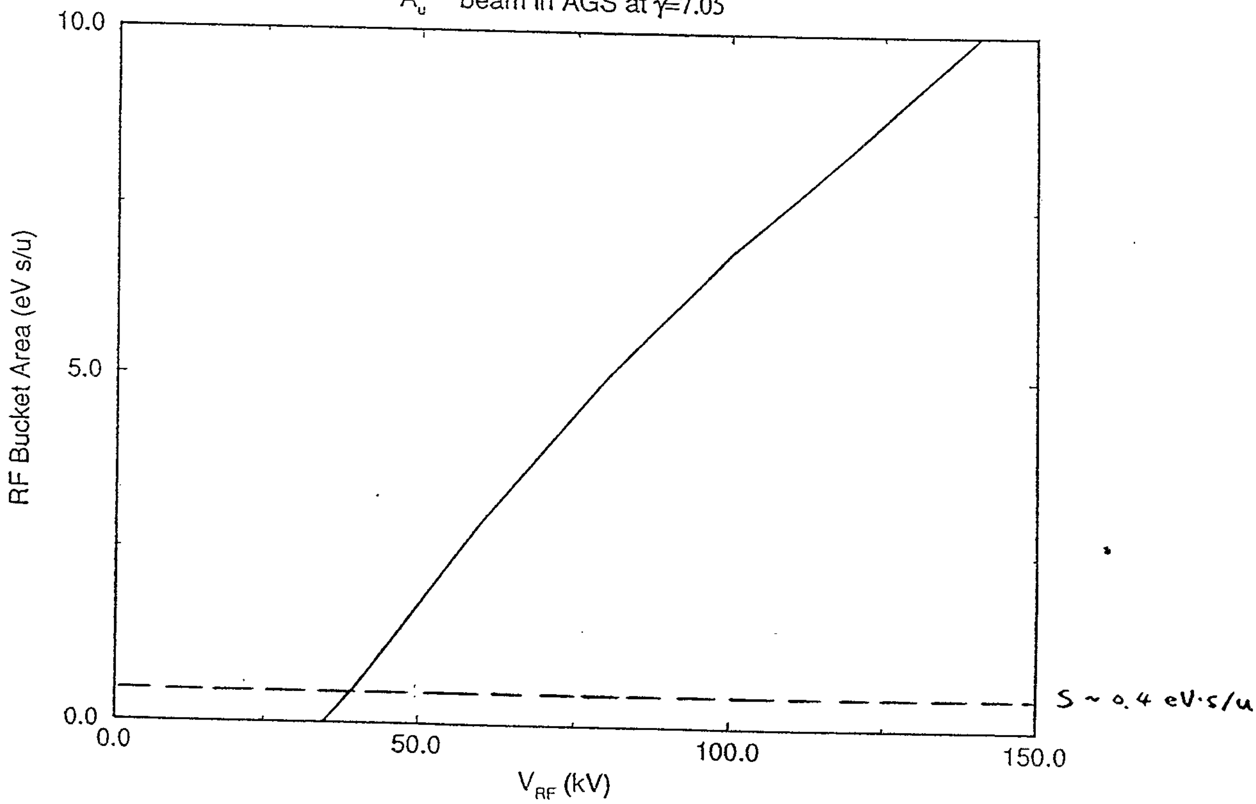
$$\frac{\Delta S}{S} \approx \begin{cases} 0.38\ \frac{T_{nl}}{T_c}, & \text{for } T_{nl} \ll T_c \\ e^{\frac{2^{1/2}}{3}\left(\frac{T_{nl}}{T_c}\right)^{3/2}} - 1, & \text{for } T_{nl} \geq T_c \end{cases}$$

beam loss vs. rf voltage

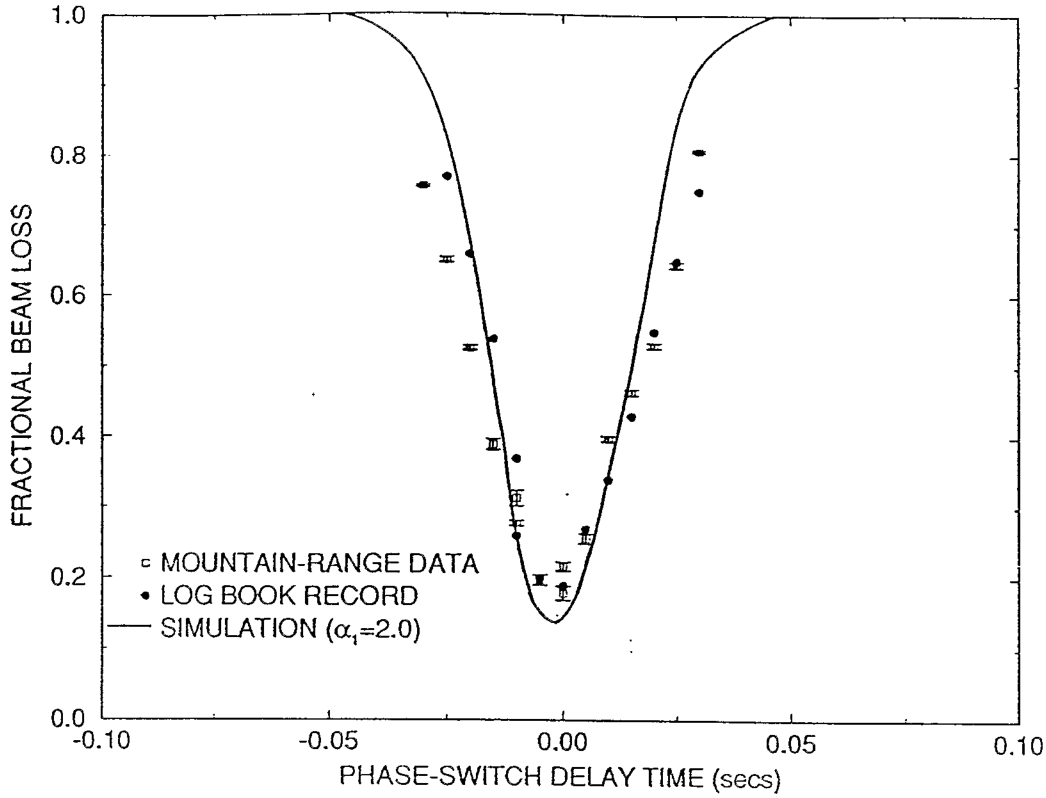


RF Bucket Area at B_{dot}=0.5 T/s

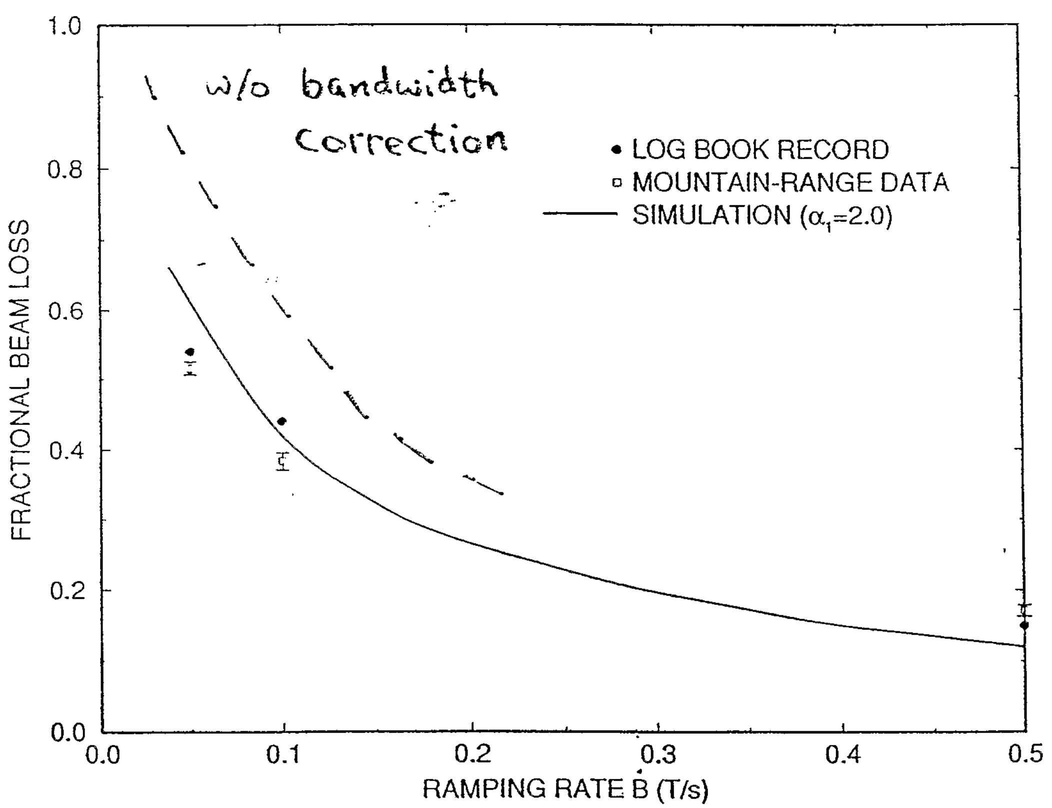
A_u^{+77} beam in AGS at γ=7.05



beam loss vs. switch time

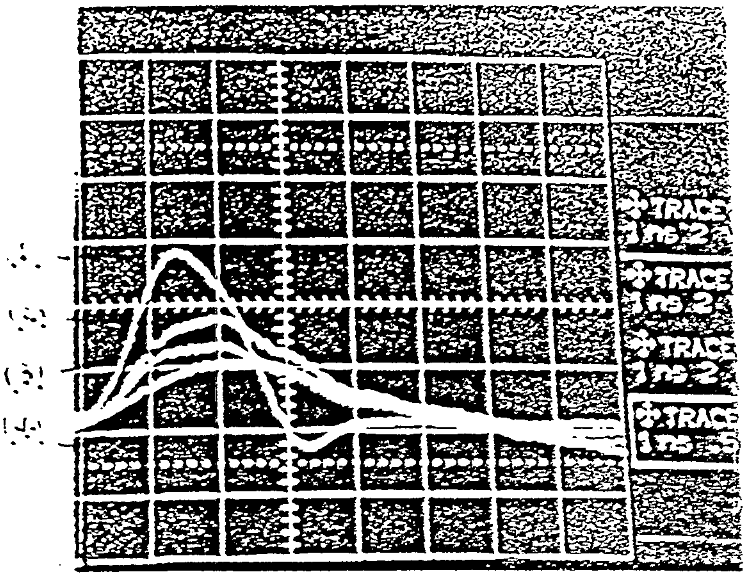


beam loss vs. ramp rate

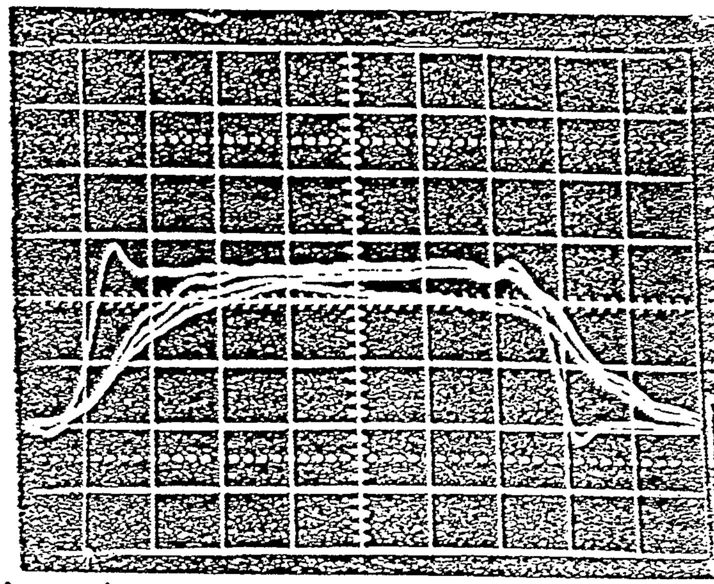


Cable loss and bandwidth measurements

2 ns pulse



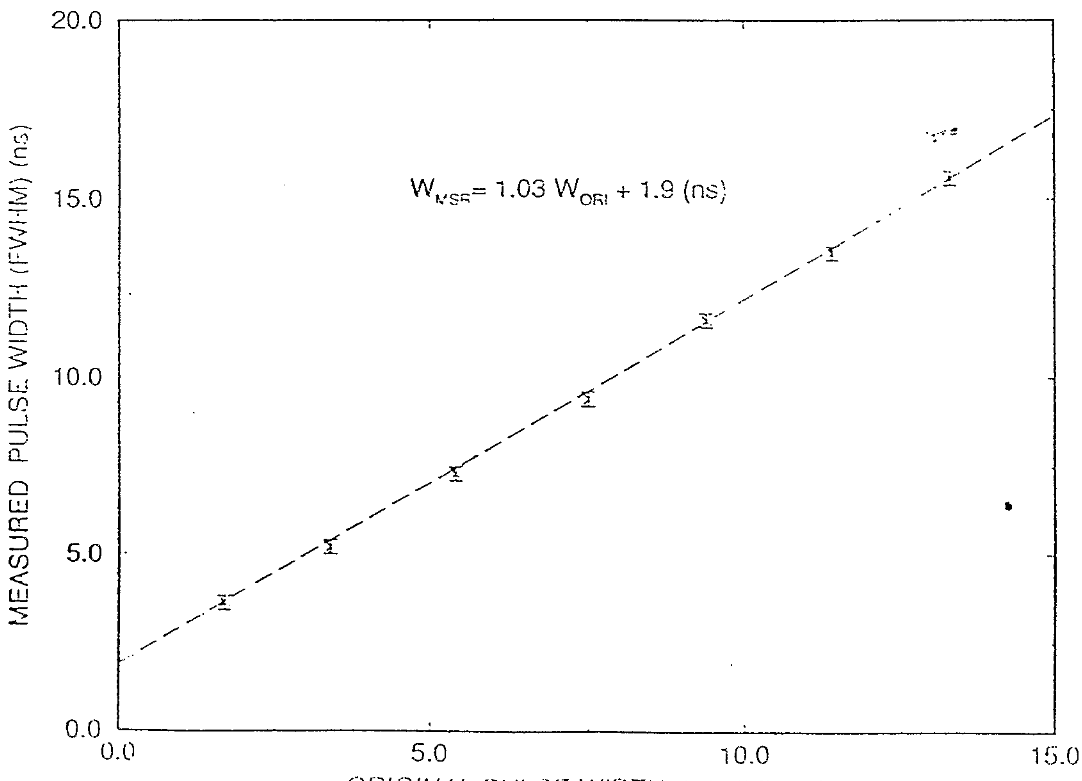
14 ns pulse



(1) original signal
(2) measured signal at the start of 3/8" ...
(3) measured signal at the start of 213 cable
(4) measured signal at gap monitor termin...

SIGNAL BROADENING AT AGS

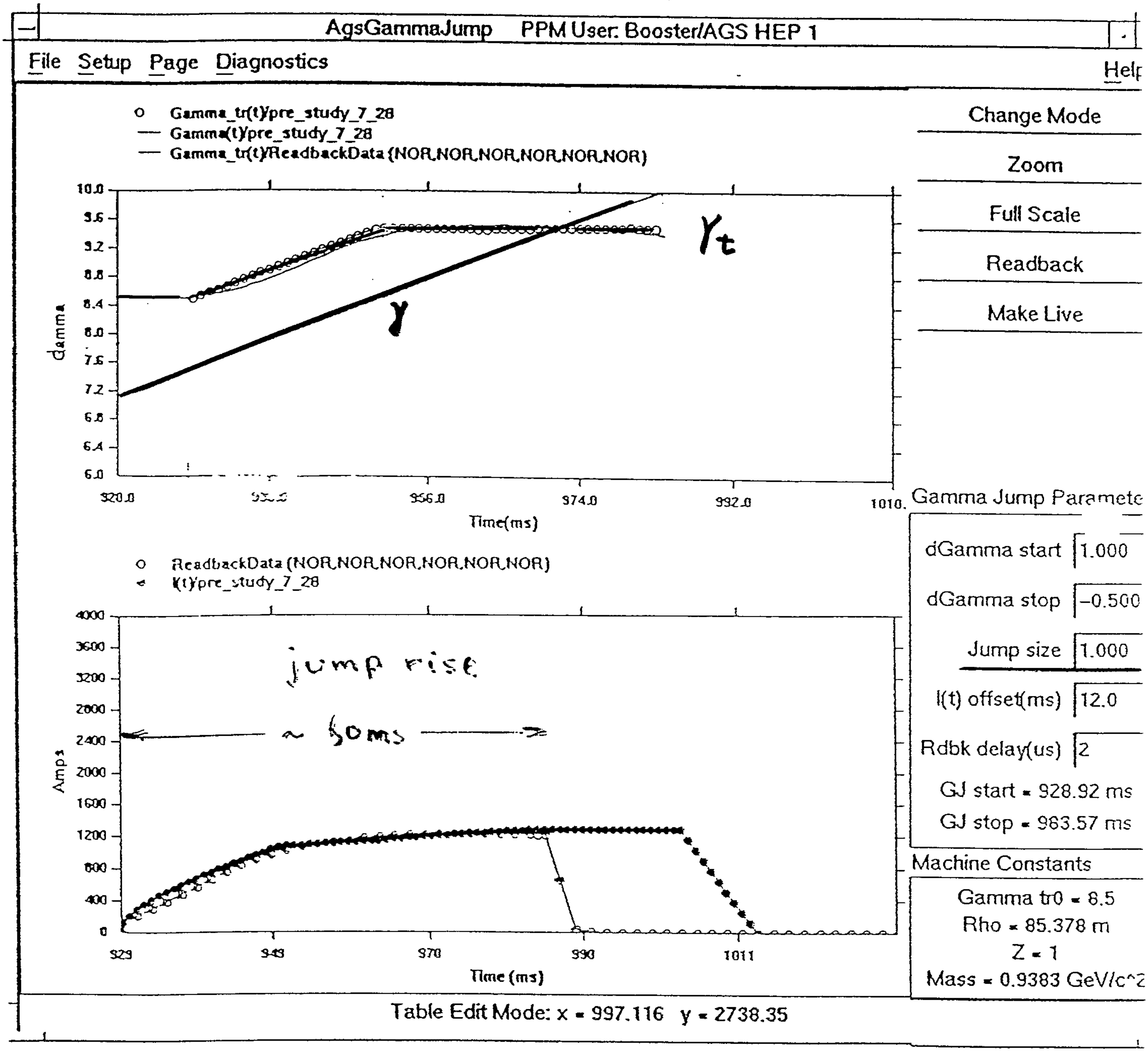
MEASURED BEFORE 213 CABLE WITH PREAMPLIFIER BY LECROY 7200



γ_t-jump study & α_1 measurement

during γ_t-jump. lattice distortion is signi...

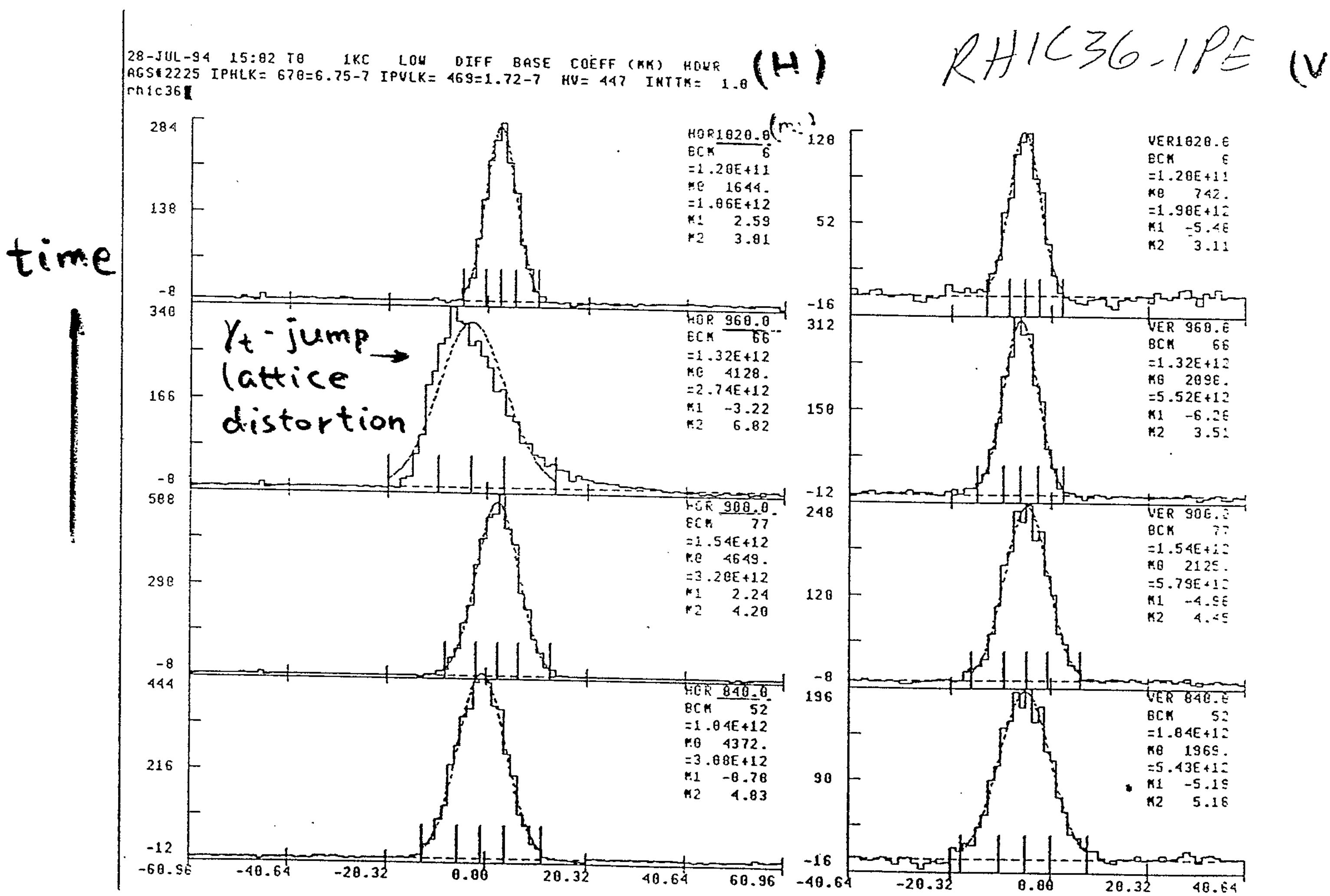
α_1 deviates from normal value



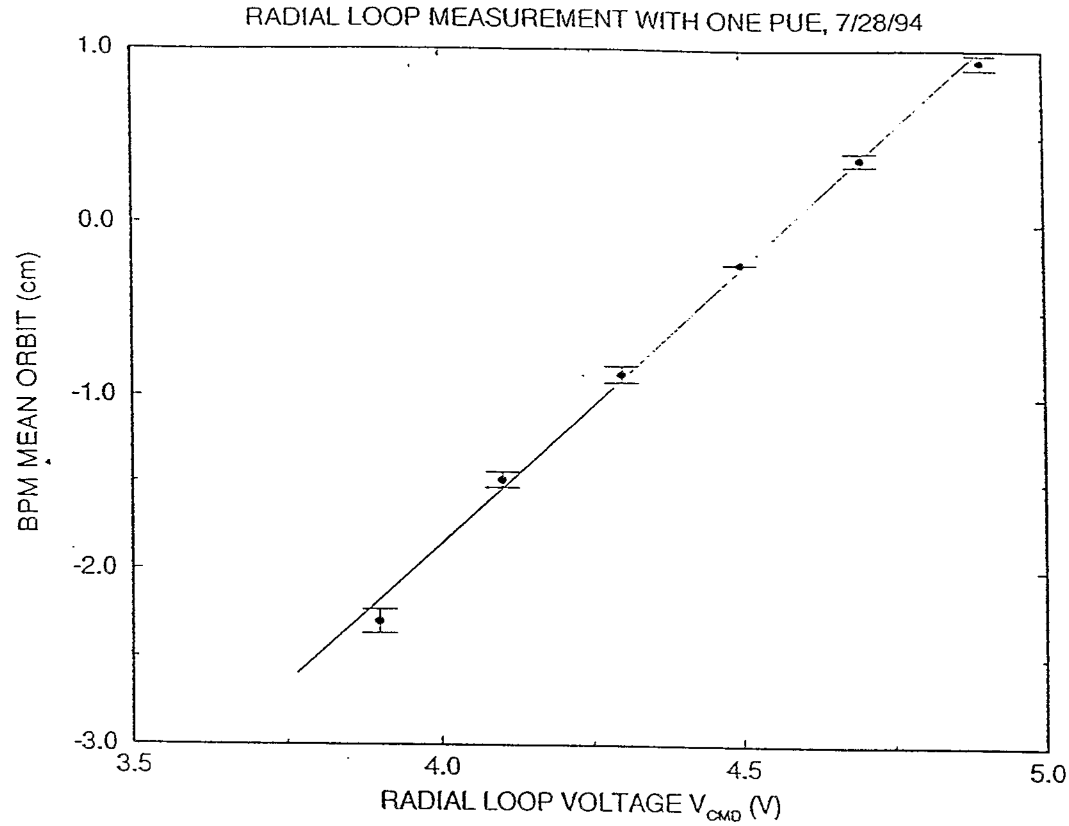
Synchronized recording of :

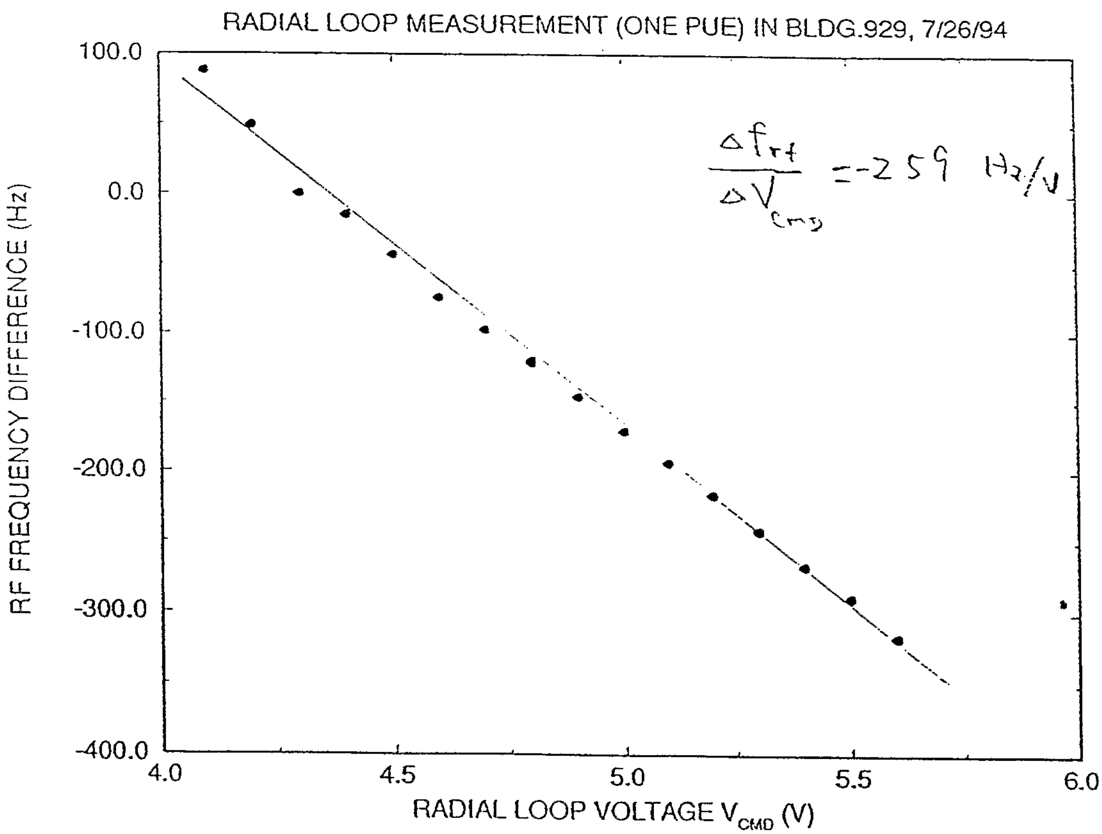
* instantaneous $\dot{B}$
* loss monitor reading
* digital mountain-range profile.
* transverse IPM profile

IPM measurement

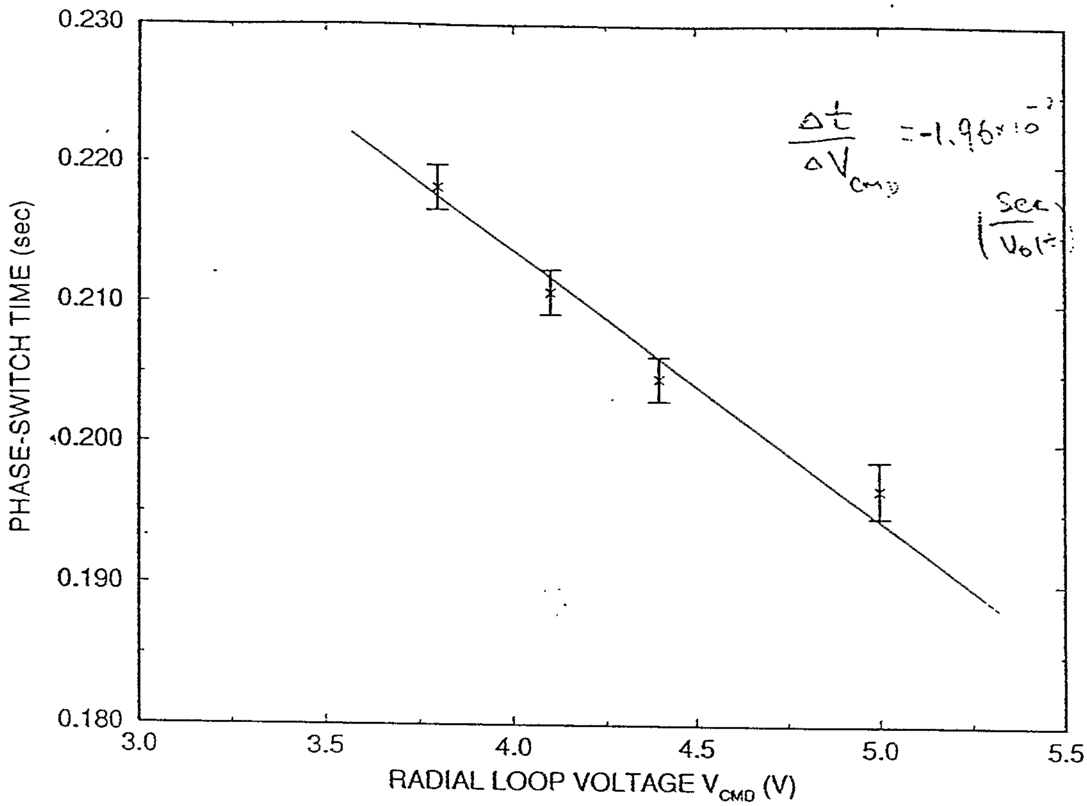


Calibration





extraction of α_1 in γ_t-jump lattice



"normal" value

$\alpha_1 = 10 \pm 1$ 5

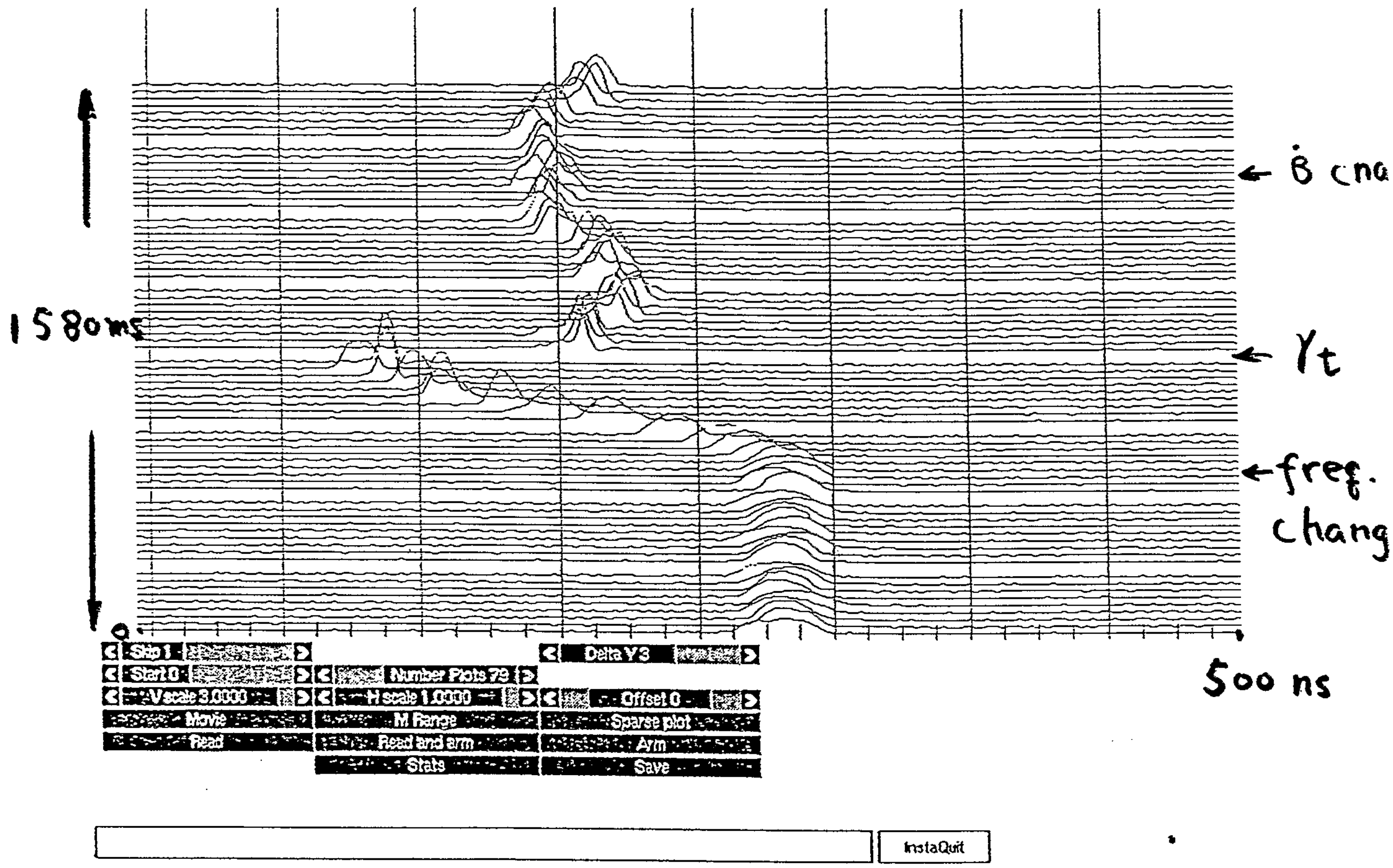
SYNCH :   13.6   3.7

$\alpha_2 \simeq 0$

$\Rightarrow$ α_1 varies significantly during γ_t-jum

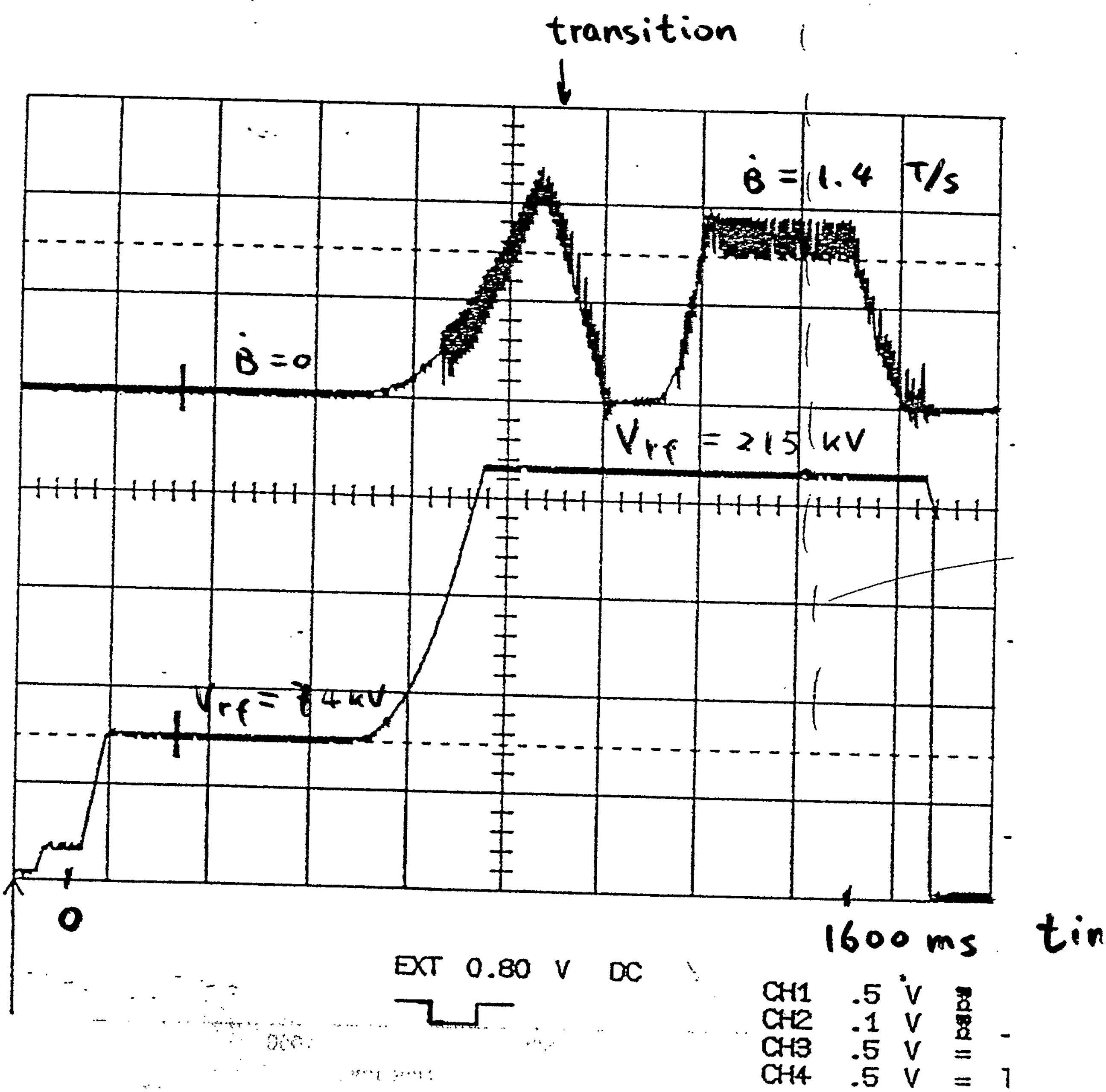
To meet RHIC proton specifications

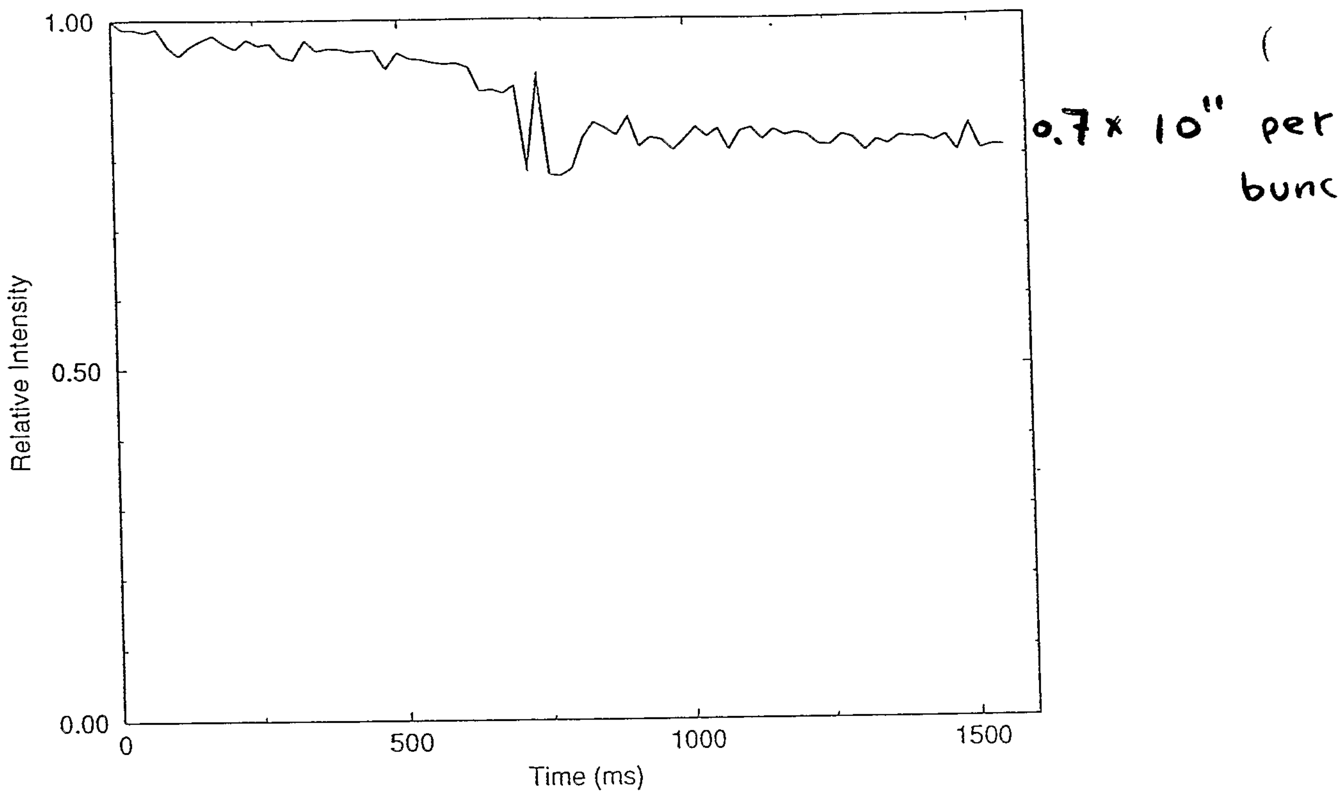
10^{11} per bunch
$S = 0.3$ eV·s
$\varepsilon_{x,y} = 10\ \pi$ mm·mr
} goal



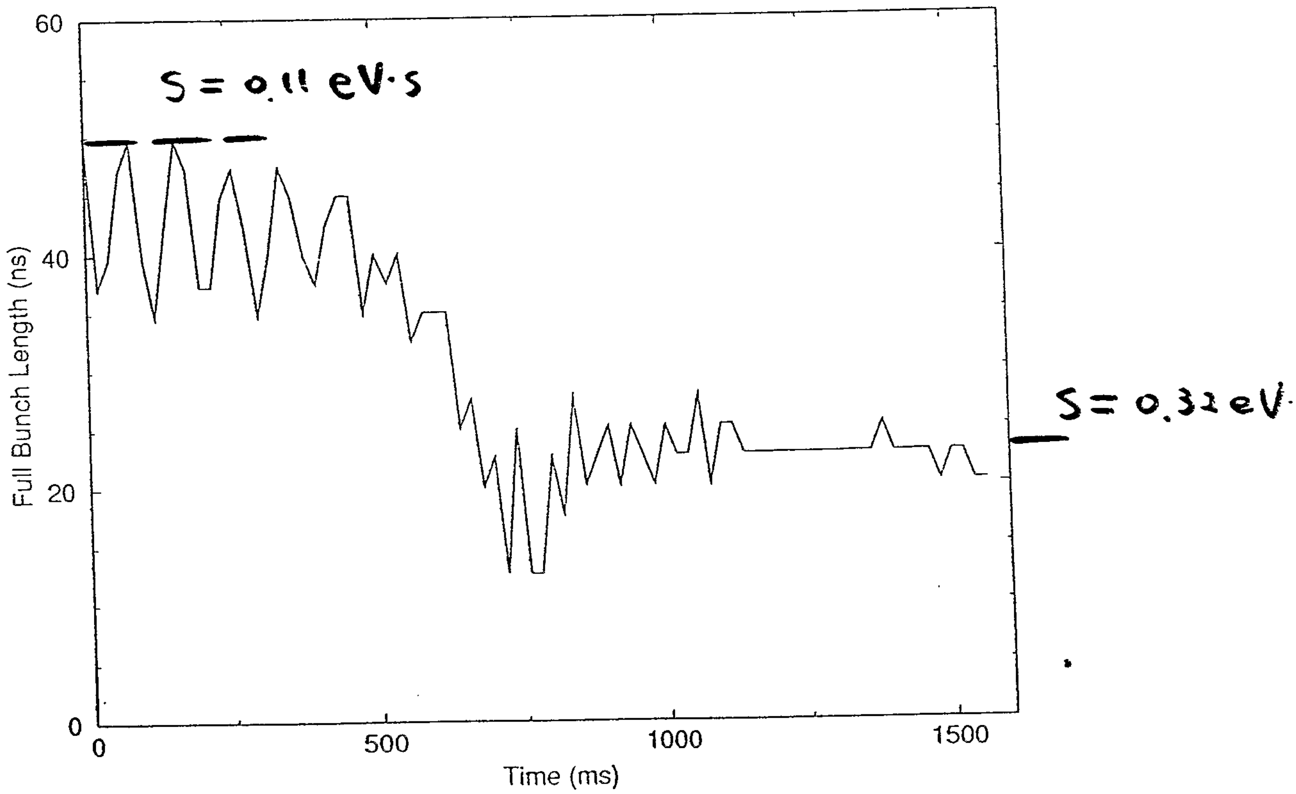
γ_t - jump on

J. M. Brennan etc.

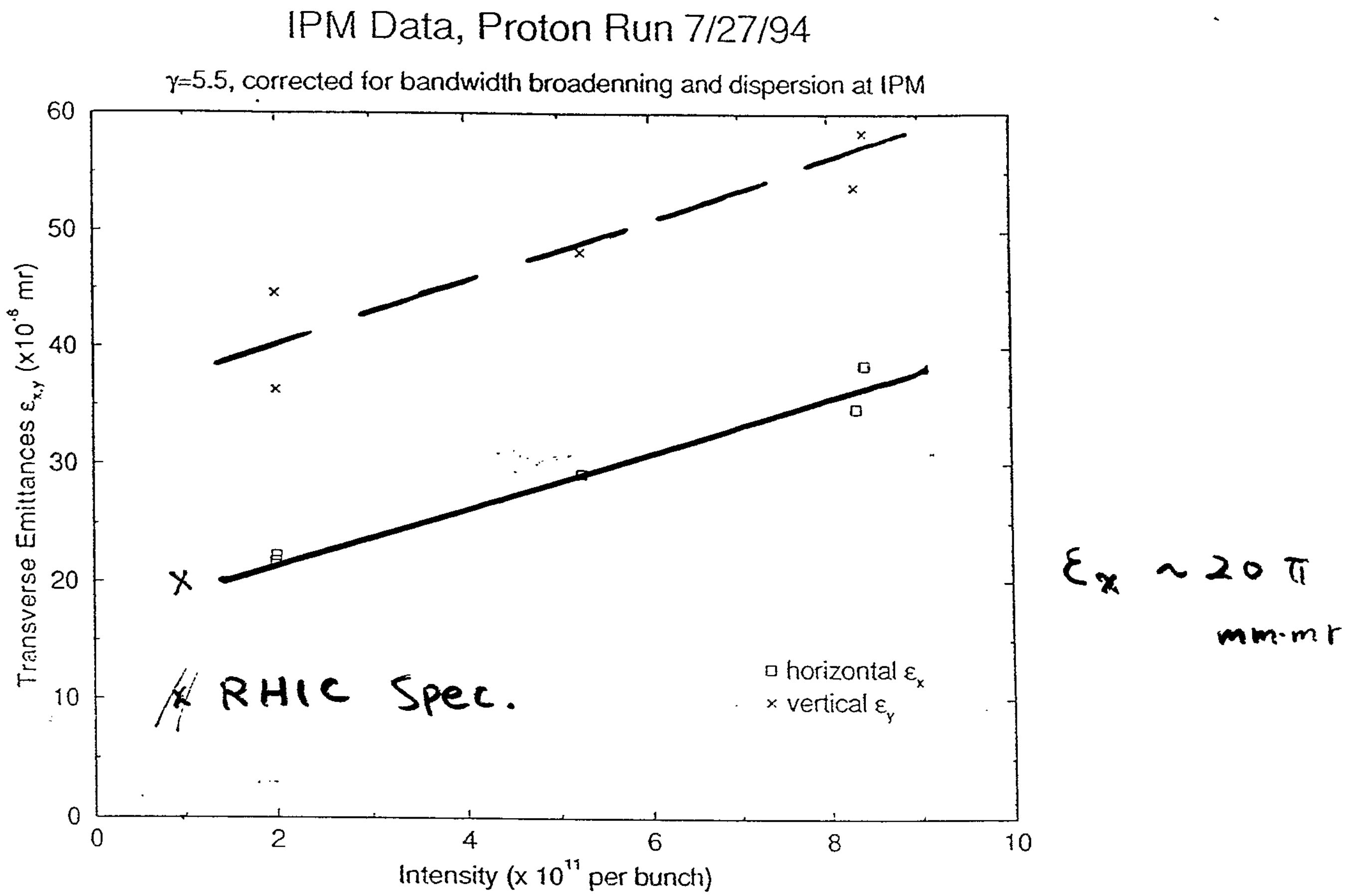




1.00
0.50
0.00
Relative Intensity
0
500
1000
1500
Time (ms)
0.7 x 10'' per bunc



60
40
20
0
Full Bunch Length (ns)
0
500
1000
1500
Time (ms)
S = 0.11 eV·s
S = 0.32 eV·


IPM Data, Proton Run 7/27/94
γ=5.5, corrected for bandwidth broadenning and dispersion at IPM
Transverse Emittances ε_x,y (x10^-6 mr)
Intensity (x 10^11 per bunch)
0
10
20
30
40
50
60
2
4
6
8
10
□ horizontal ε_x
× vertical ε_y
RHIC Spec.
ε_x ~ 20 π mm·mr

Bunch Rotation Gymnastic in AGS

1. 1/2 bunch length implies x16 matching voltage

   - for protons only

   - γ close to γ_{Tr}

2. "classical" technique

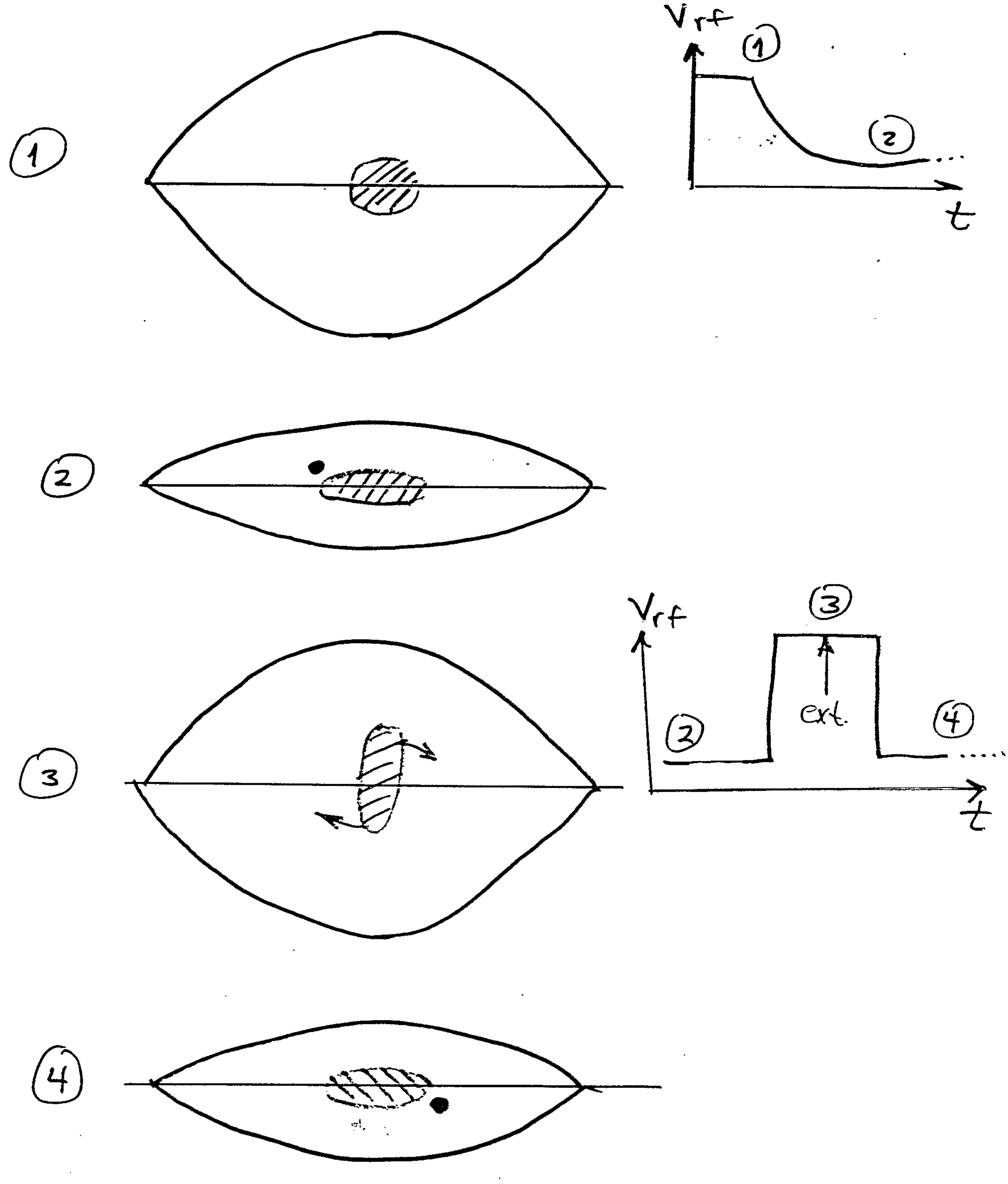
3. single bunch transfer implies must repeat 12 times

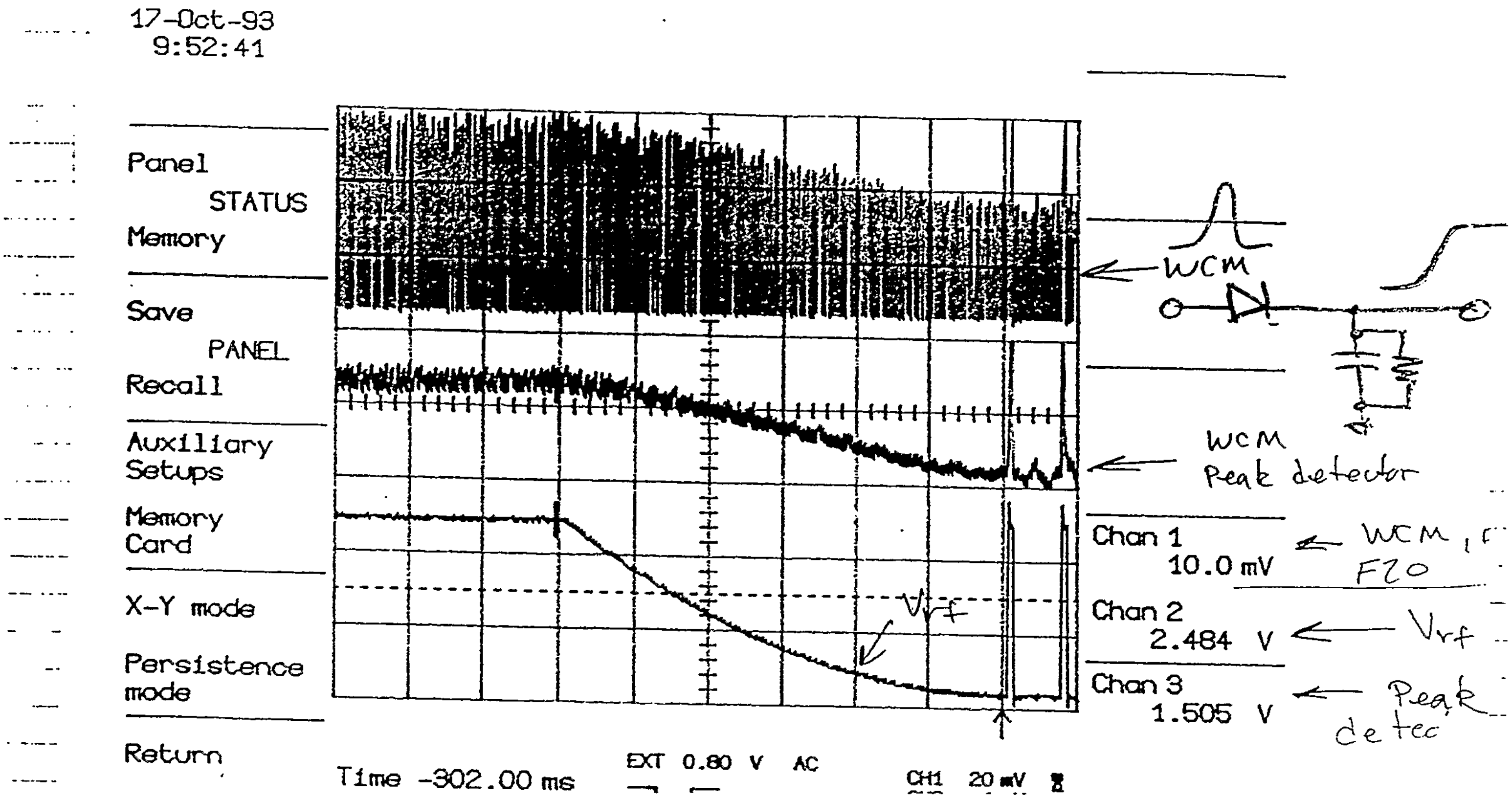
4. small bucket fill fraction implies;

   - no filamentation

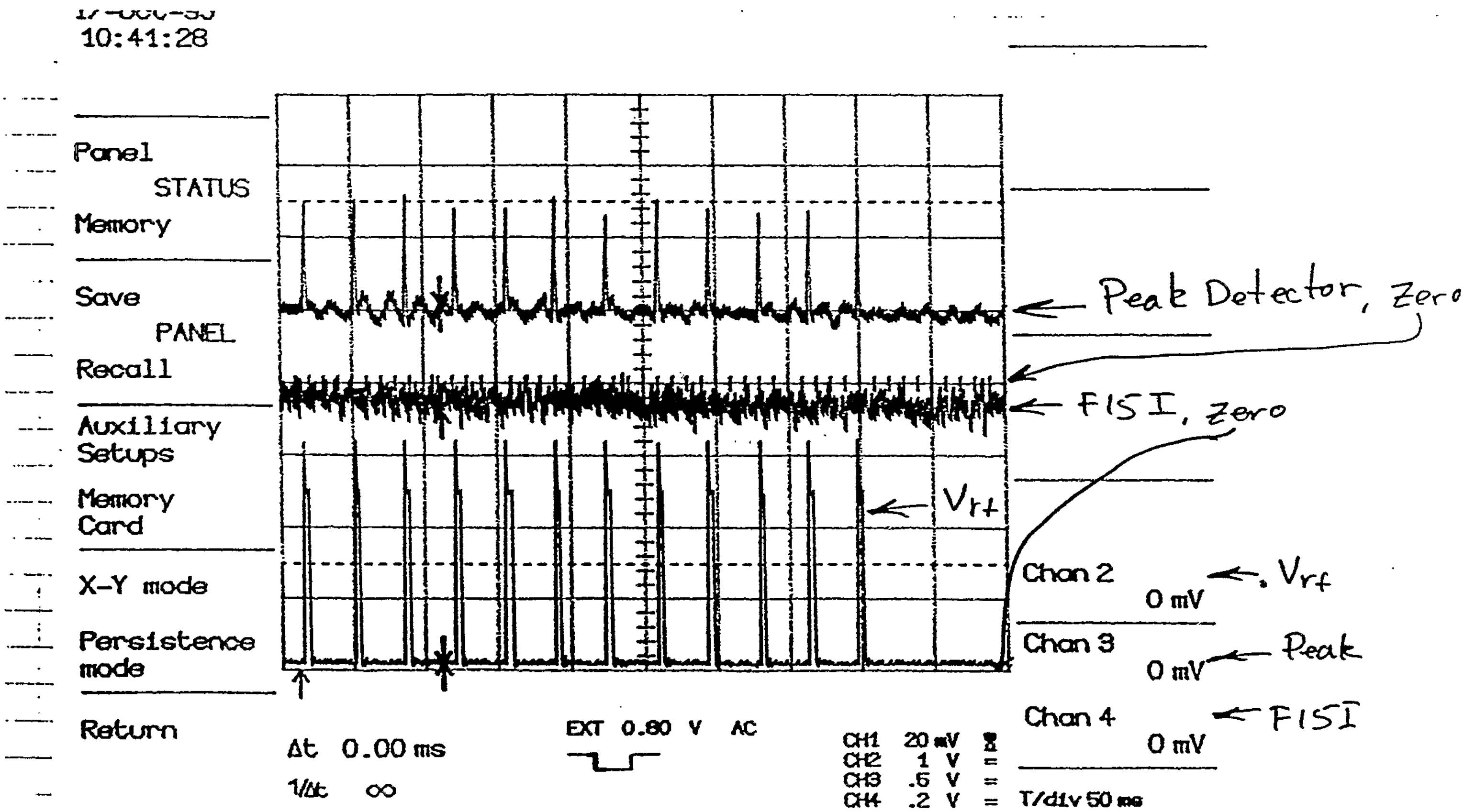
   - rotations are "reversible"

5. practice with Gold ions


1
2
3
4
Vrf
t
ext.



17-Oct-93
9:52:41
Panel
STATUS
Memory
Save
PANEL
Recall
Auxiliary
Setups
Memory
Card
X-Y mode
Persistence
mode
Return
Time -302.00 ms
EXT 0.80 V AC
CH1 20 mV
Chan 1
10.0 mV
Chan 2
2.484 V
Chan 3
1.505 V
WCM
WCM
Peak detector
WCM, F
F20
Vrf
Vrf
Peak
detec



10:41:28
Panel
STATUS
Memory
Save
PANEL
Recall
Auxiliary
Setups
Memory
Card
X-Y mode
Persistence
mode
Return
Δt 0.00 ms
1/Δt ∞
EXT 0.80 V AC
CH1 20 mV
CH2 1 V
CH3 .5 V
CH4 .2 V
T/div 50 ms
Chan 2
0 mV
Chan 3
0 mV
Chan 4
0 mV
Peak Detector, Zero
FISI, zero
Vrf
Vrf
Peak
FISI

III. Future Study Plan

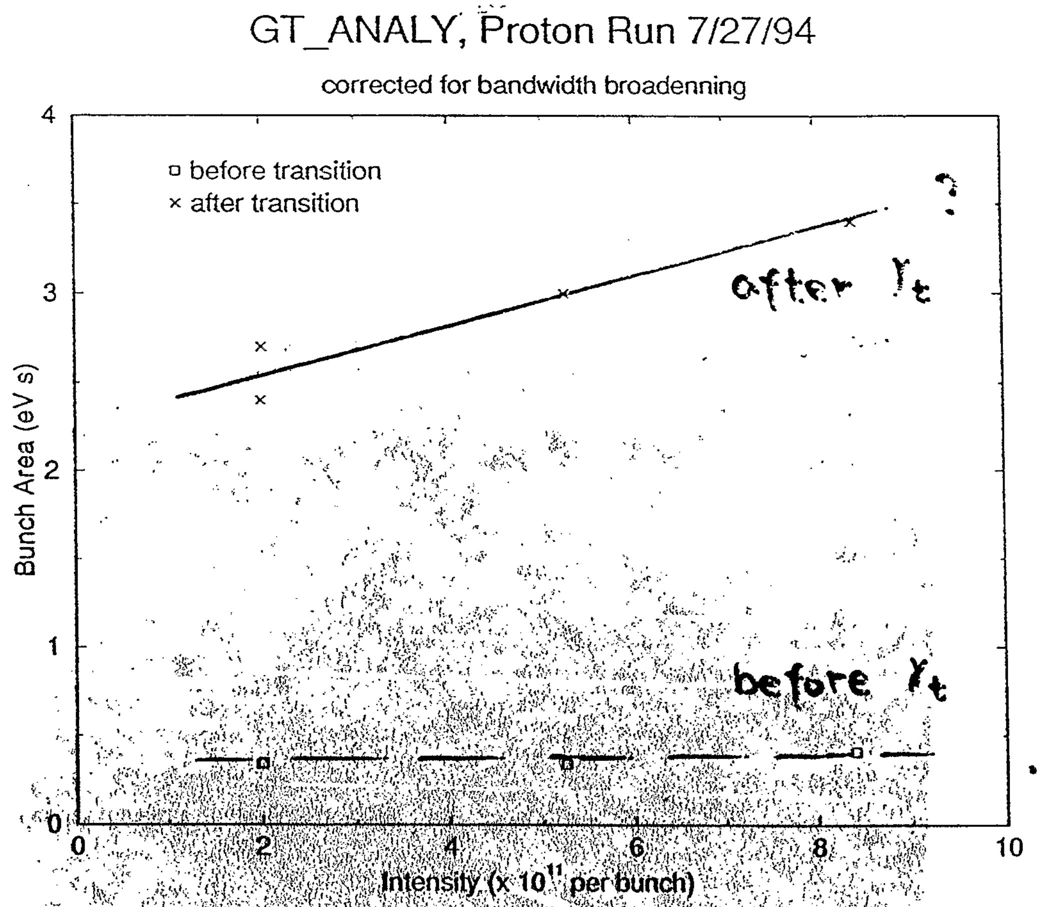
More studies on intensity dependence

(7/27/94 experiment)

growth in longitudinal area:

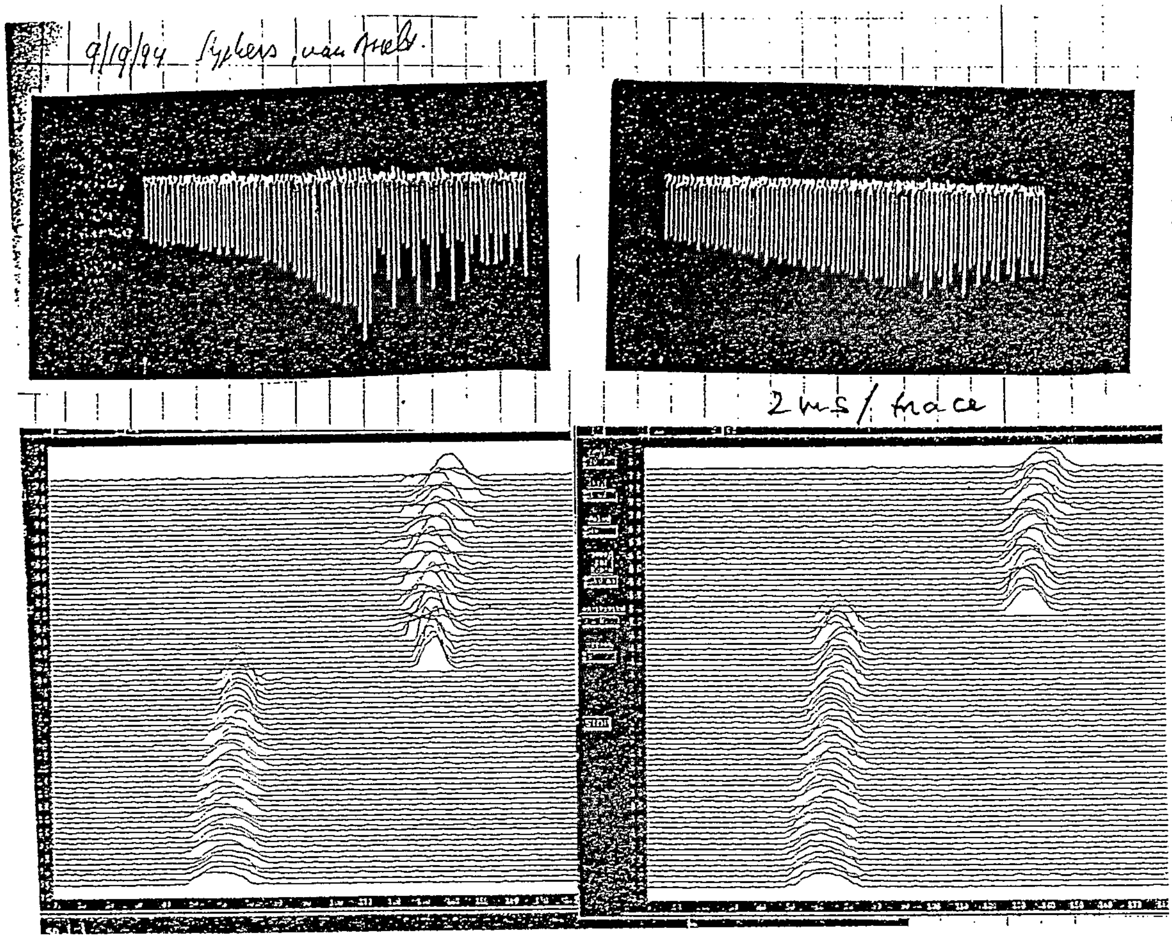
(1) impedance mismatch

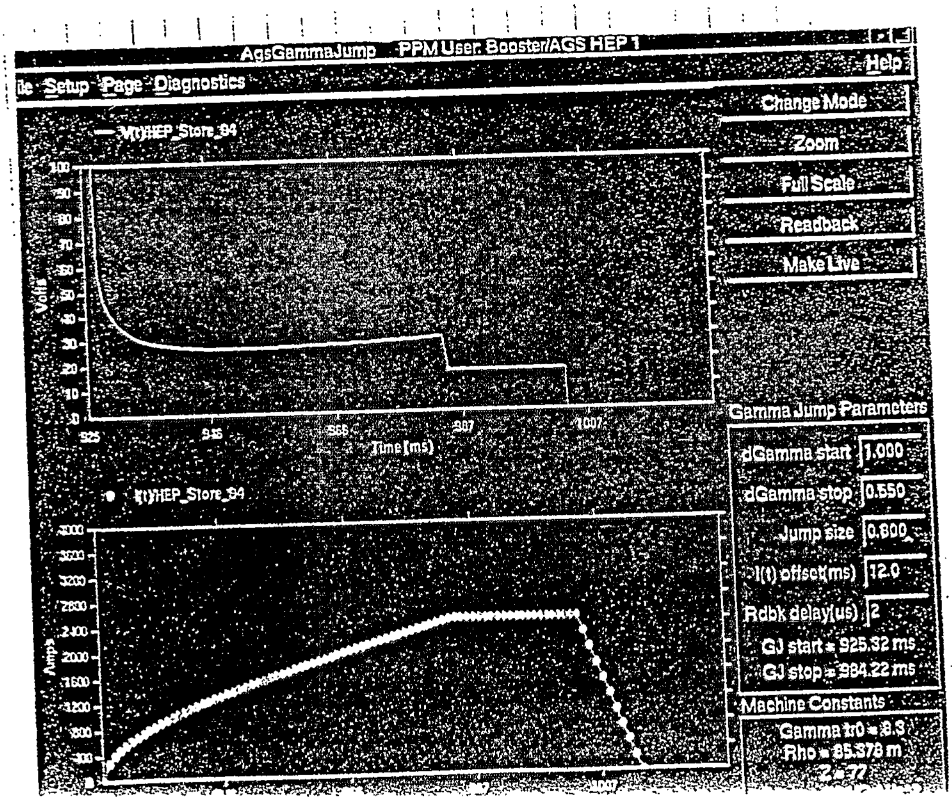
(2) damage in electronics due to radiation



More studies on γ_t-jump

W. Van Asselt





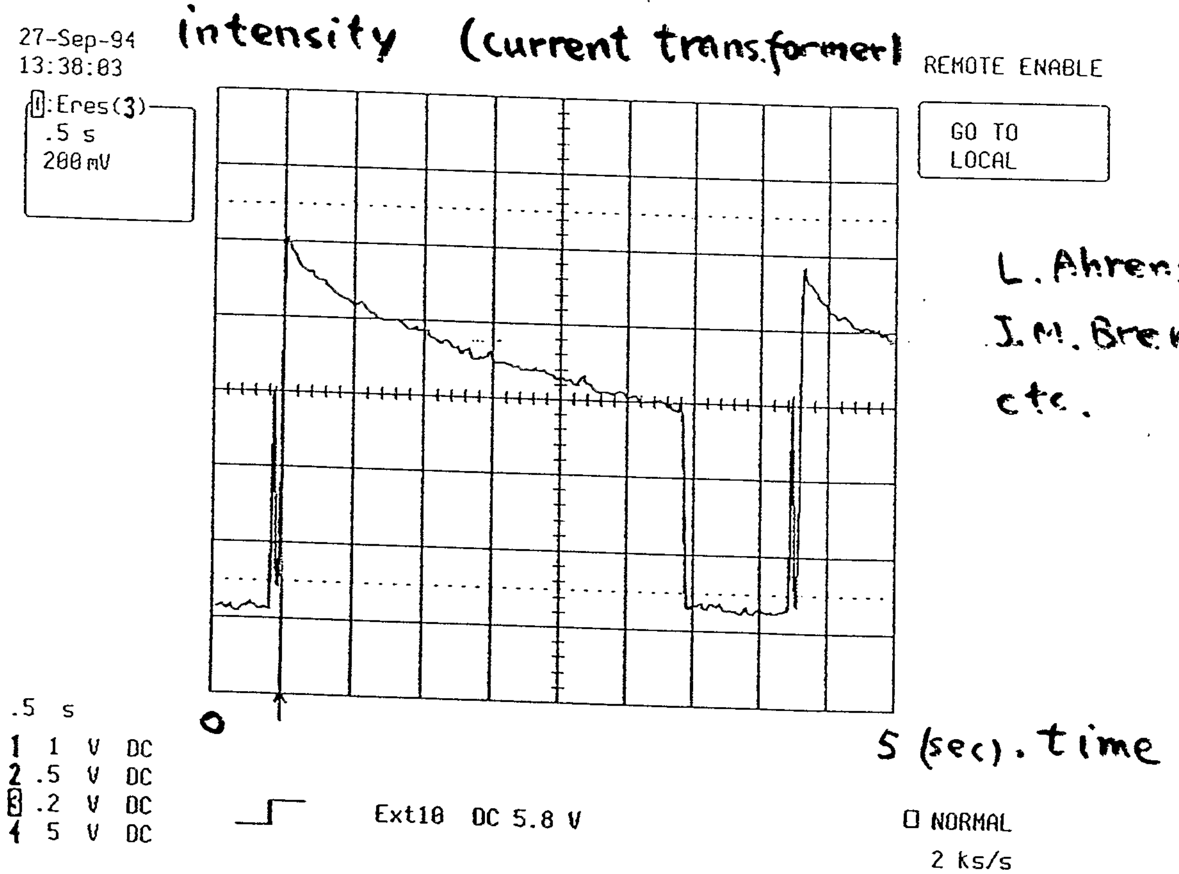
Intrabeam scattering at AGS injection

RHIC. Au^{79}. injection 2 min.

strong IBS growth

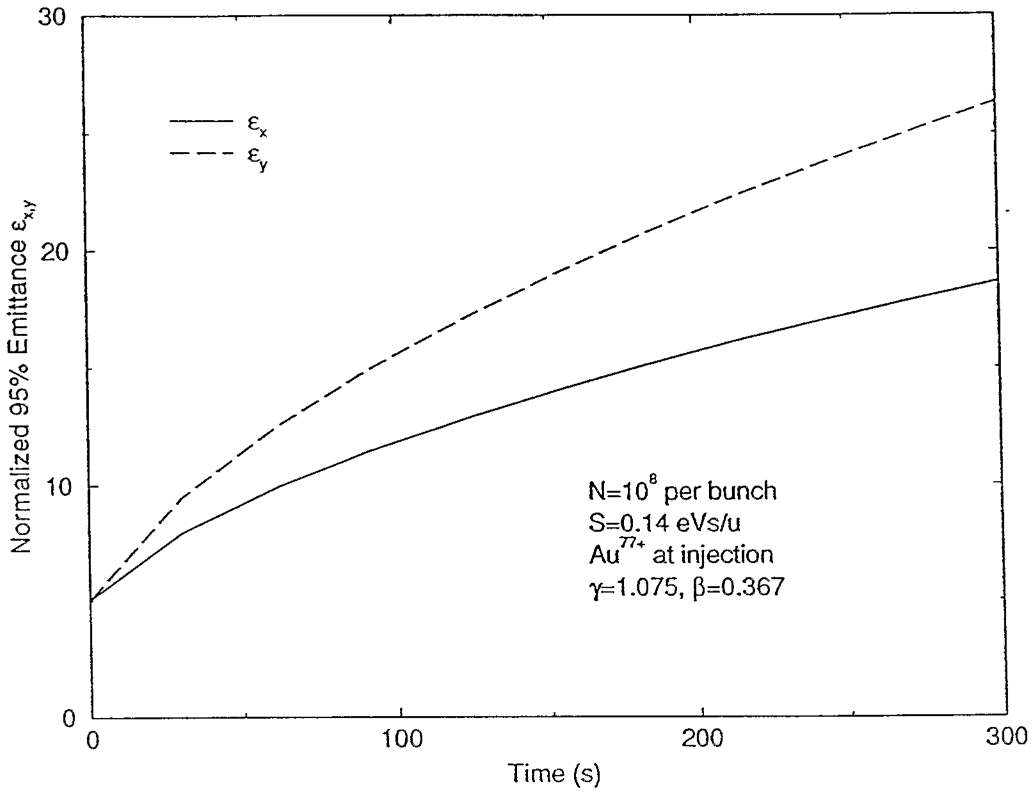
AGS injection, $\dot{B}=0$, Au^{77+} beam

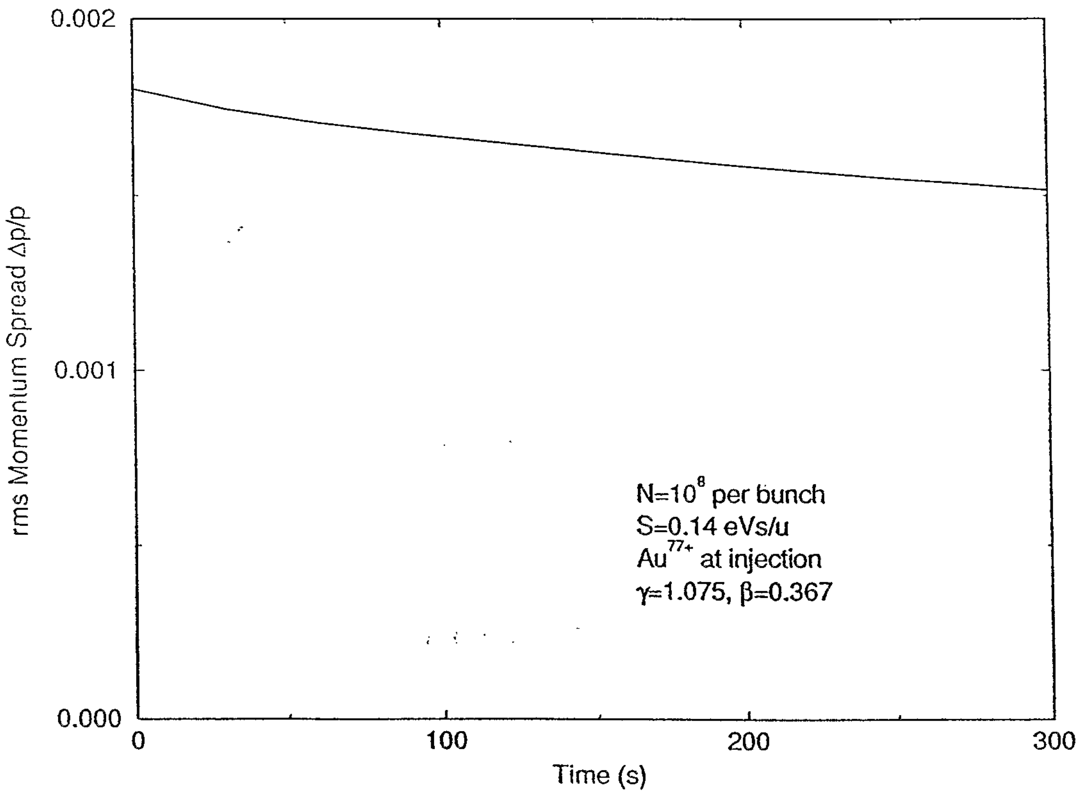
intensity (current transformer)

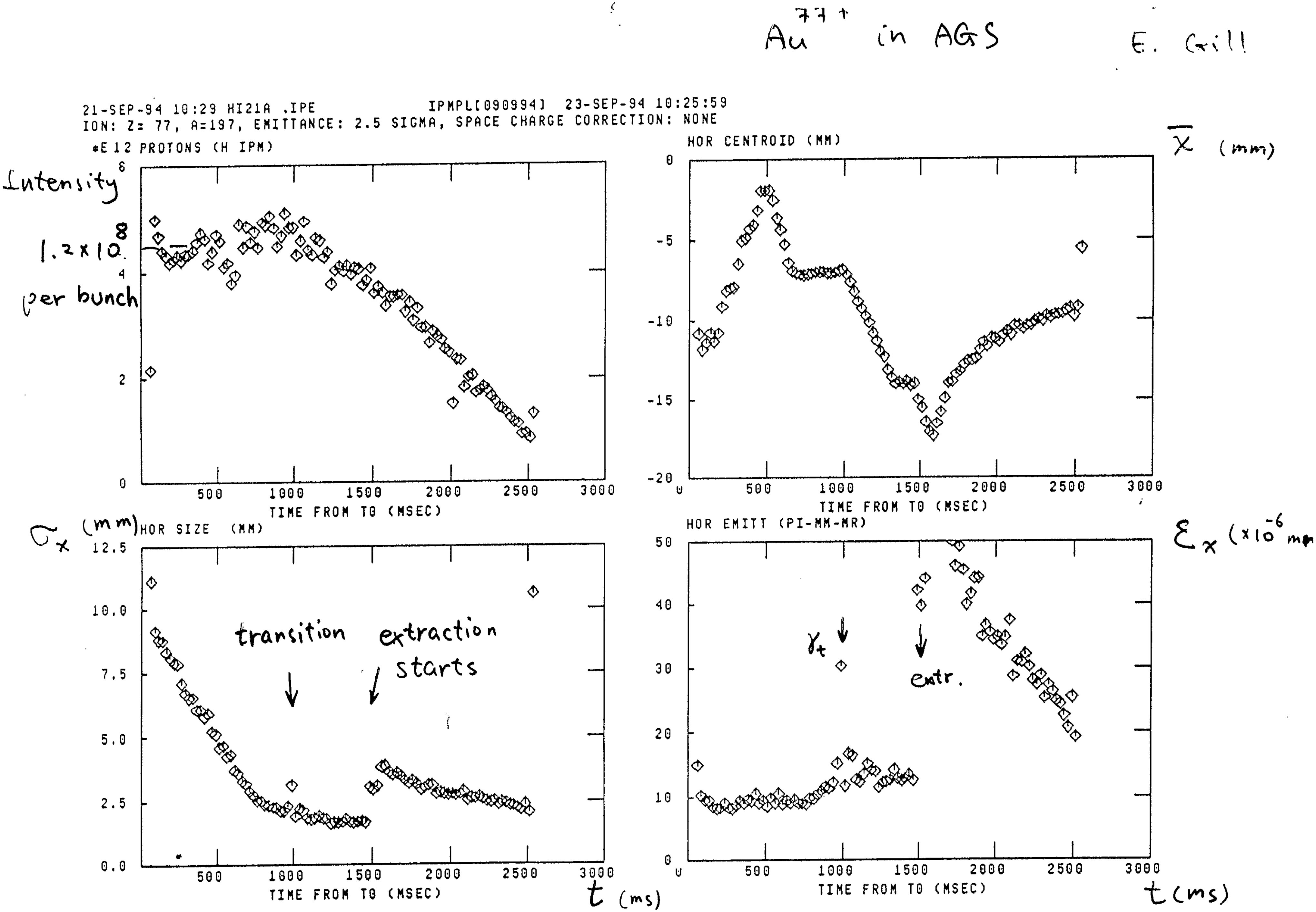


L. Ahrens
J.M. Brennan
etc.

Growth due to IBS at AGS Injection Flattop



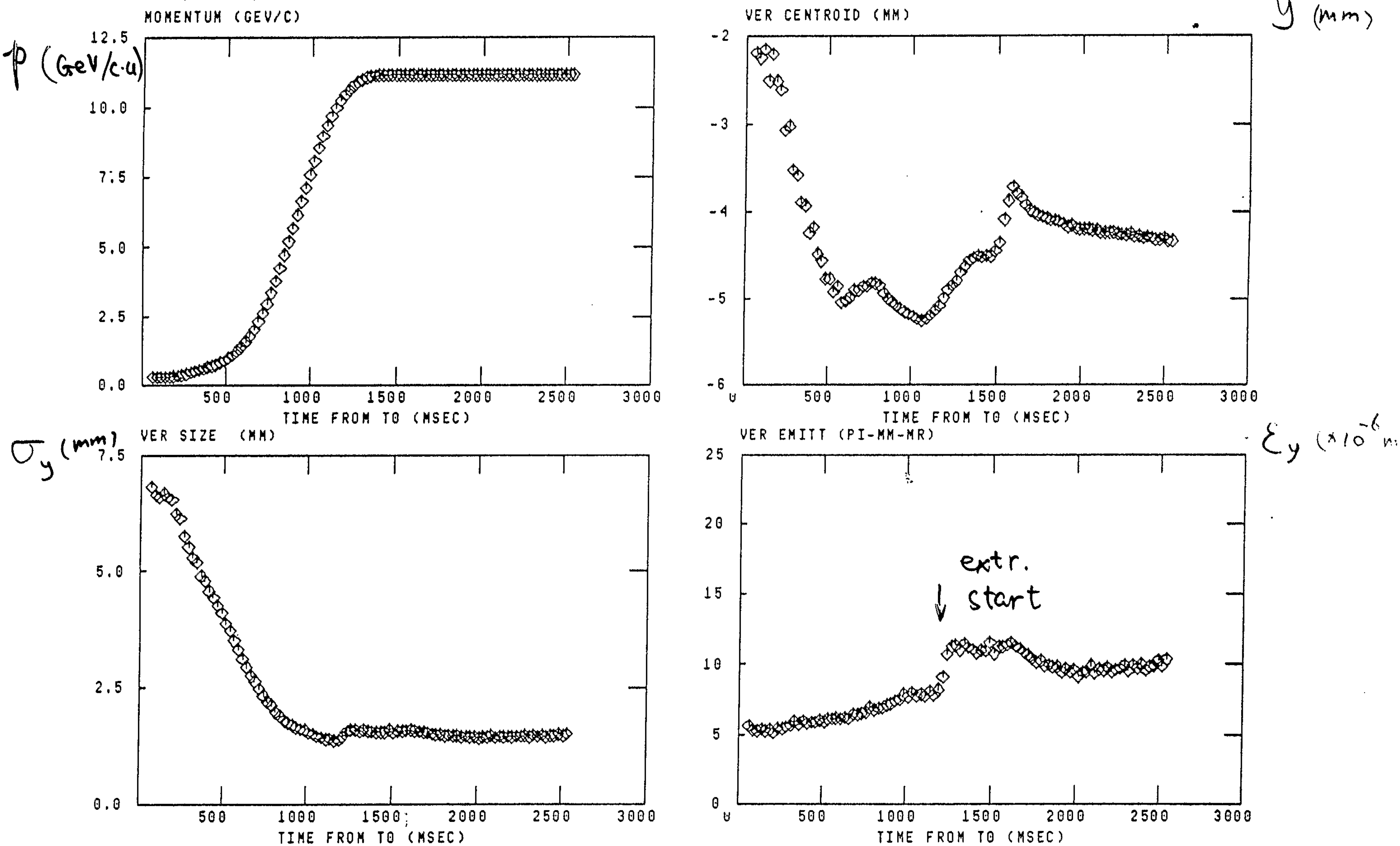




Au^{77+} in AGS
E. Gill
21-SEP-94 10:29 HI21A .IPE
IPMPL[090994] 23-SEP-94 10:25:59
ION: Z= 77, A=197, EMITTANCE: 2.5 SIGMA, SPACE CHARGE CORRECTION: NONE
*E 12 PROTONS (H IPM)
Intensity
1.2x10^8 per bunch
HOR CENTROID (MM)
$\bar{x}$ (mm)
HOR SIZE (MM)
σ_x (mm)
transition
extraction starts
HOR EMITT (PI-MM-MR)
ε_x ($\times 10^{-6}$ m
γ_t
extr.
TIME FROM T0 (MSEC)
t (ms)

Au^{77+} in AGS E. Gill

21-SEP-94 10:29 HI21A .IPE IPMPL[090994] 23-SEP-94 10:27:23
ION: Z= 77, A=197, EMITTANCE: 2.5 SIGMA, SPACE CHARGE CORRECTION: NONE



To achieve RHIC beams (proton, Au^{77+})

proton : preserve longitudinal emittance

lower transverse emittance

Au^{77+} : more work (see J.M. Brennan talk)

on intensity issues

IV. Conclusions

1. AGS machine study has been very successful. We improved our understanding on slow-rate transition crossing, rf manipulation, γ_t-jump etc., and gained confidence in RHIC performance;

2. We understand the AGS machine better (transition crossing, γ_t-jump, α_1, cable loss and bandwidth limitation, etc.);

3. RHIC proton specifications have been met within a factor of 2 with relatively small effort;

4. More AGS machine-study time is highly desirable and essential to the successful RHIC operation.