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:
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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 (Johnsen 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

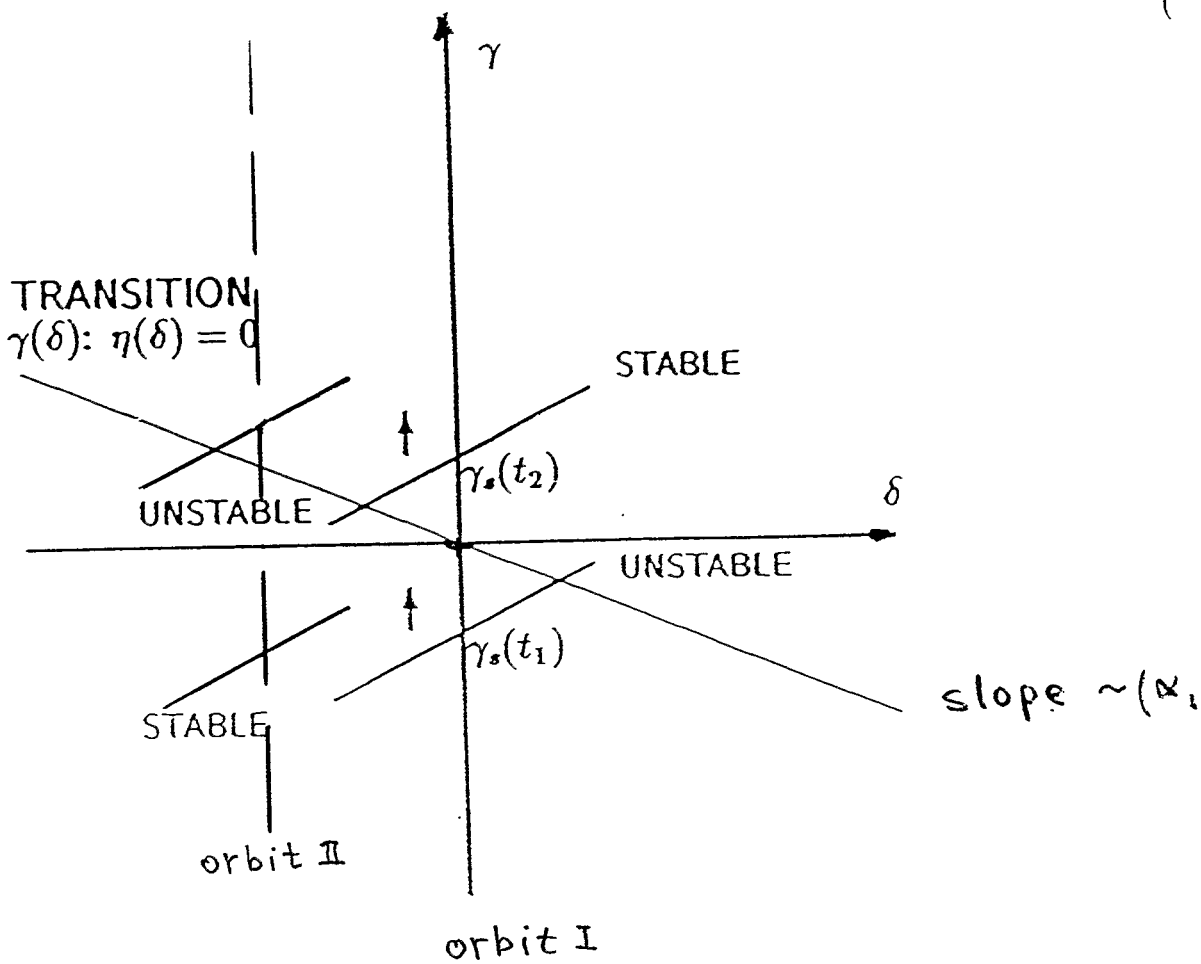
* combination of self fields and non-linearity

  high current, slow ramp, e.g. RHIC

* micro wave instability

  beam microwave signal, break up.

  secondary bunches



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

particles of different momenta cross transition at different time

transition energy : γ_T

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

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

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

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

* 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

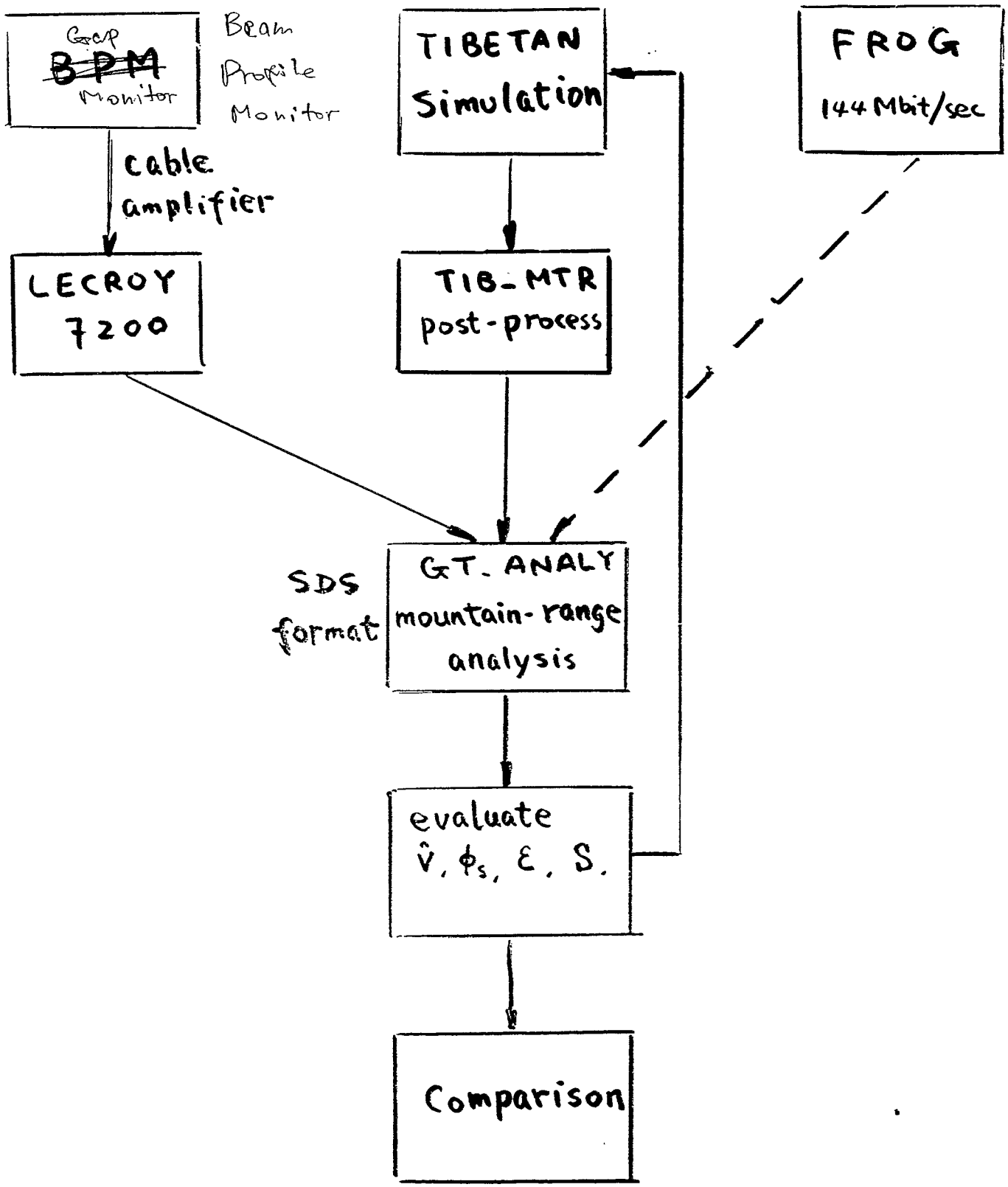
   $\Rightarrow$ $\frac{\Delta p}{p}$ vs. ΔV_{CMD}

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

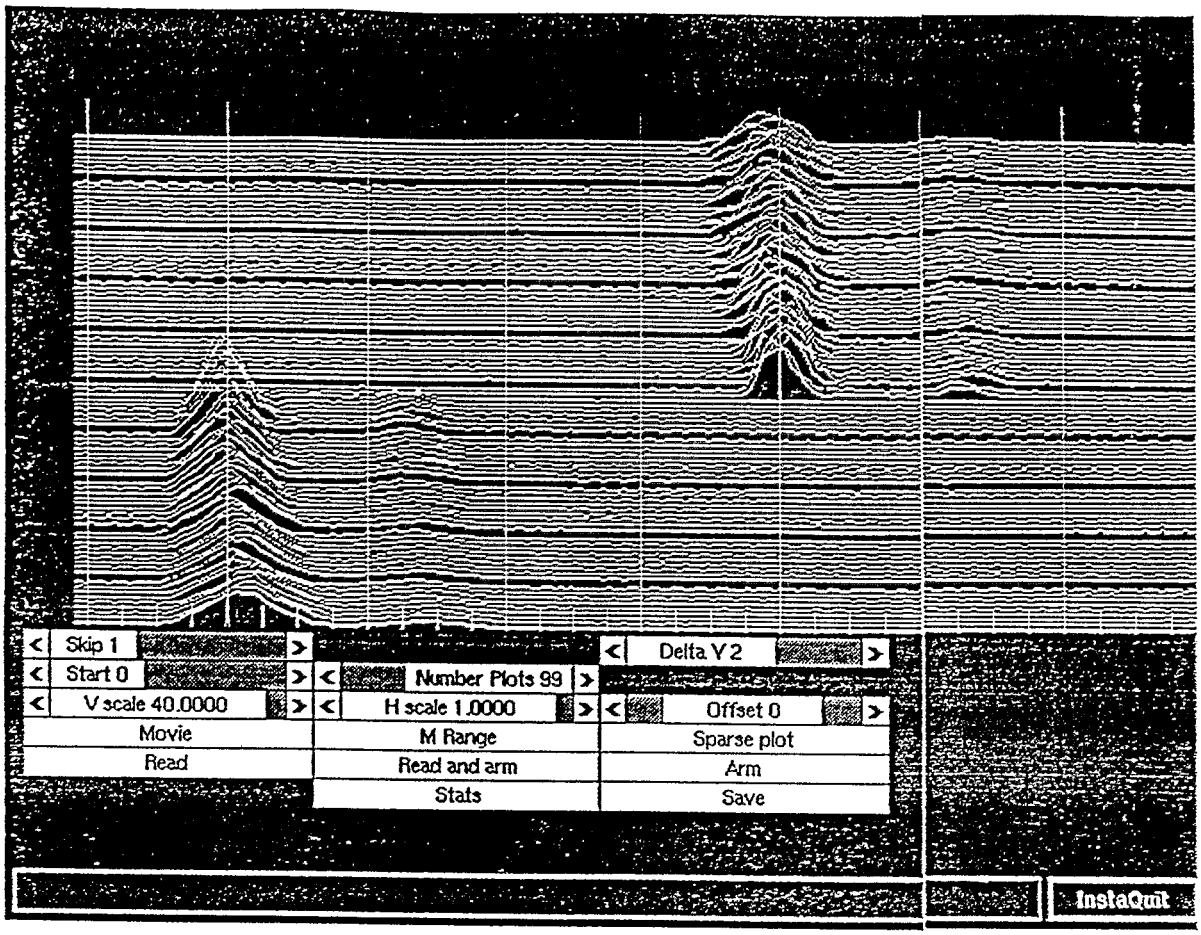
minimum beam loss $\Leftrightarrow$ transition energy

confirmed by simulation

Experimental set-up & data reduction

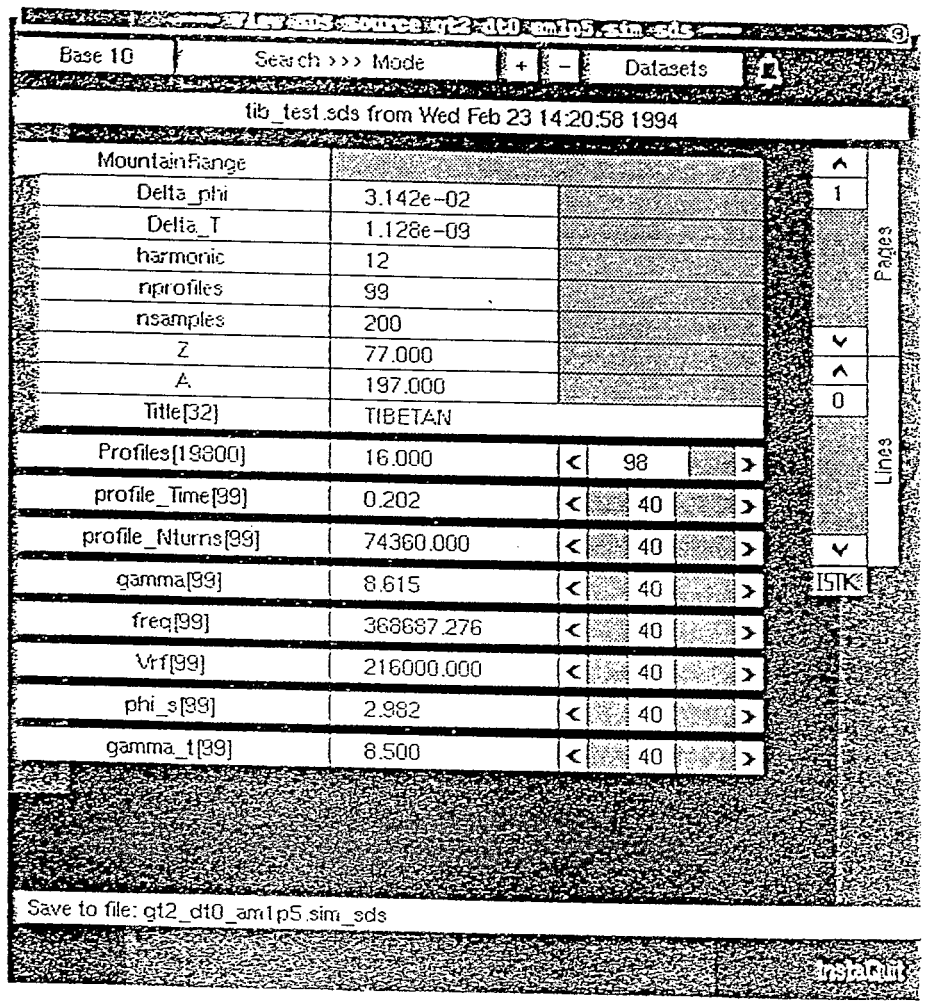


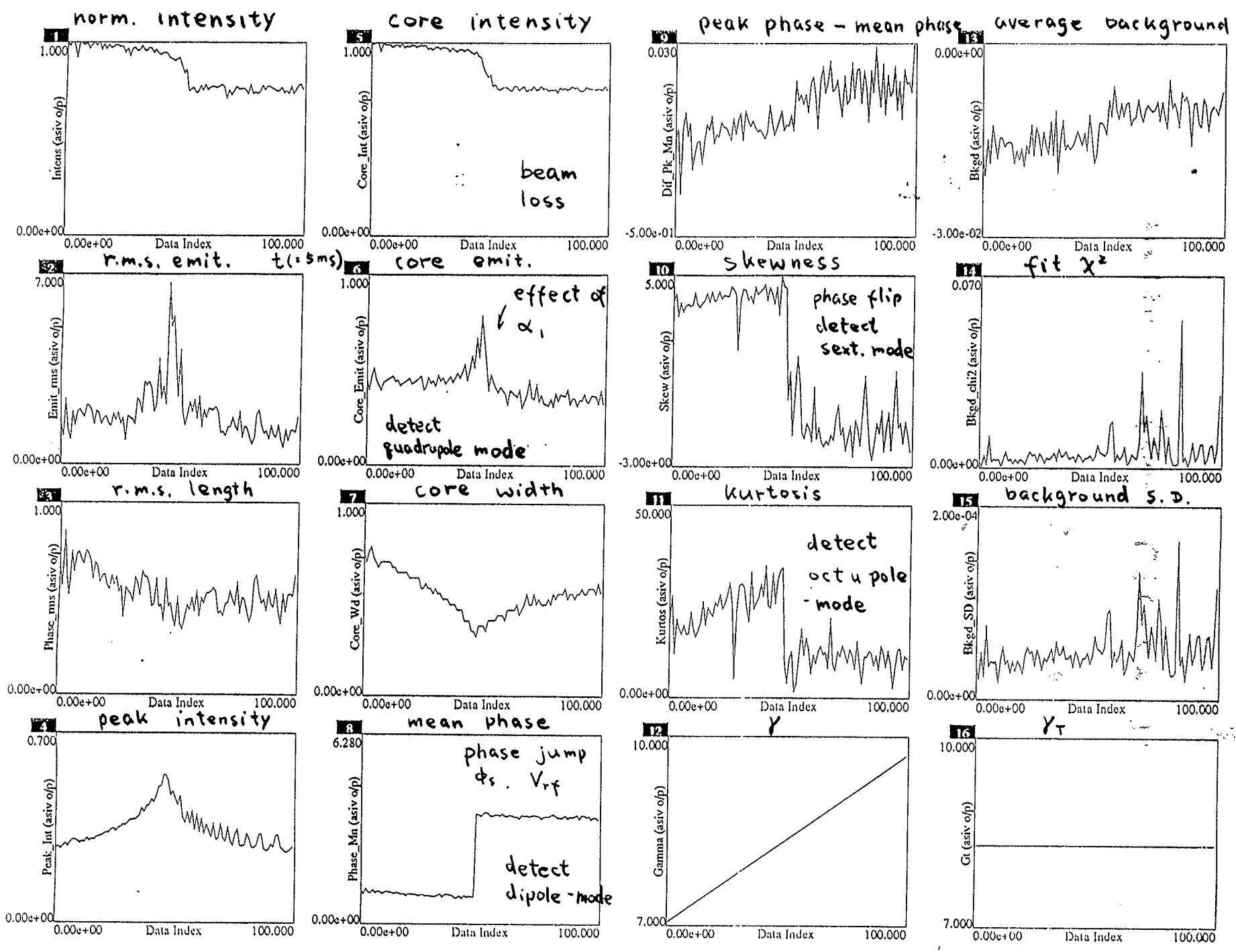
LECROY
7200
⇓
SDS



* 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
Intens (asiv o/p)
1.000
0.00e+00
0.00e+00
Data Index
100.000
core intensity
5
Core_Int (asiv o/p)
1.000
0.00e+00
beam loss
peak phase - mean phase
9
Dif_Pk_Mn (asiv o/p)
0.030
-5.00e-01
average background
13
Bkgd (asiv o/p)
0.00e+00
-3.00e-02
r.m.s. emit. t(=5ms)
2
Emit_rms (asiv o/p)
7.000
core emit.
6
Core_Emit (asiv o/p)
effect of α1
detect quadrupole mode
skewness
10
Skew (asiv o/p)
5.000
-3.00e+00
phase flip
detect sext. mode
fit χ²
14
Bkgd_chi2 (asiv o/p)
0.070
r.m.s. length
3
Phase_rms (asiv o/p)
core width
7
Core_Wd (asiv o/p)
kurtosis
11
Kurtos (asiv o/p)
50.000
detect octupole-mode
background s.d.
15
Bkgd_SD (asiv o/p)
2.00e-04
peak intensity
4
Peak_Int (asiv o/p)
0.700
mean phase
8
Phase_Mn (asiv o/p)
6.280
phase jump
φs . Vrf
detect dipole-mode
γ
12
Gamma (asiv o/p)
10.000
7.000
γT
16
Gt (asiv o/p)
10.000
7.000

* 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

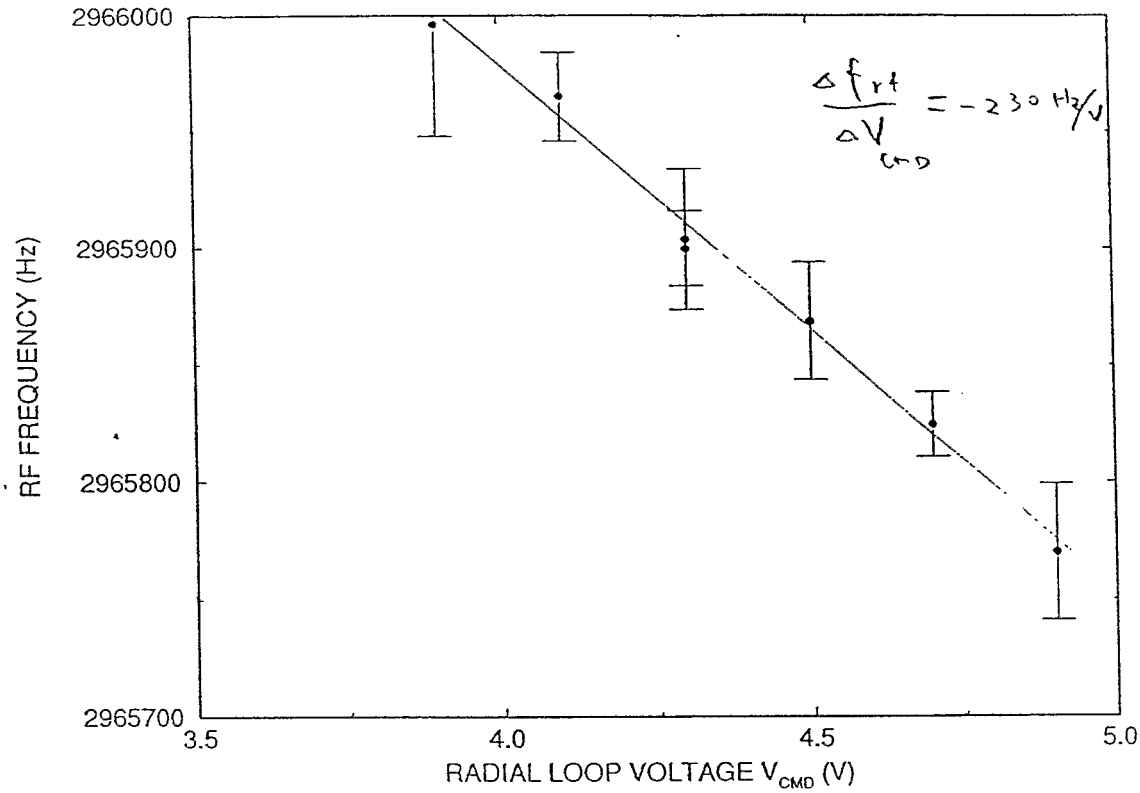
measure signal broadening due to cable attenuation and bandwidth limitation

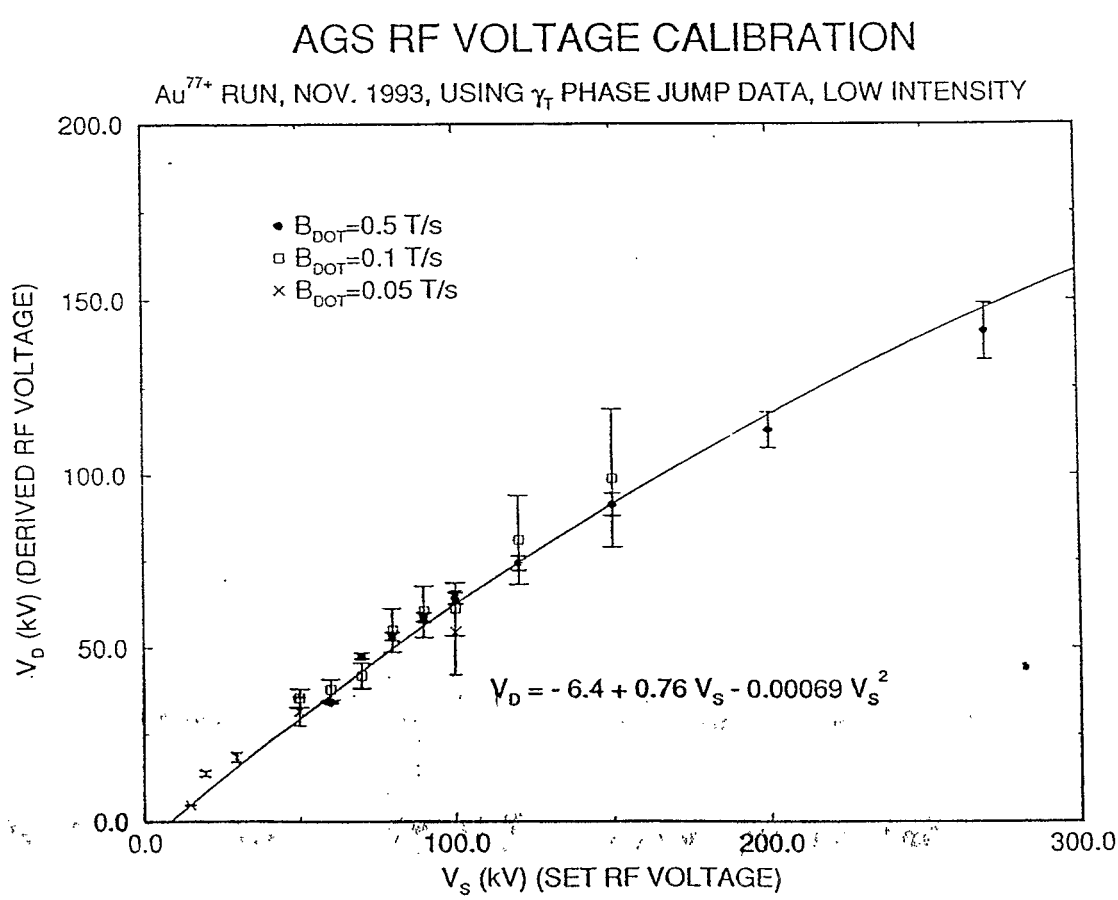
(insert 1 ns ~ 15 ns signal at BPM

measure from LECROY 7200)

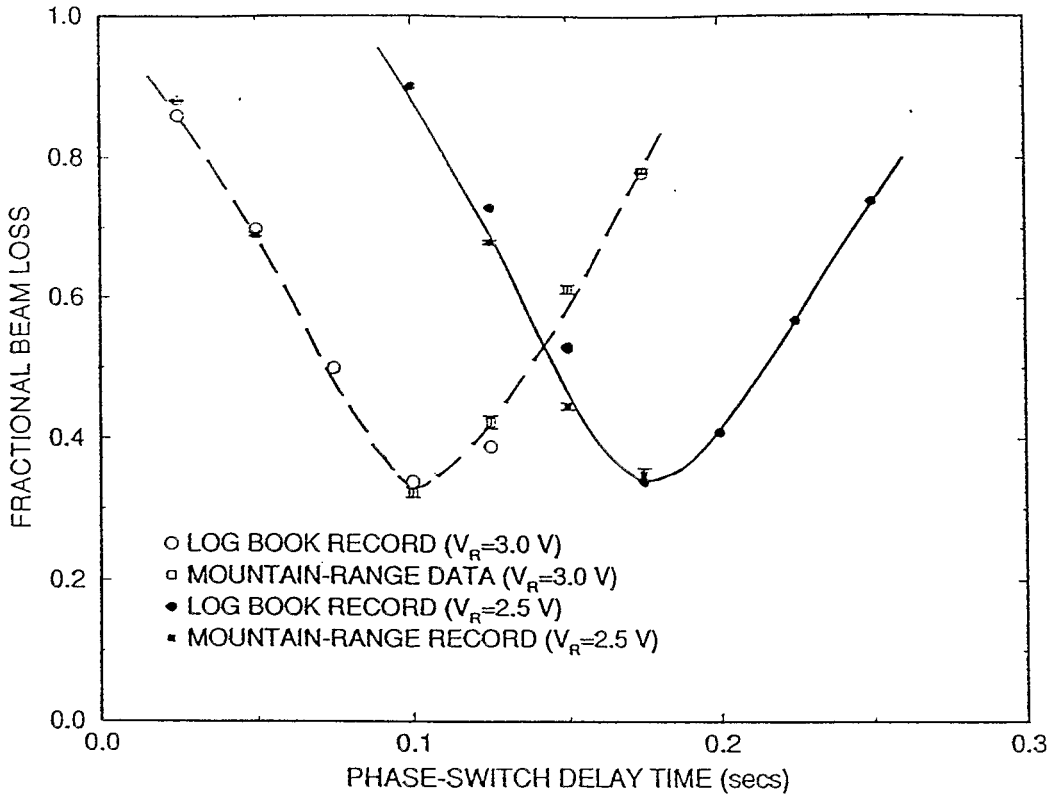
Calibrations

radial loop voltage





extraction of α_1 factor



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

(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

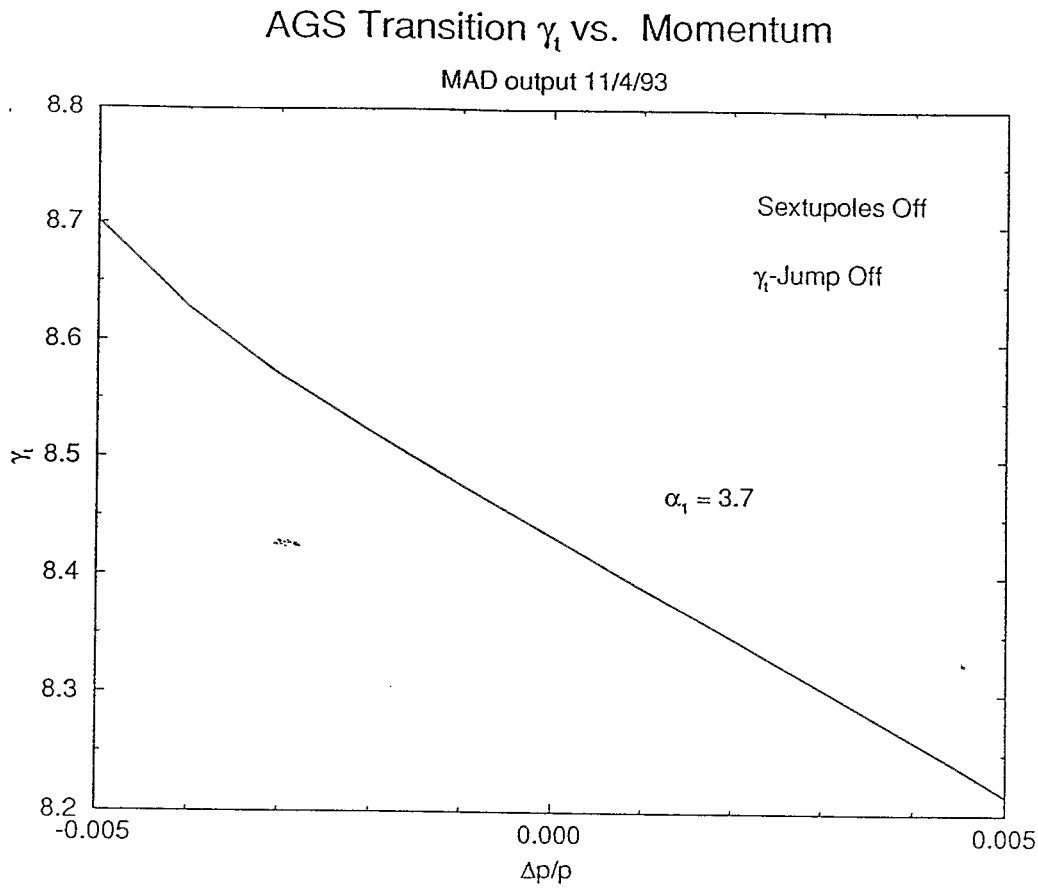
← sextupole currents

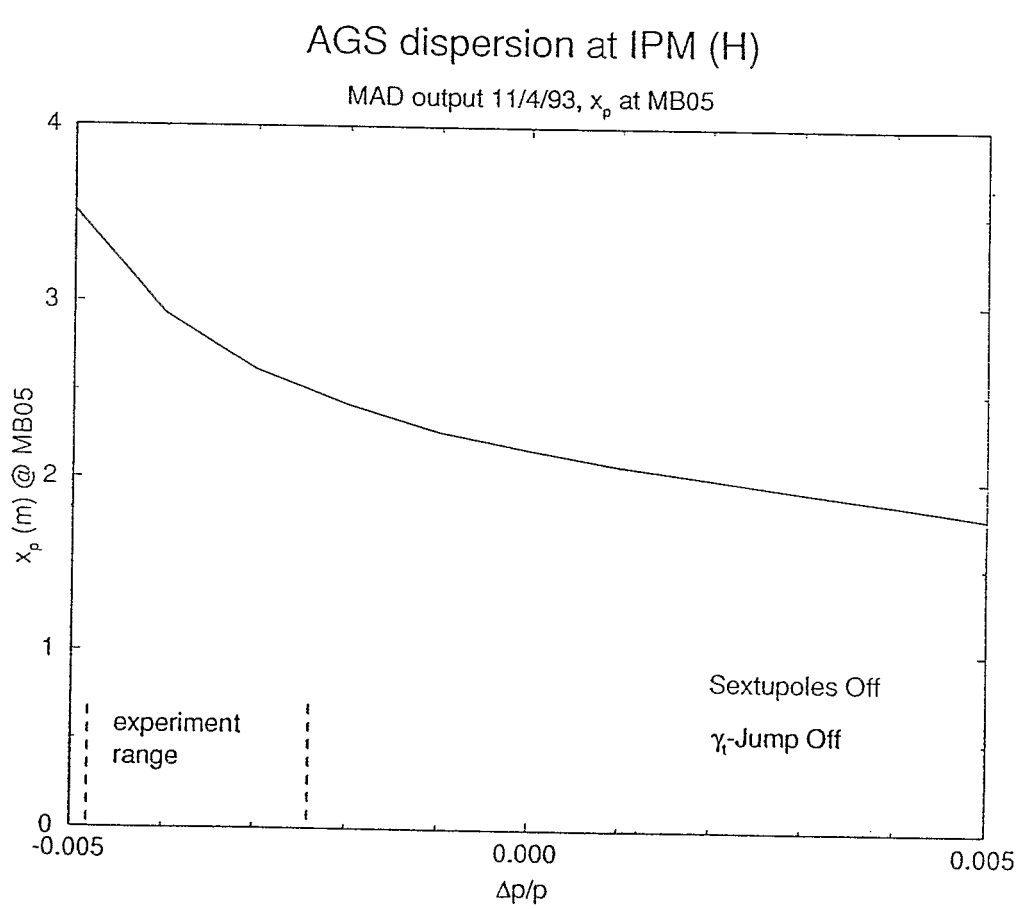
MAD α_1 : 3.7

SYNCH α_1 : 0.4 ?

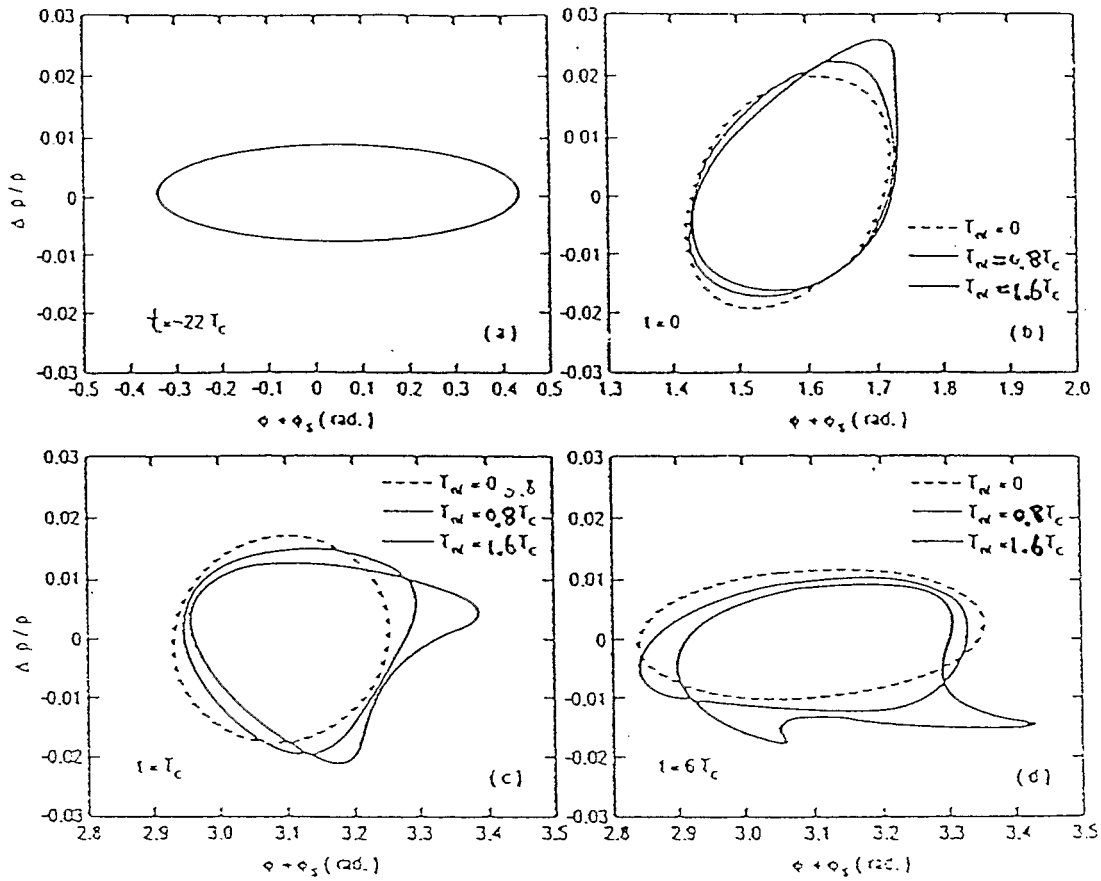
agrees with MAD calculation

consistant 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
Sextupoles Off
γ_t-Jump Off
α_1 = 3.7
-0.005
0.000
0.005
Δp/p


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

Johnsen effect



non-adiabatic time:

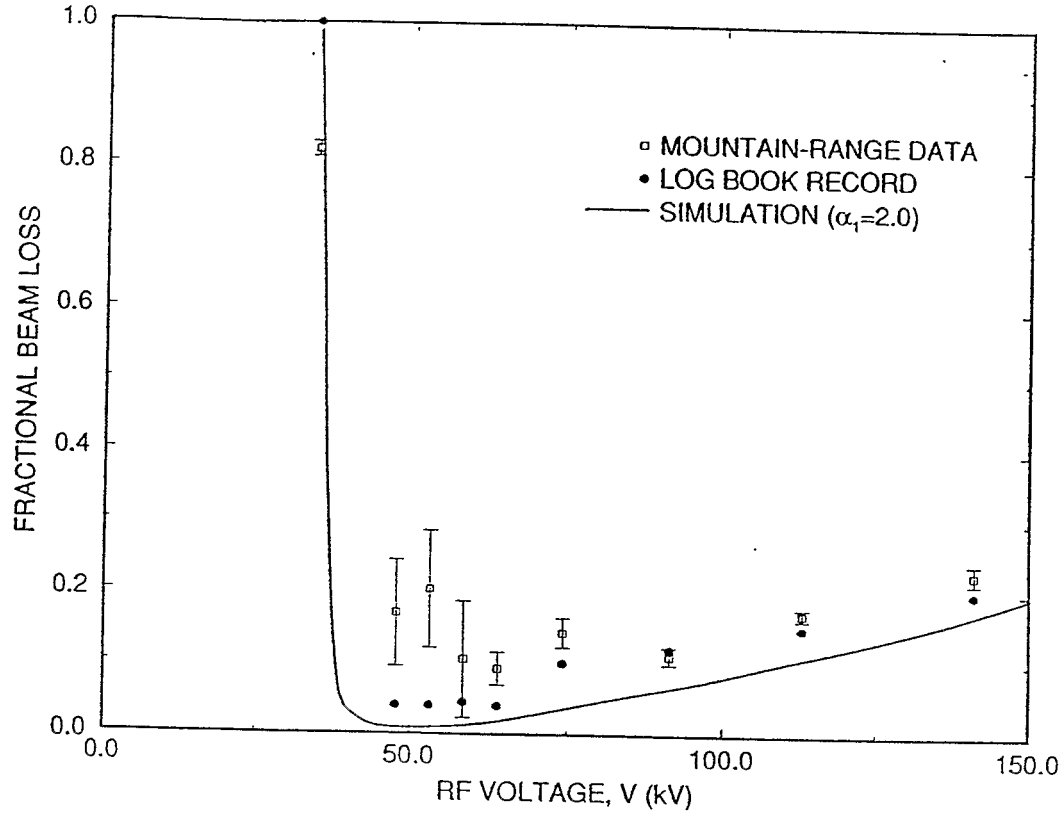
$$T_C = \left(\frac{\pi E \beta_s^2 \gamma_T^3}{qeV |\cos\phi_s| \dot{\gamma}_s h \omega_s^2} \right)^{\frac{1}{3}}$$

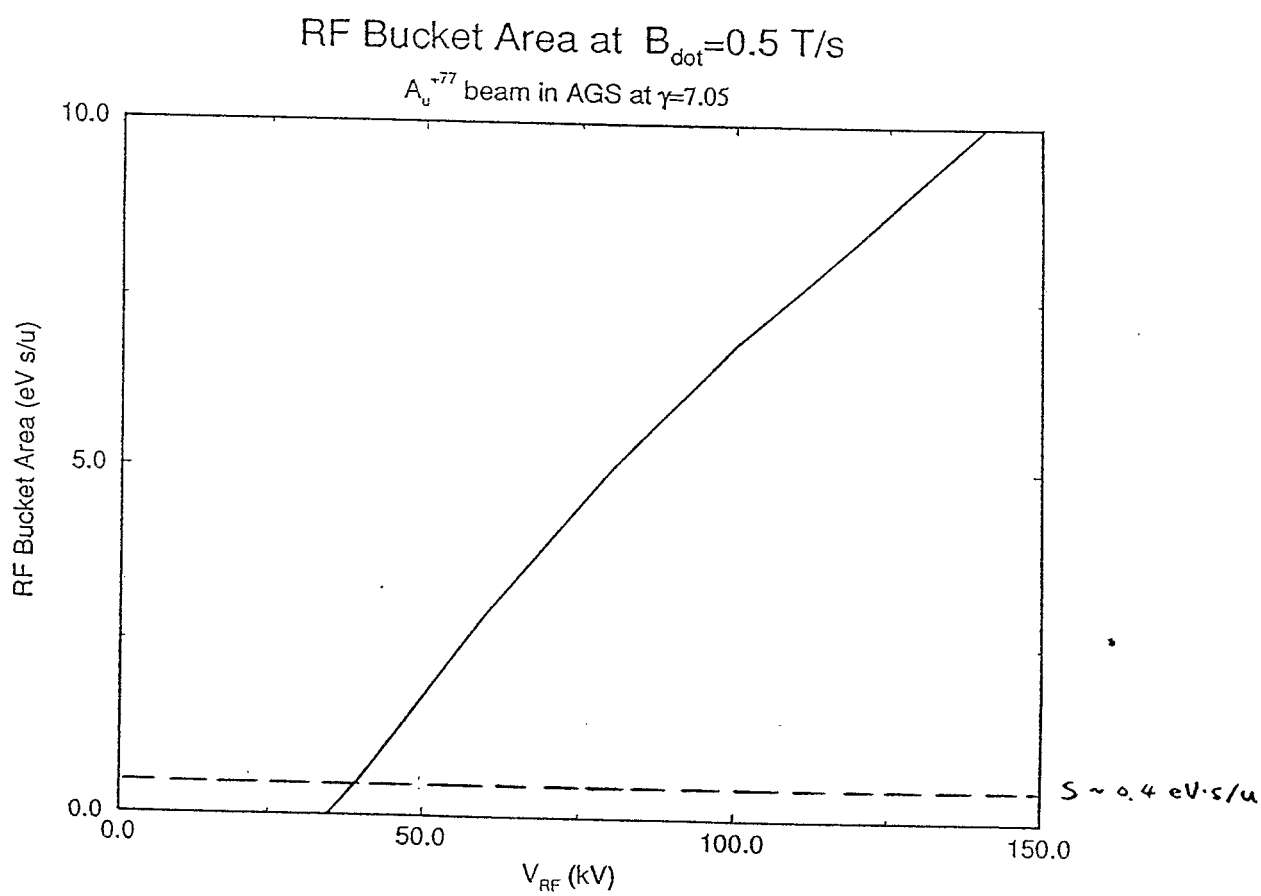
nonlinear time:

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

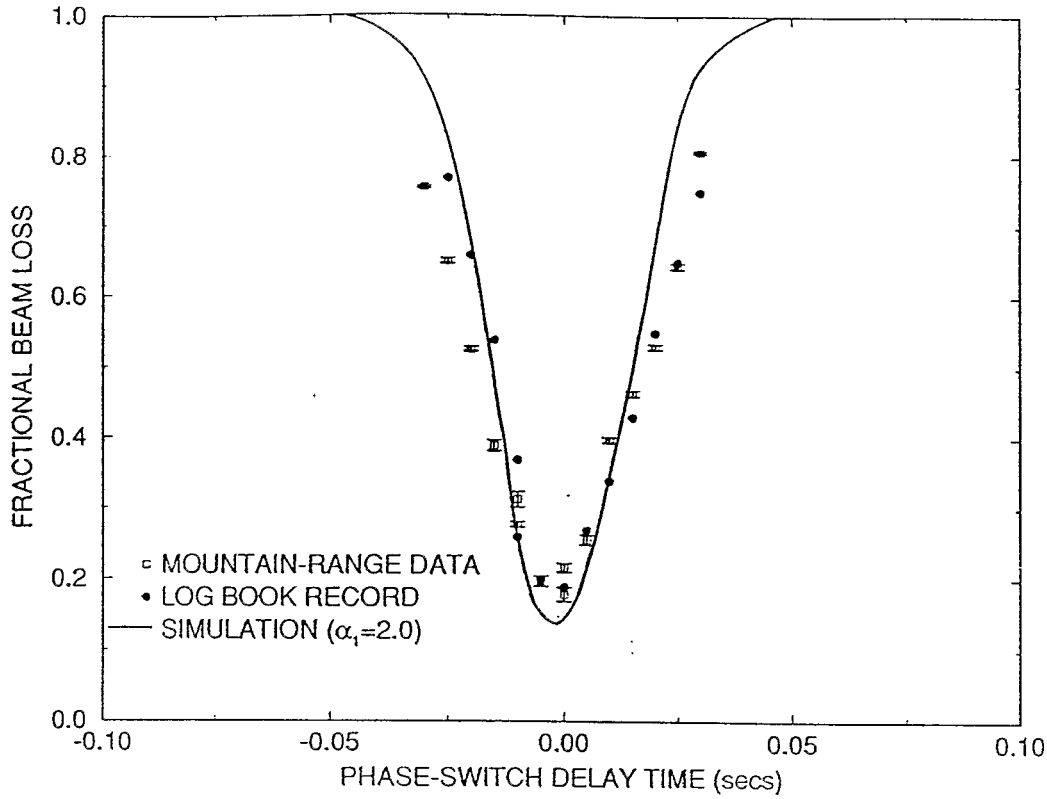
$$\frac{\Delta S}{S} \approx \begin{cases} 0.38\ \dfrac{T_{nl}}{T_c}, & \text{for } T_{nl} \ll T_c \\ e^{\frac{2^{1/2}}{3}\left(\frac{T_{nl}}{T_c}\right)^{3/2}} - 1, & \text{for } T_{nl} \geq T_c \end{cases}$$

beam loss vs. rf voltage

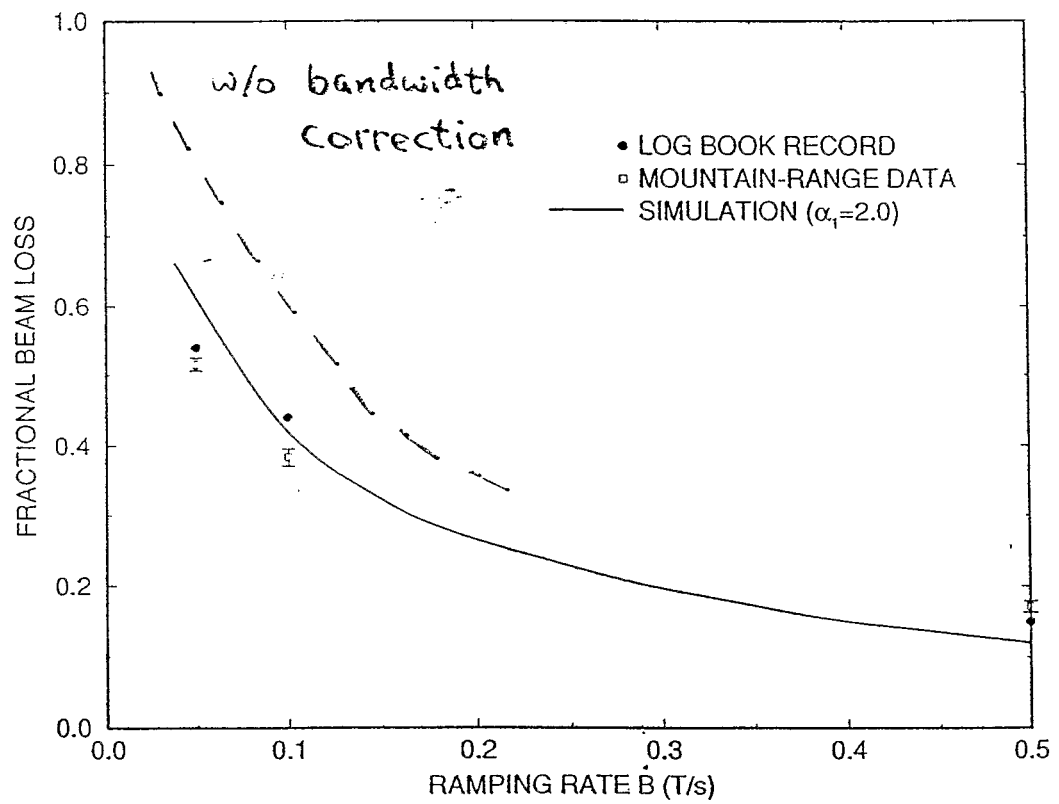




beam loss vs. switch time

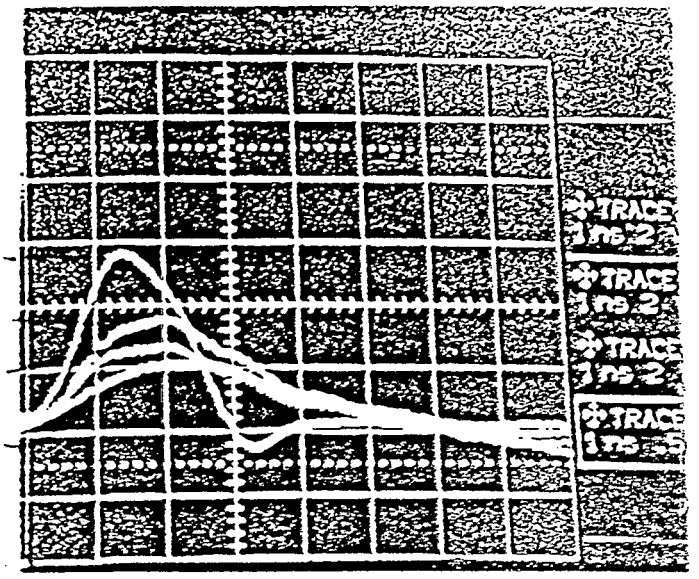


beam loss vs. ramp rate

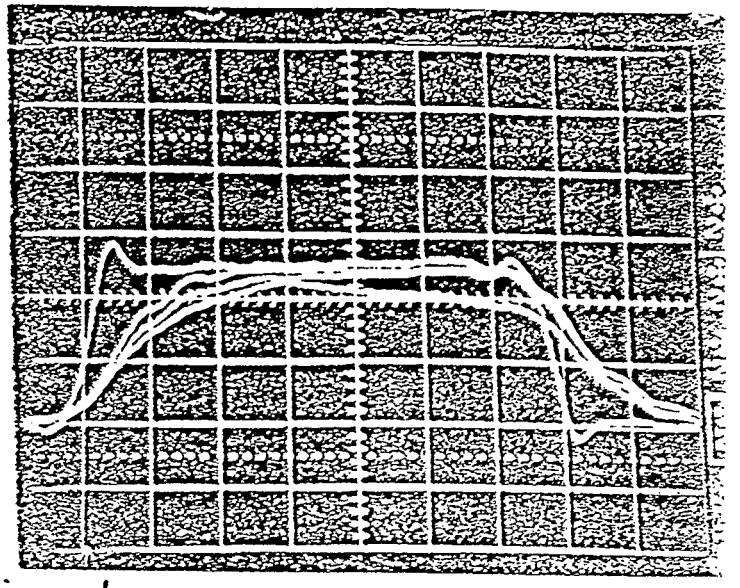


Cable loss and bandwidth measurements

2 ns pulse



14 ns pulse



(1) original signal

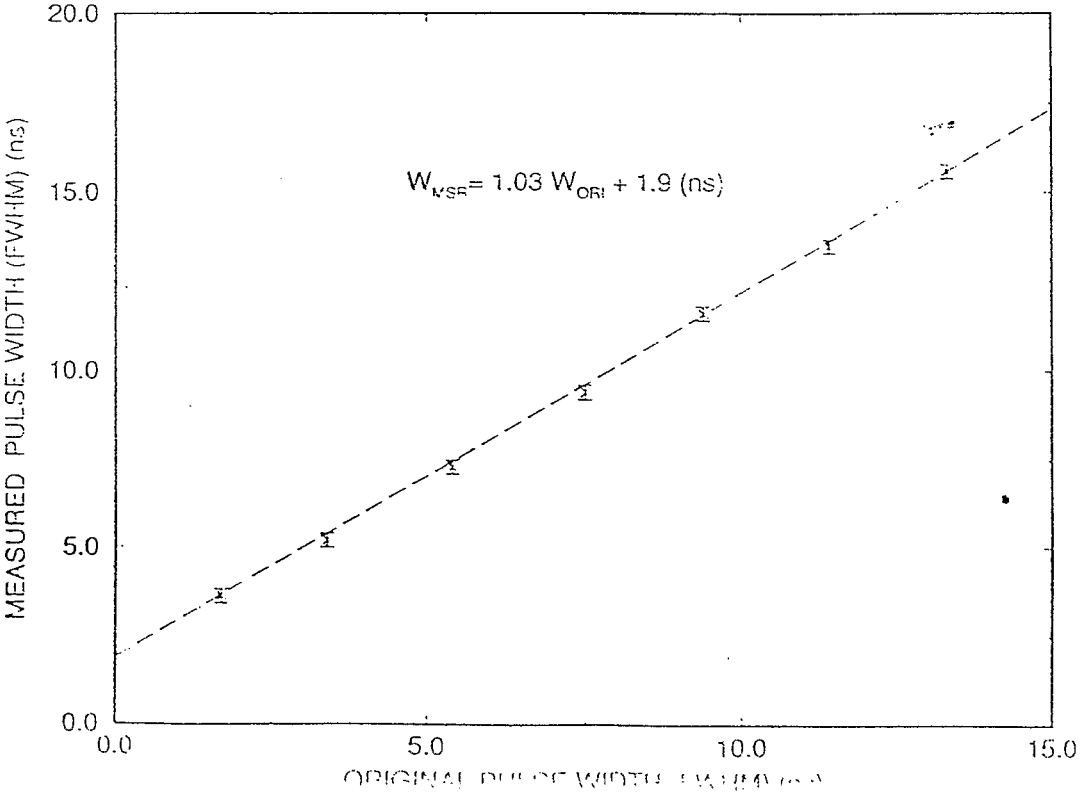
(2) measured signal at the start of 213 cable

(3) measured signal at the start of 213 cable

(4) measured signal at gap monitor station

SIGNAL BROADENING AT AGS

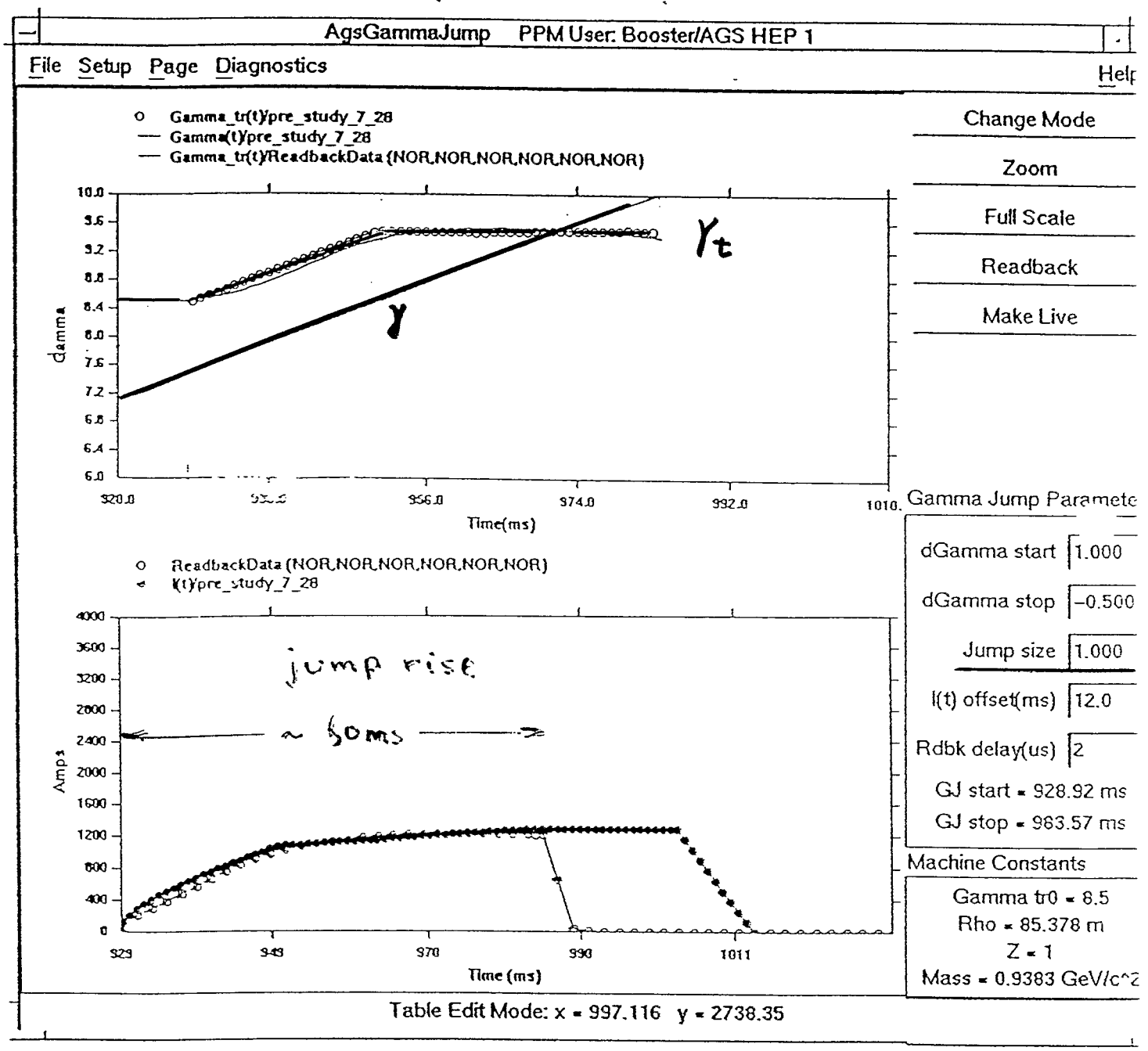
MEASURED BEFORE 213 CABLE WITH PREAMPLIFIER BY LECROY 7200



γ_t-jump study & α_1 measurement

during γ_t-jump, lattice distortion is signi

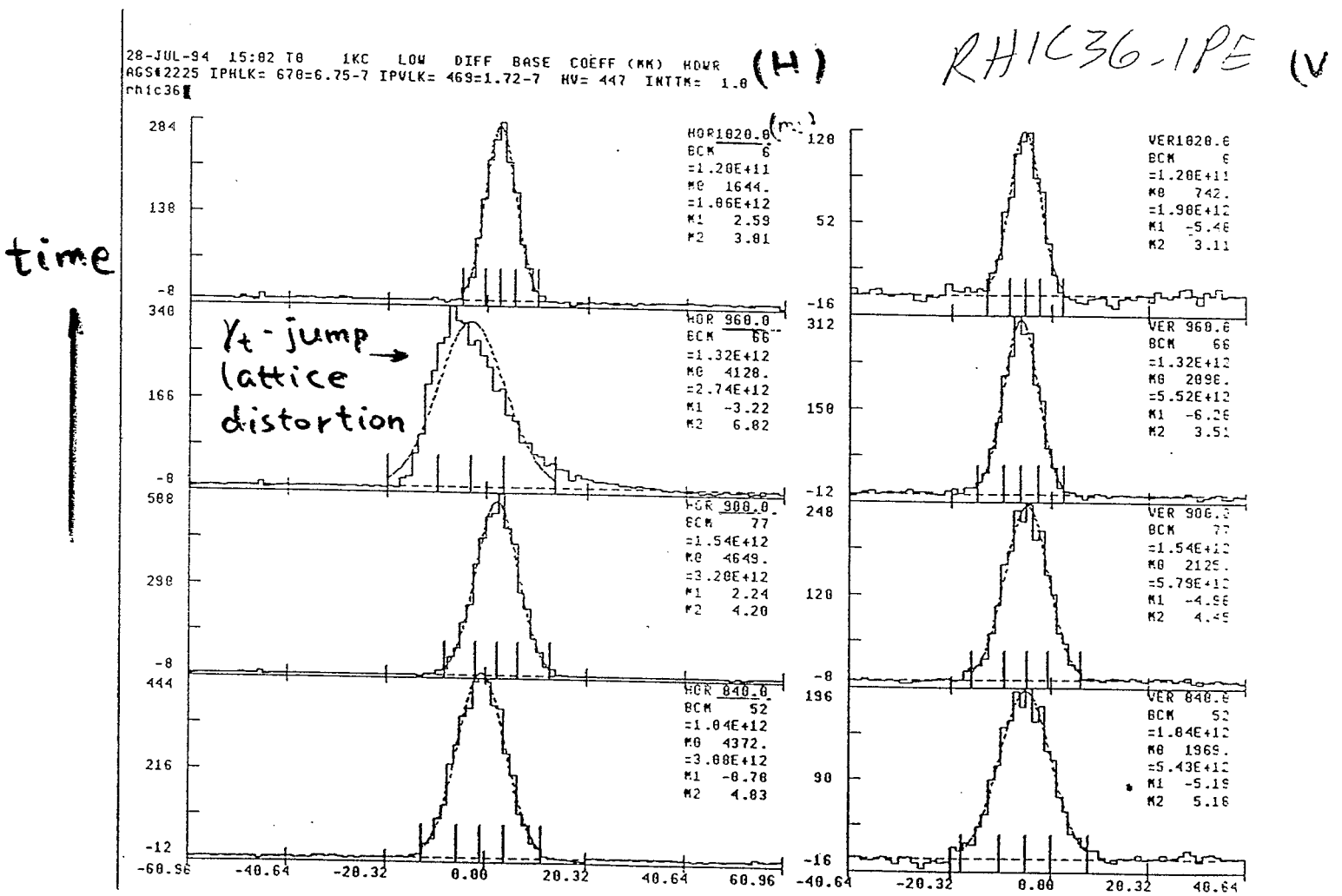
α_1 deviates from normal value



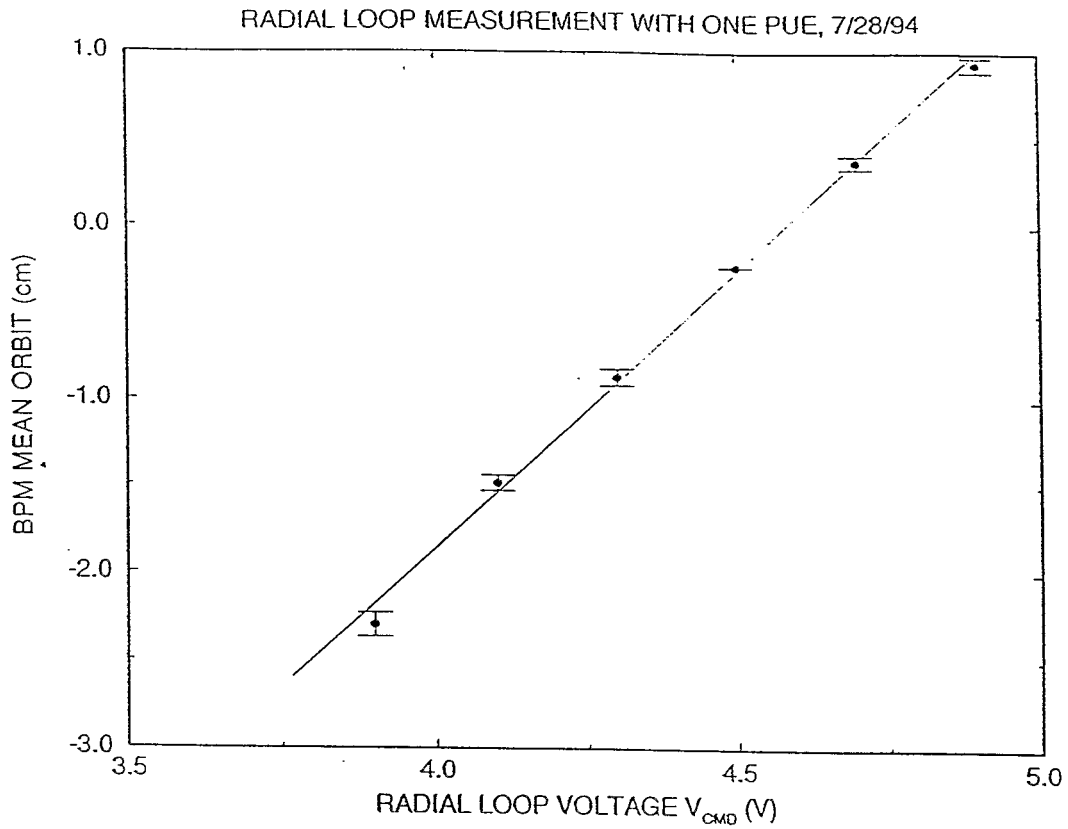
Synchronized recording of :

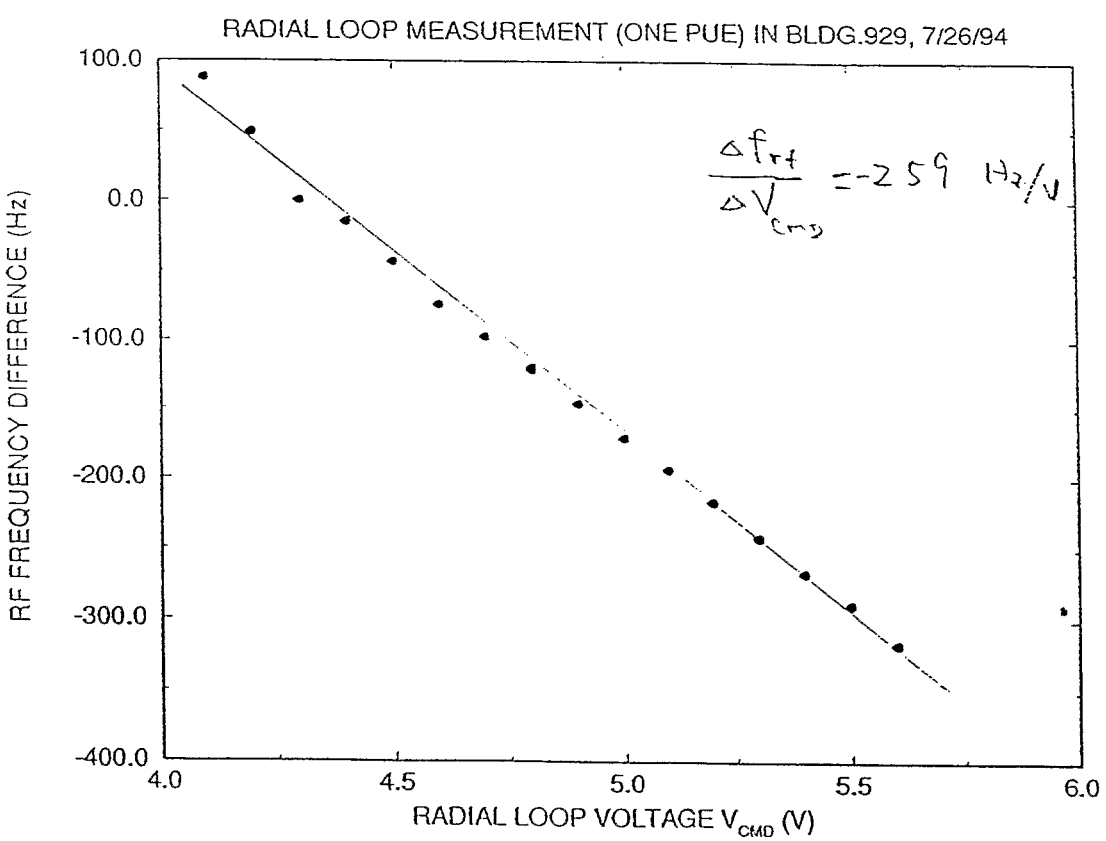
* instantaneous $\dot{B}$
* loss monitor reading
* digital mountain-range profile.
* transverse IPM profile

IPM measurement

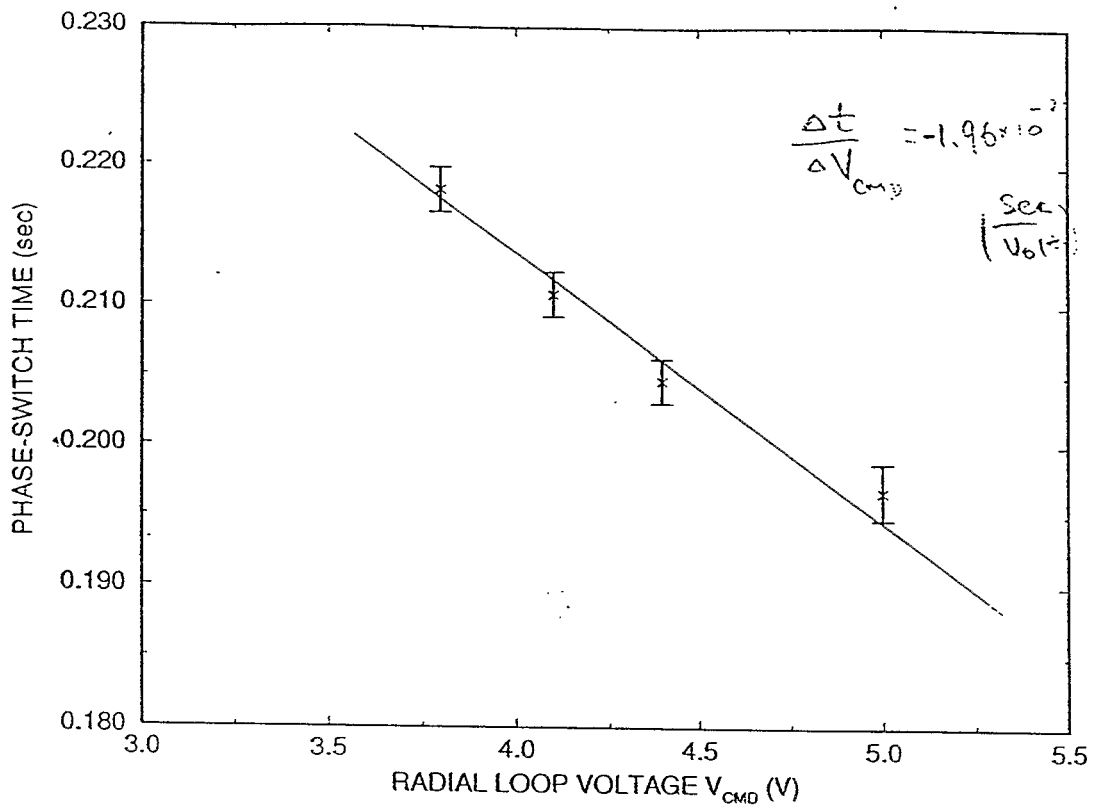


Calibration





extraction of α_1 in γ_t-jump lattice



		"normal" value
$\alpha_1 = 10 \pm 1$		5
SYNCH :	13.6	3.7

$\alpha_2 \approx 0$

$\Rightarrow$ α_1 varies significantly during γ_t-jum

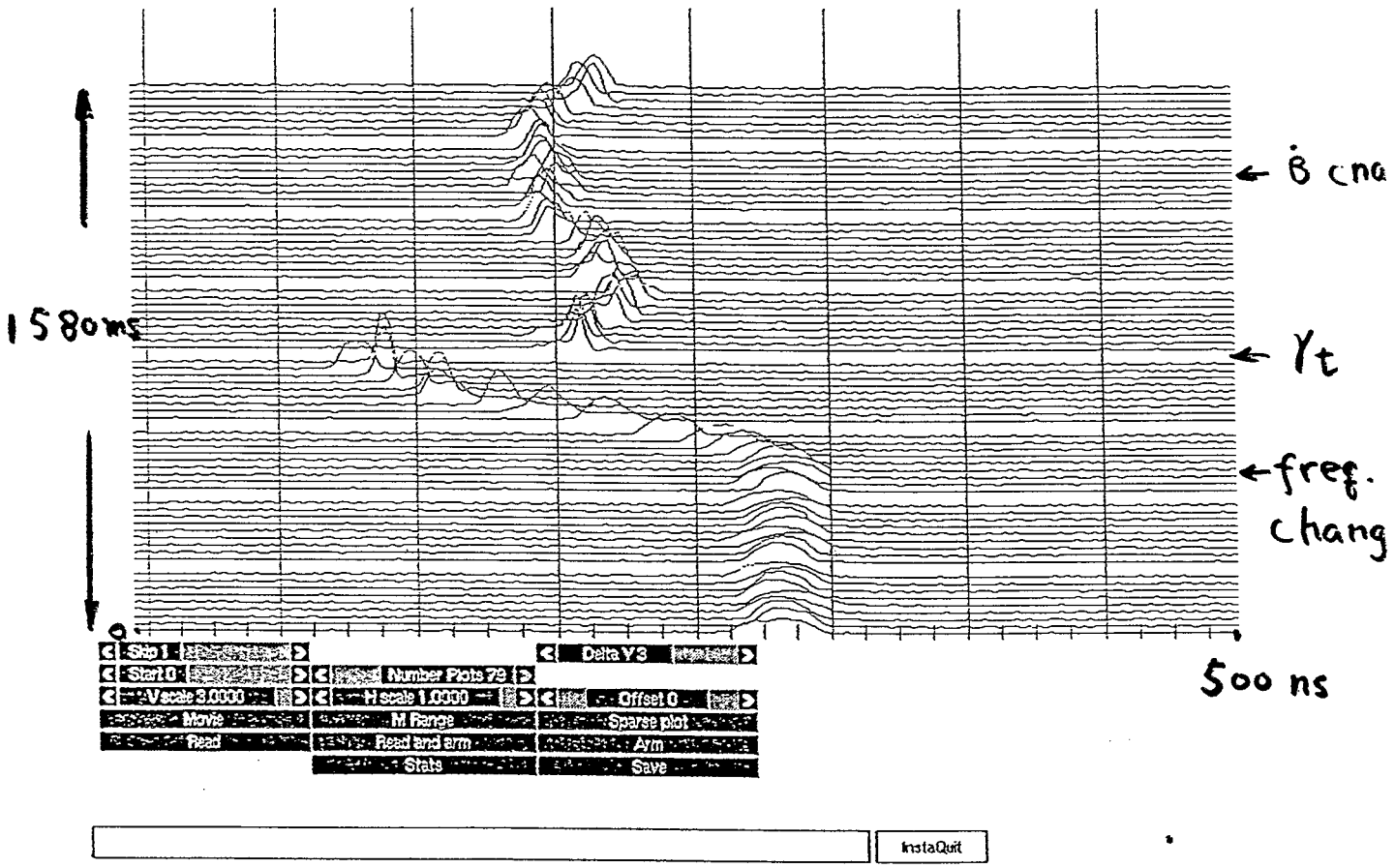
To meet RHIC proton specifications

10^{11} per bunch

$S = 0.3$ eV·s

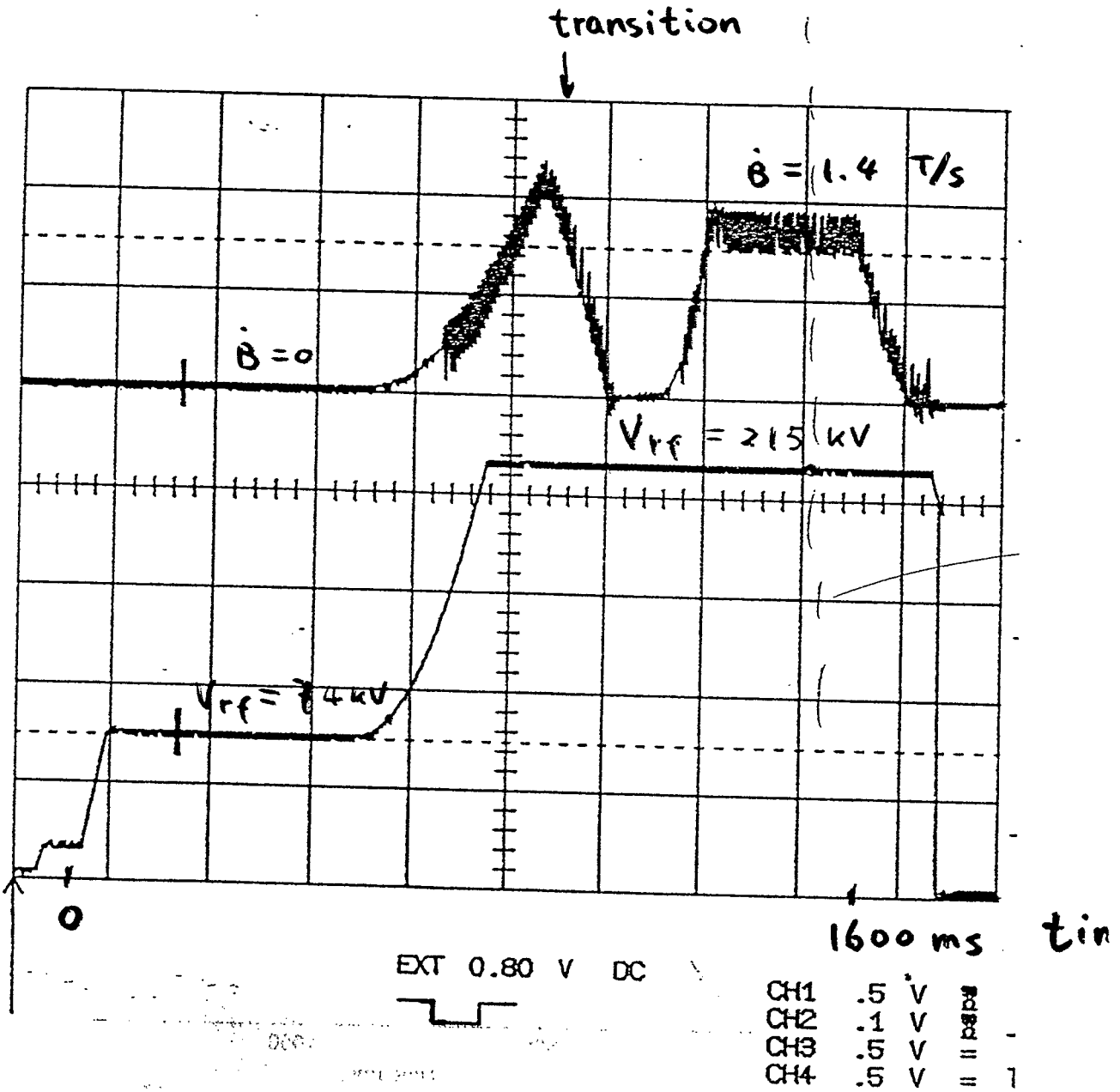
$\varepsilon_{x,y} = 10\ \pi$ mm·mr

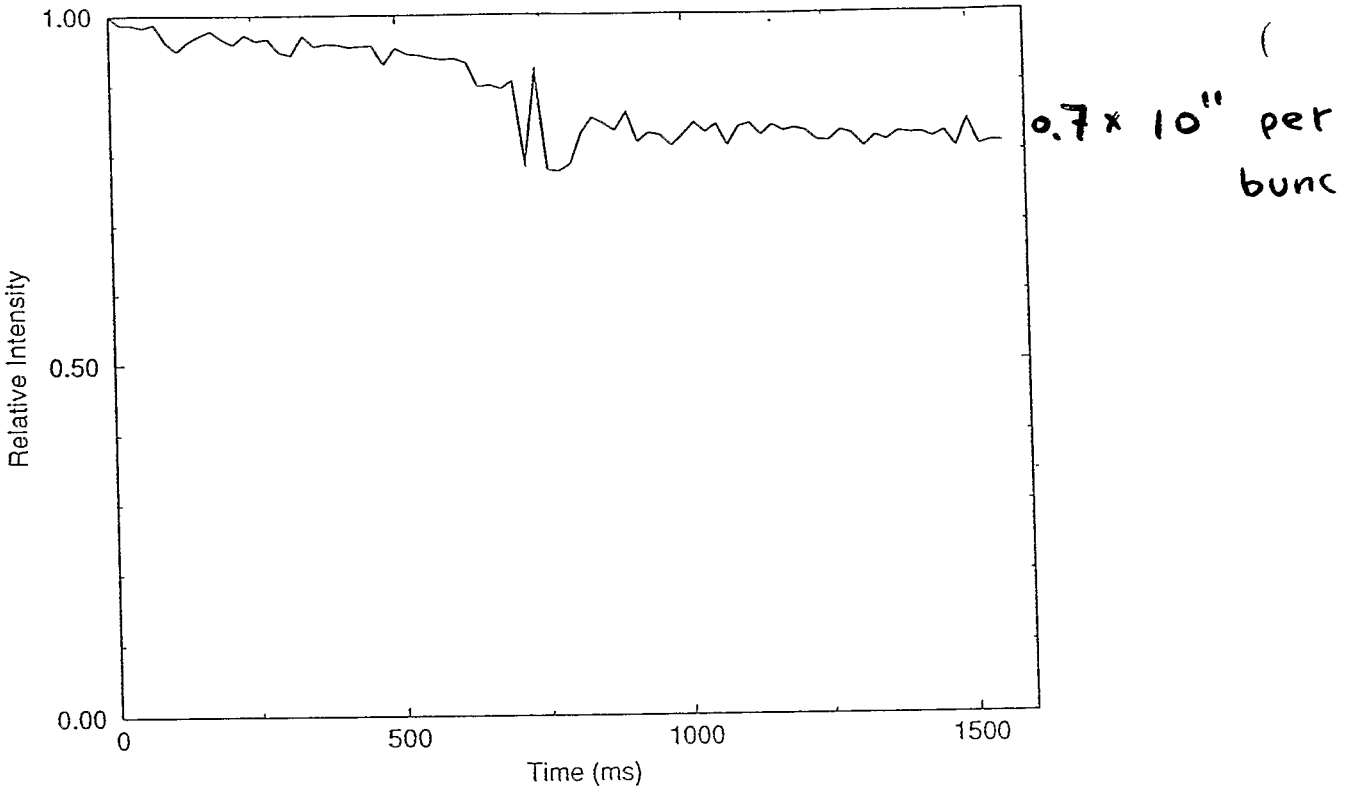
} goal

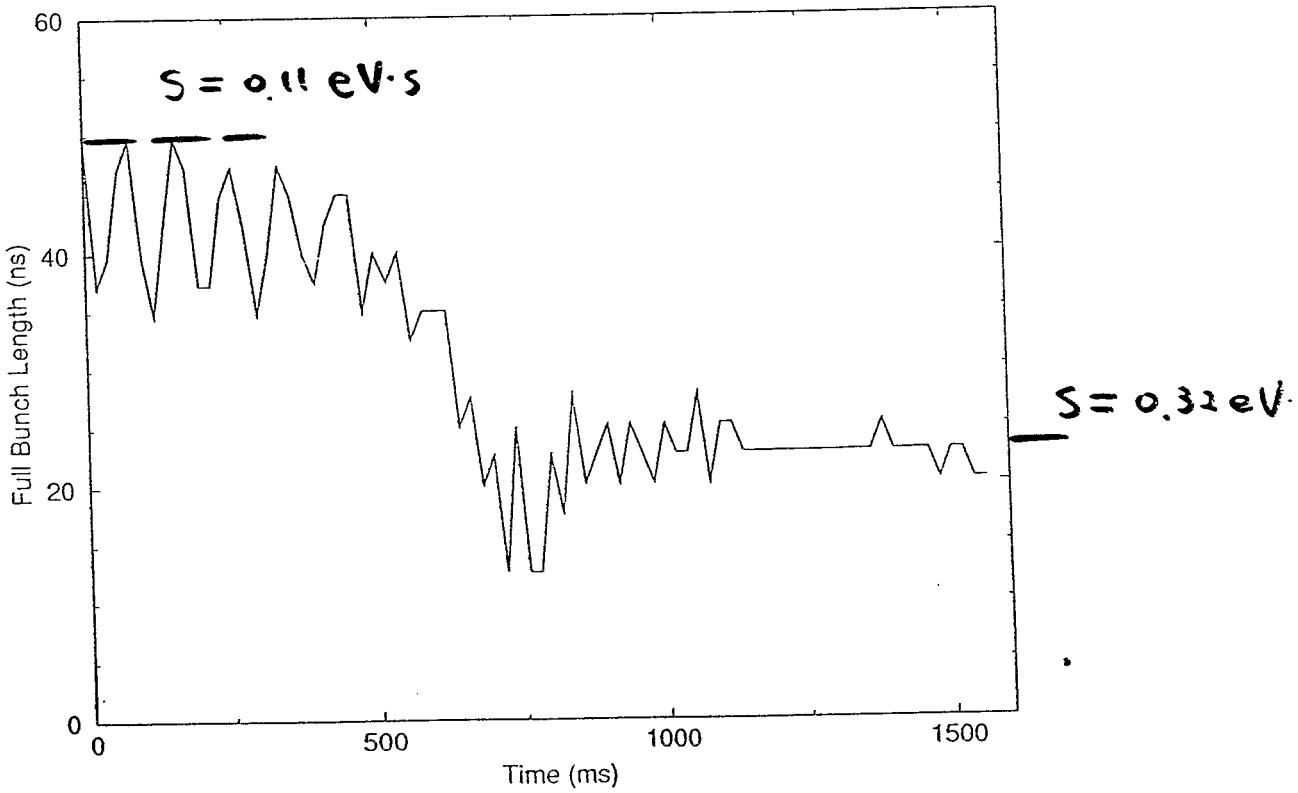


γ_t - jump on

J. M. Brennan etc.

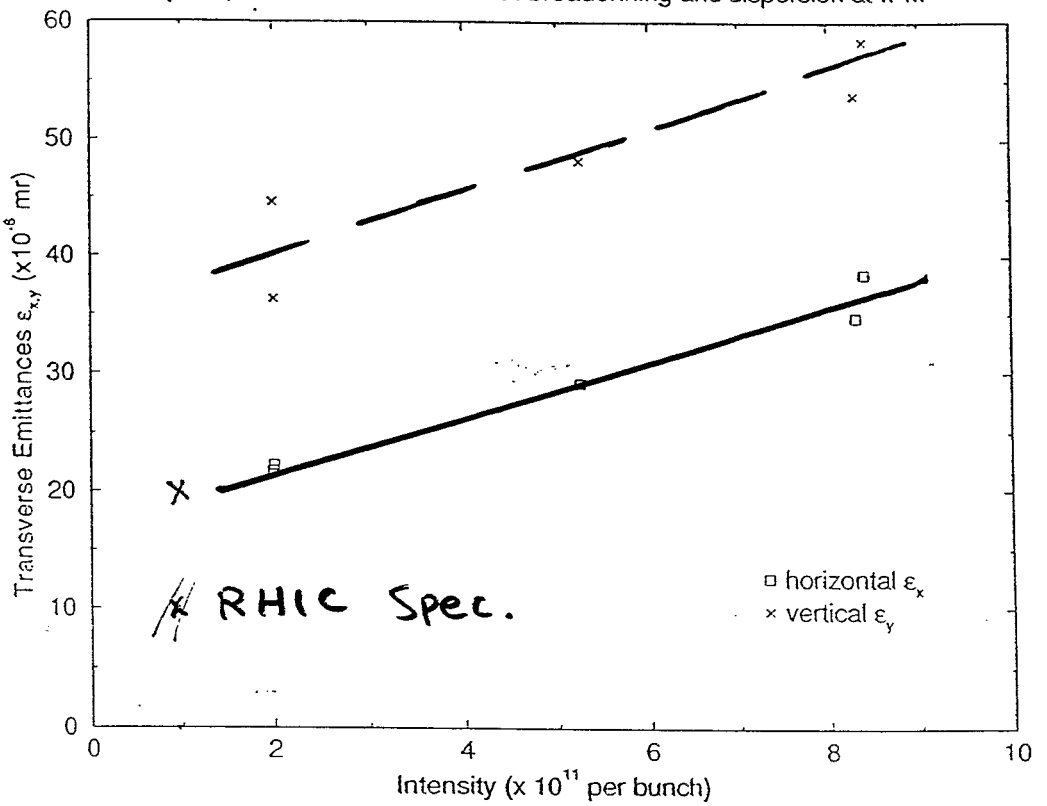



1.00
0.50
0.00
Relative Intensity
0
500
1000
1500
Time (ms)
0.7 x 10^11 per bunc


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

IPM Data, Proton Run 7/27/94

γ=5.5, corrected for bandwidth broadenning and dispersion at IPM



$\varepsilon_x \sim 20\,\pi$ 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

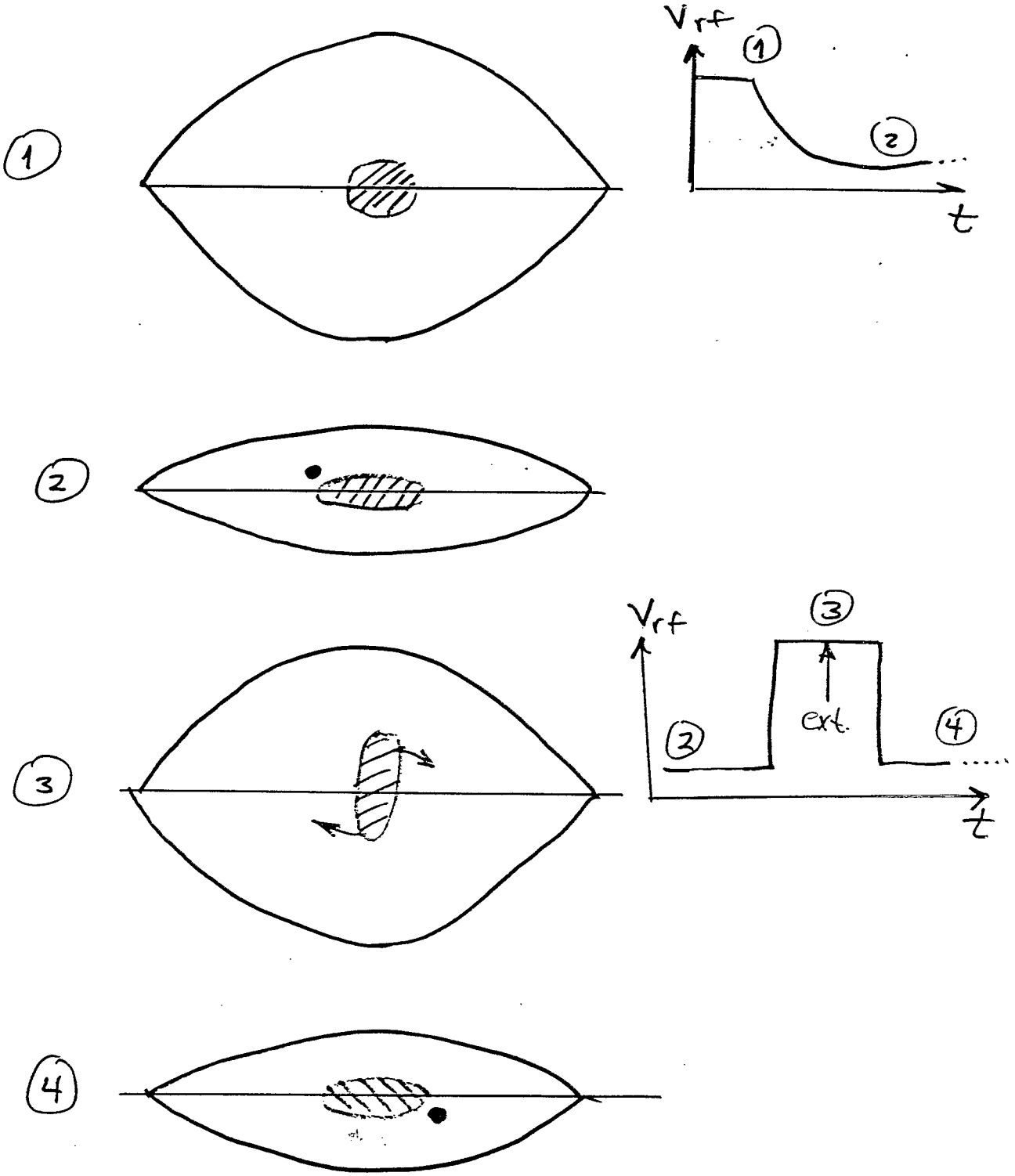
3. single bunch transfer implies must repeat 12 times

4. small bucket fill fraction implies;

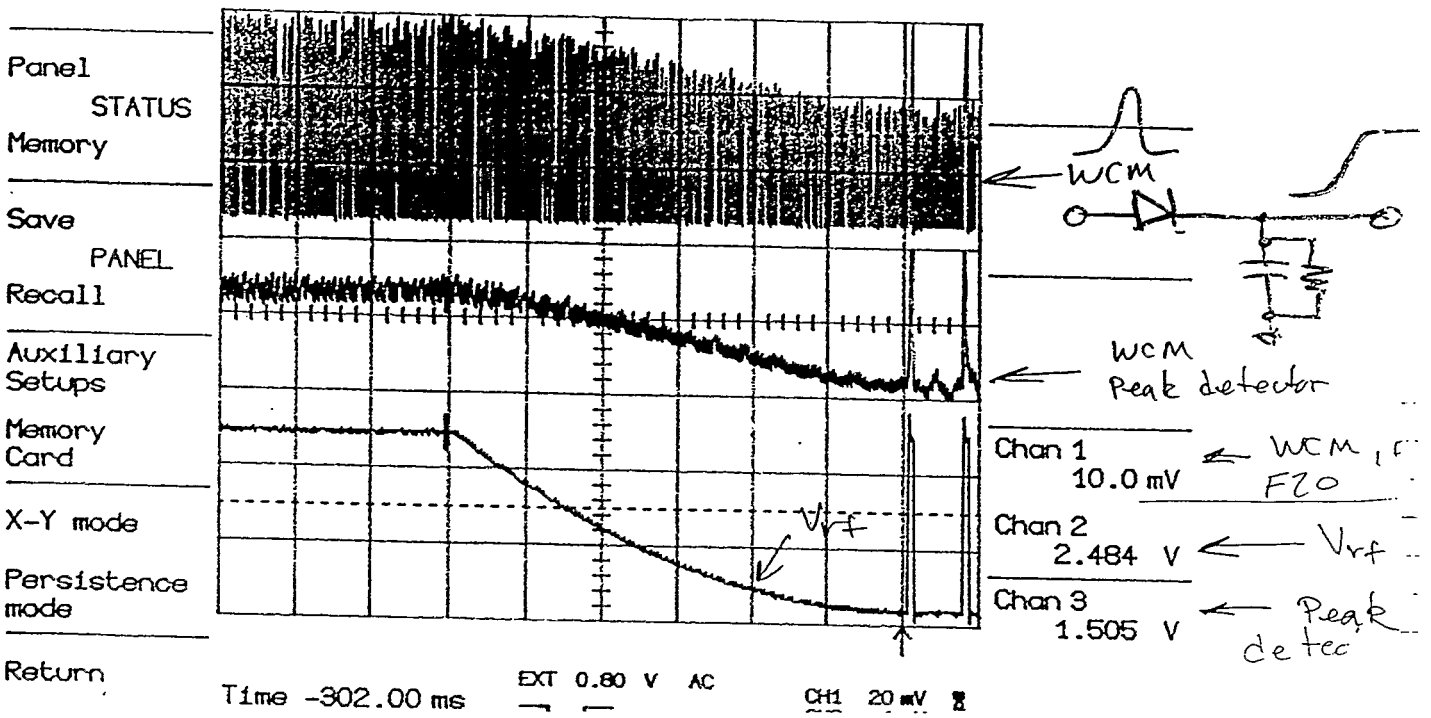
   - no filamentation

   - rotations are "reversible"

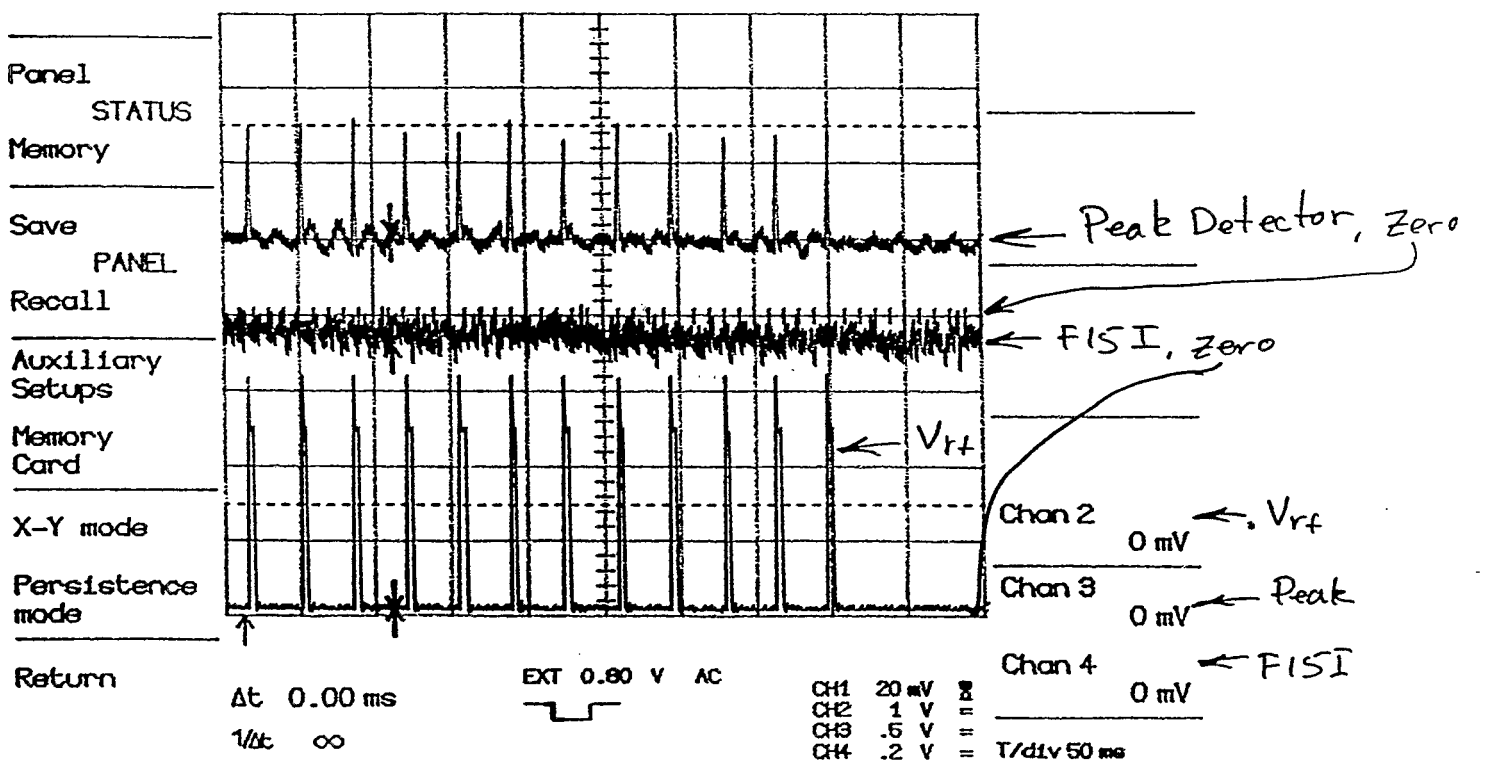
5. practice with Gold ions


1
2
3
4
V_{rf}
t
ext.

17-Oct-93
9:52:41



10:41:28



III. Future Study Plan

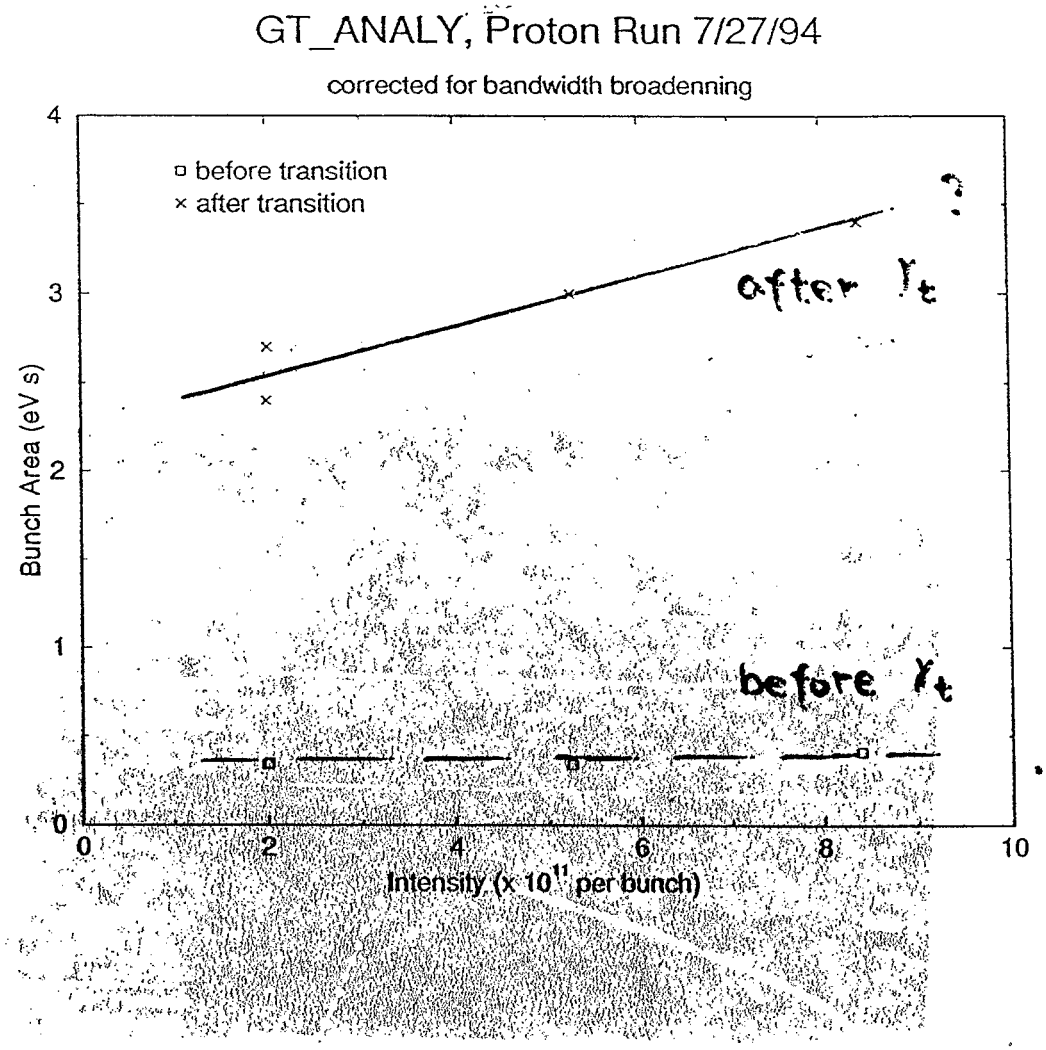
More studies on intensity dependence

(7/27/94 experiment)

growth in longitudinal area :

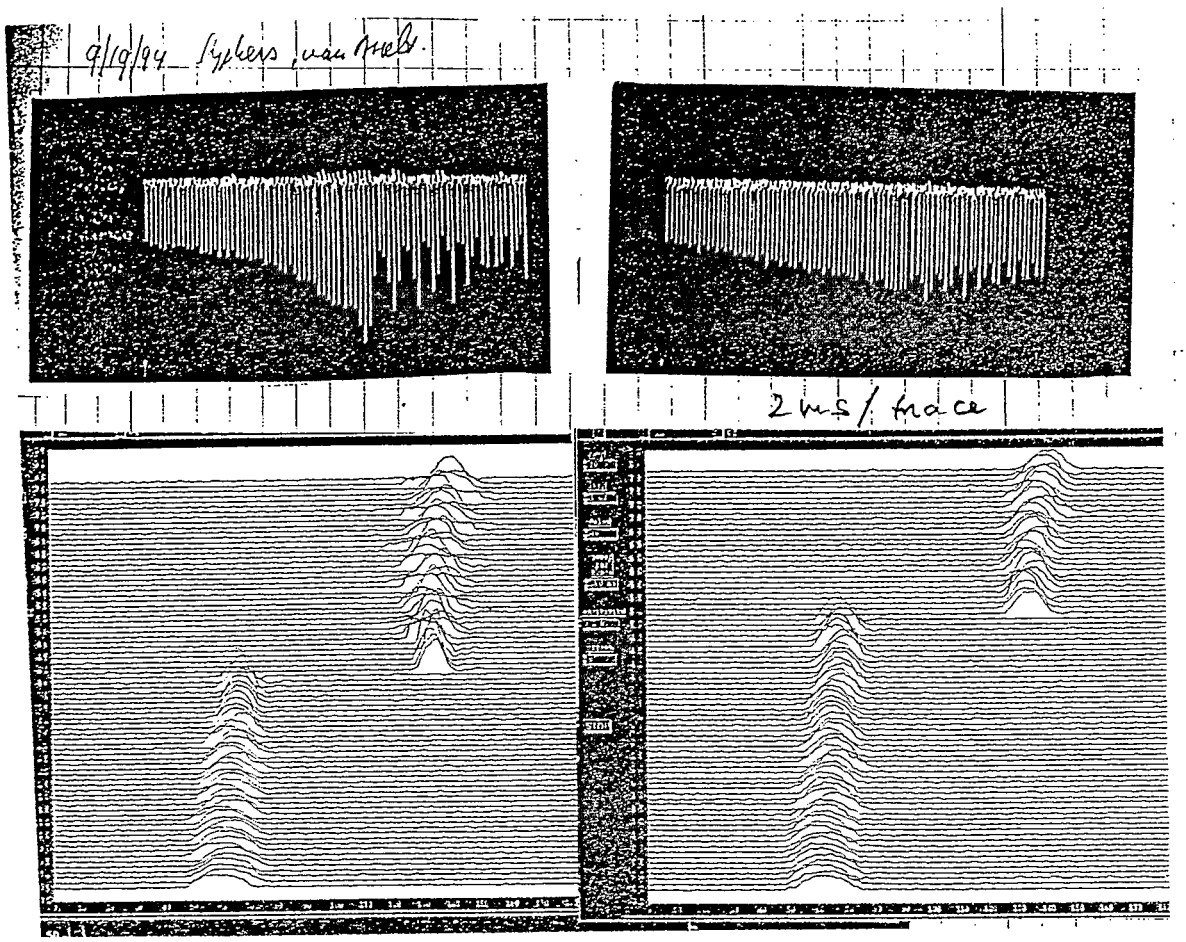
(1) impedance mismatch

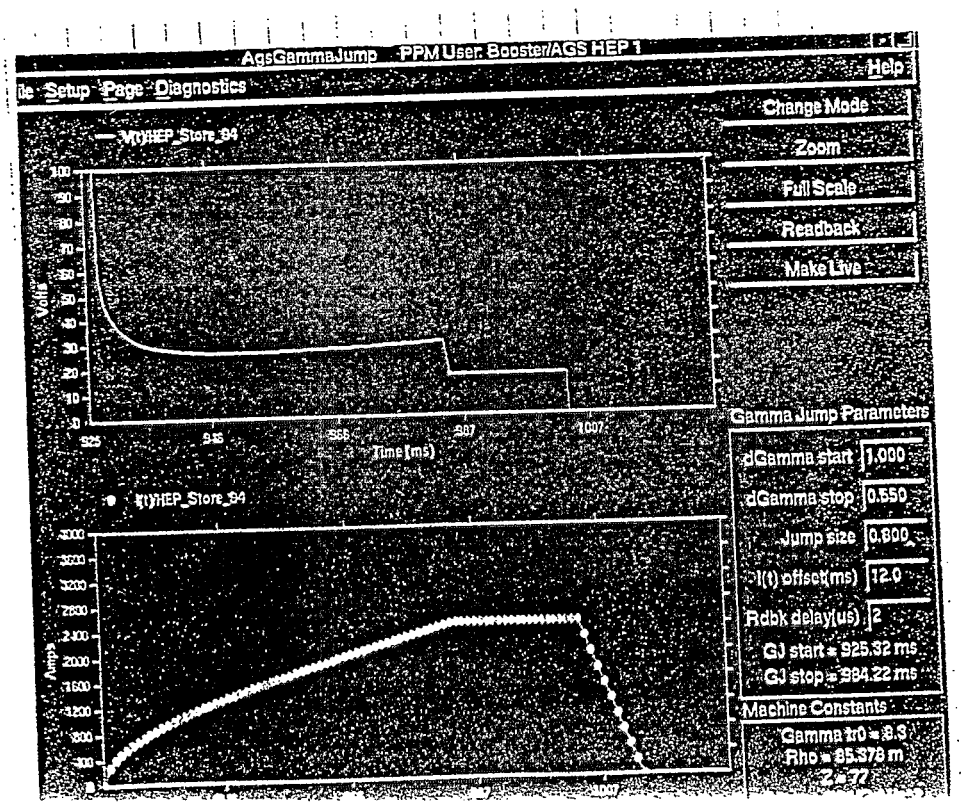
(2) damage in electronics due to radiation



More studies on γ_t-jump

W. Van Asselt





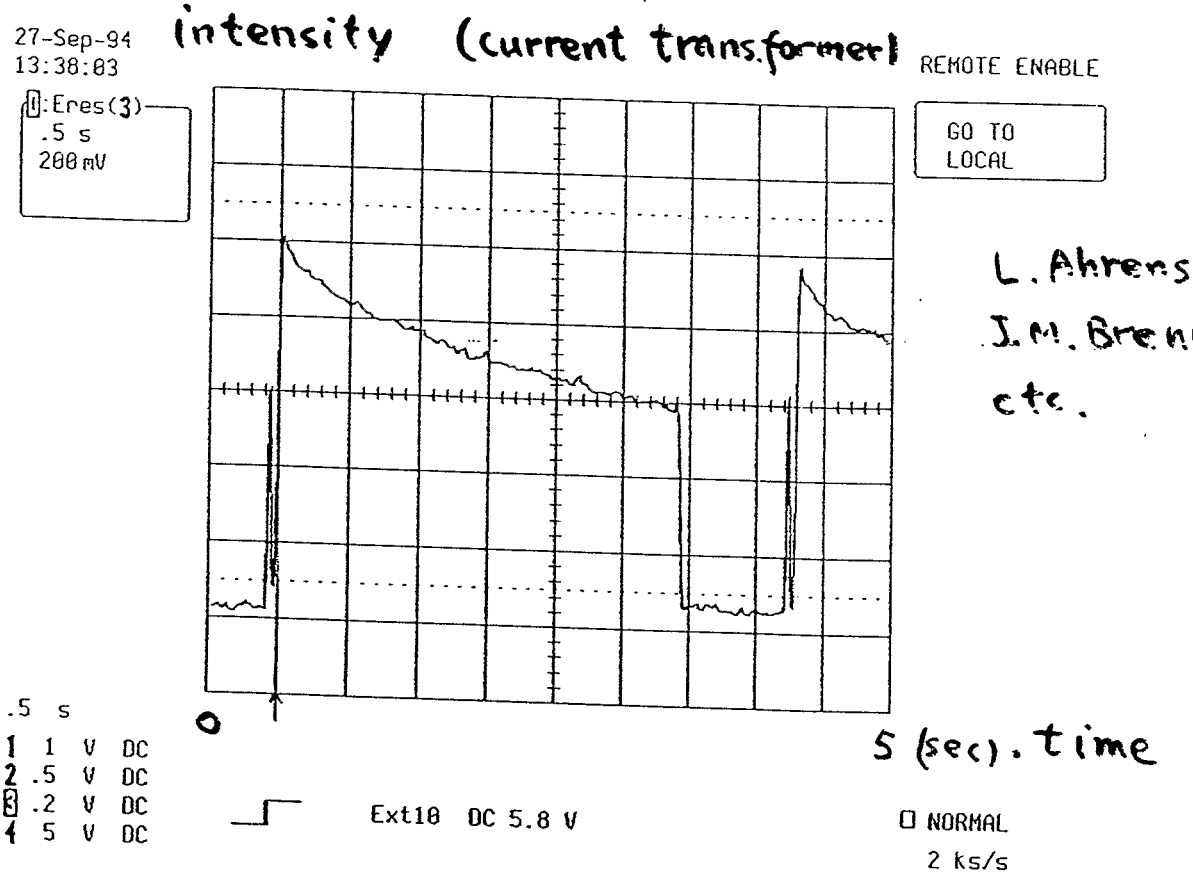
Intrabeam scattering at AGS injection

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

strong IBS growth

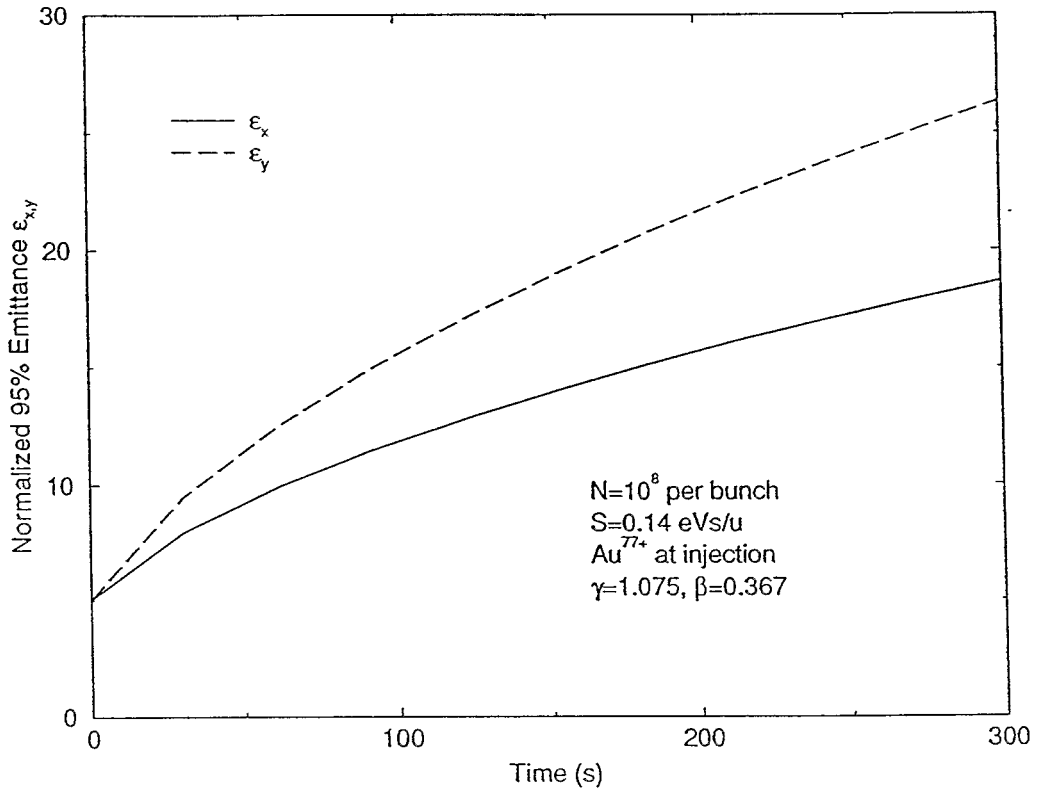
AGS injection, $\dot{B}=0$, Au^{77+} beam

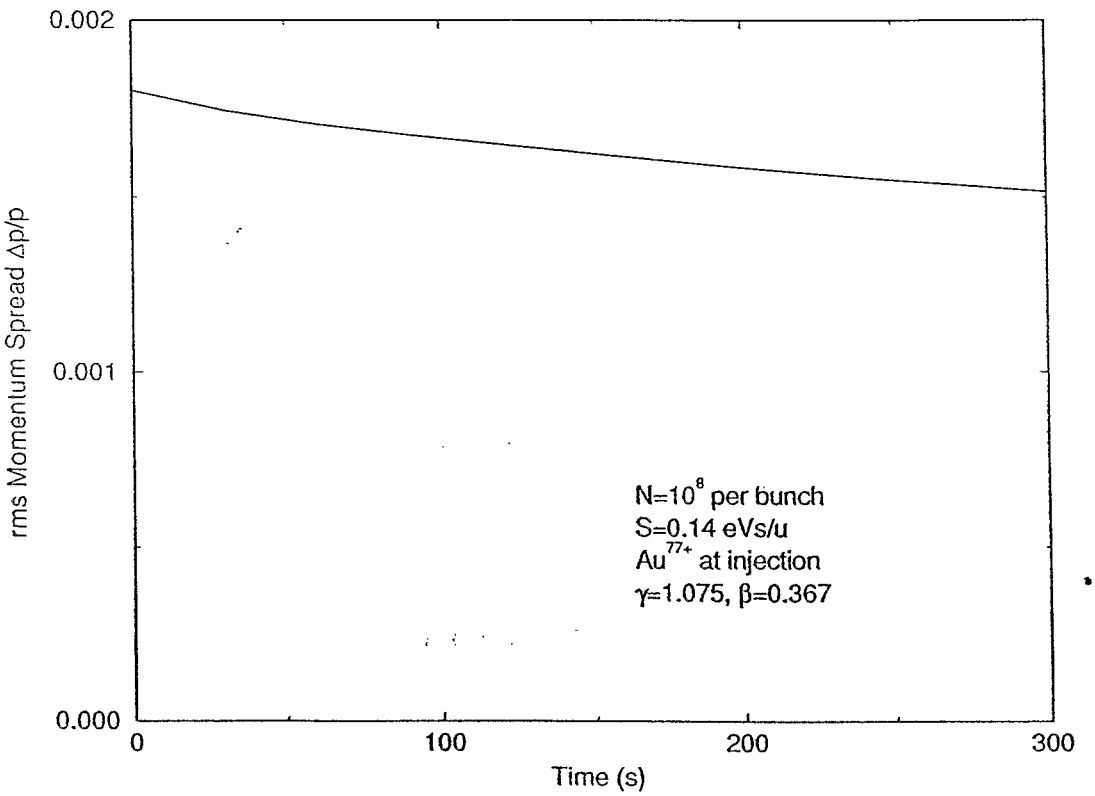
intensity (current transformer)



L. Ahrens
J.M. Brennan
etc.

Growth due to IBS at AGS Injection Flattop

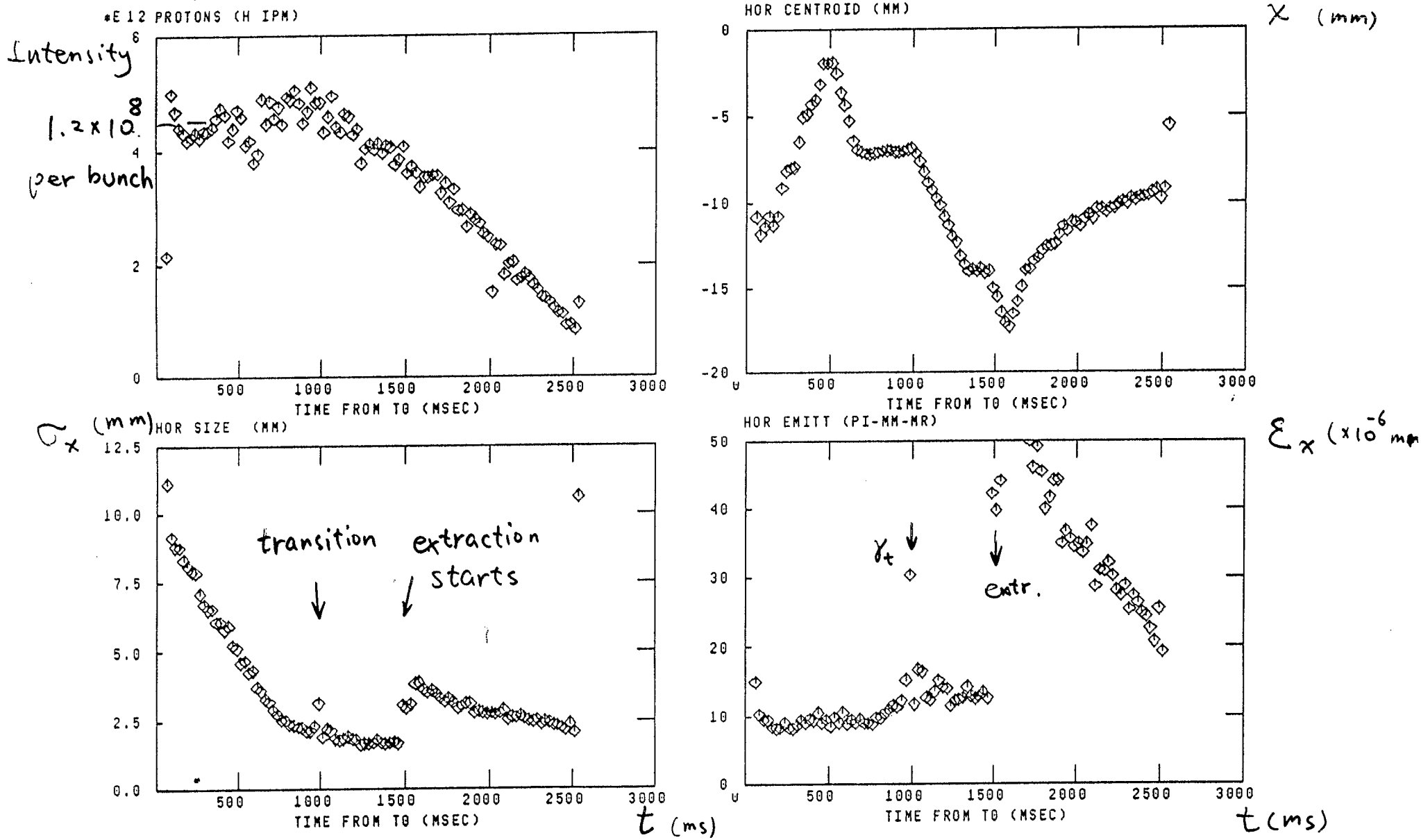




Au^{77+} in AGS

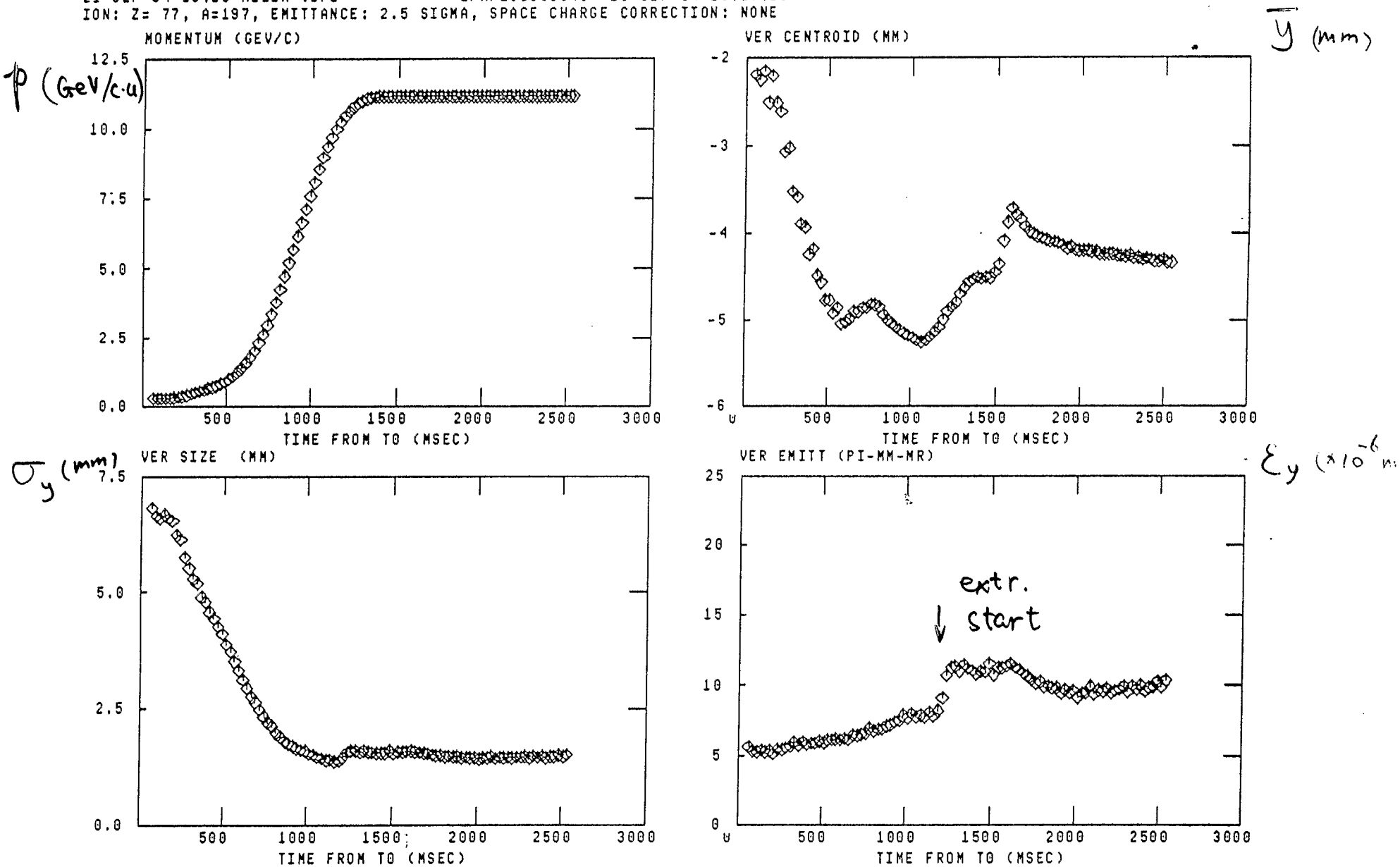
E. Gill

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



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.