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Experimental Study of Transition Crossing at AGS

J. Wei

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Collider Accelerator Department
Brookhaven National Laboratory

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Jie Wei, BNL, May 4, 1996

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* evaluation of α_1 and dispersion using MAD
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talk at 1996 APS/AAPT Joint meeting

Personnel:

July 27, 1994:	Feburary 2, 1995:
L.A. Ahrens	L.A. Ahrens
J.M. Brennan	M.M. Blaskiewicz
W.W. Mackay	J.M. Brennan
S. Peggs	D-P. Deng
T. Satogata	W.K. Van Asselt
D. Trbojevic	J. Wei
W.K. Van Asselt	
A. Warner	...
J. Wei	

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C. Saltmarsh, M. Syphers, S. Tepikian, ...
AGS operation crew

I. Introduction

Transition energy: energy at which particles of different momenta have the same revolution frequency.

(No longitudinal focusing, non-adiabatic synchrotron motion, emittance growth, instabilities, beam loss)

Single-particle effects:

- mismatch in phase switching timing, non-linear bucket
- * chromatic nonlinear effects

Multi-particle effects:

- bunch mismatch due to beam self fields
- combination of self fields and nonlinearity
- microwave instability

Cure:

- avoid transition energy
  (un-conventional machine lattice)
- * γ_T-jump by pulsing quadrupoles
  (distort lattice, enhance α_1, increase dispersion)

History:

- Discovery of the transition energy

  N.M. Blackman and E.D. Courant, Rev. Sci. Instr. **20** 596 (1949)

- Discussion on chromatic nonlinear effect

  K. Jøhnson, Proc. CERN Symp. High-Energy Accel. and Pion Phys. (1956)

- First successful transition crossing on CERN PS and BNL AGS (1960s)

  ... still, beam loss at γ_T on AGS.

- Still needs to cross transition in newly designed machines

  Relativistic Heavy Ion Collider (RHIC)

  (superconducting magnets, slow ramping rate, enhanced chromatic effects)

  Fermilab Main Injector

- More recent theoretical studies:

  K. Takayama, S.Y. Lee, J. Wei, et. al.

- More recent experimental studies:

  P. Faugeras, et. al., second order effects in SPS, 1979

  ...

  J. Wei, M. Brennan, ei. al., experiments done at AGS since 1993

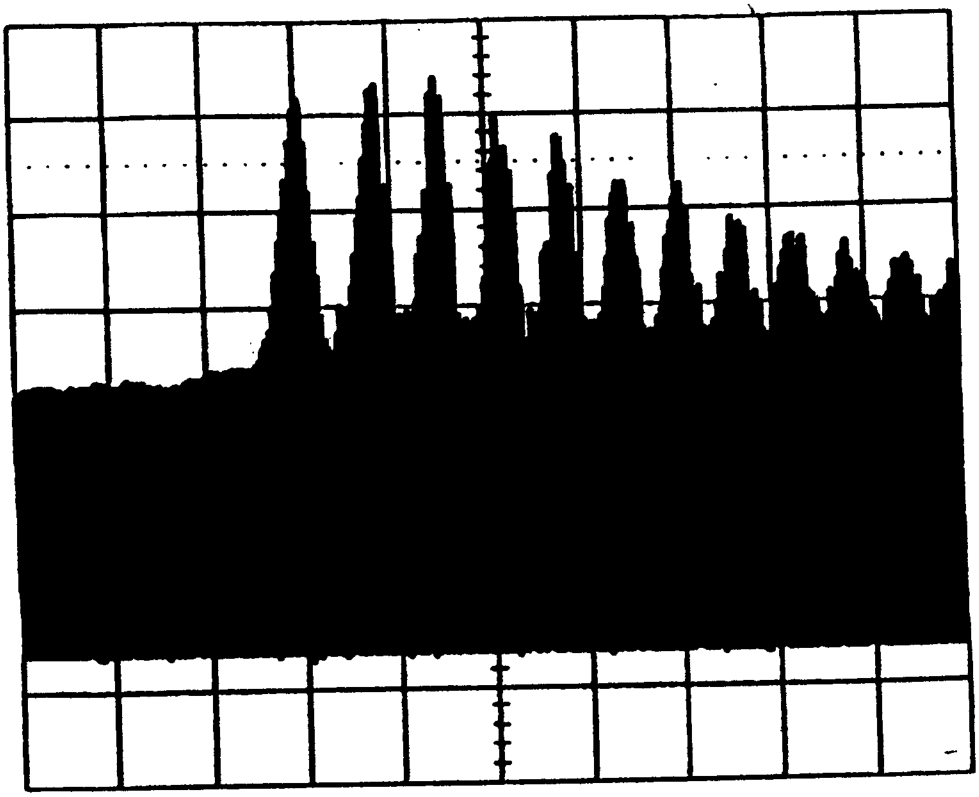


Figure. 1. The envelop of the longitudinal pick-up signal during transition showing more than 100% amplitude modulation. The abscissa is time (5 ms per division).

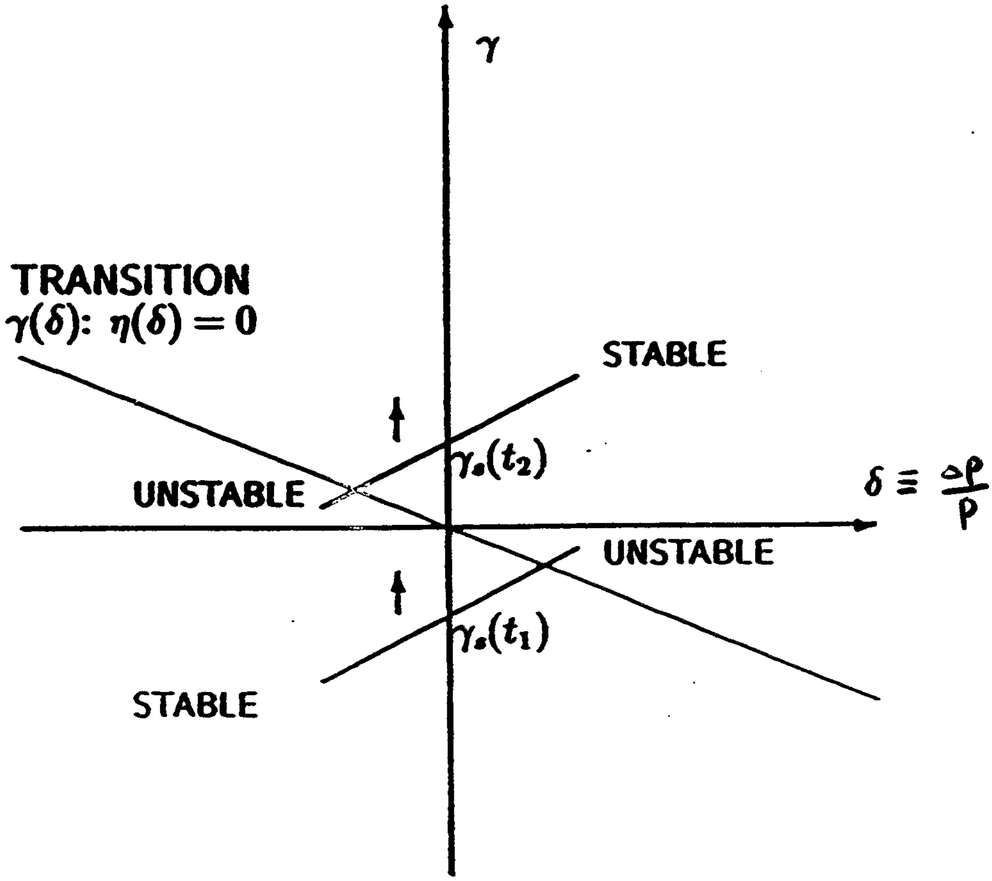
(AGS. low intensity)

For high intensity proton

1.5 Tp loss at 60 Tp intensity

II. Results of Experimental Study

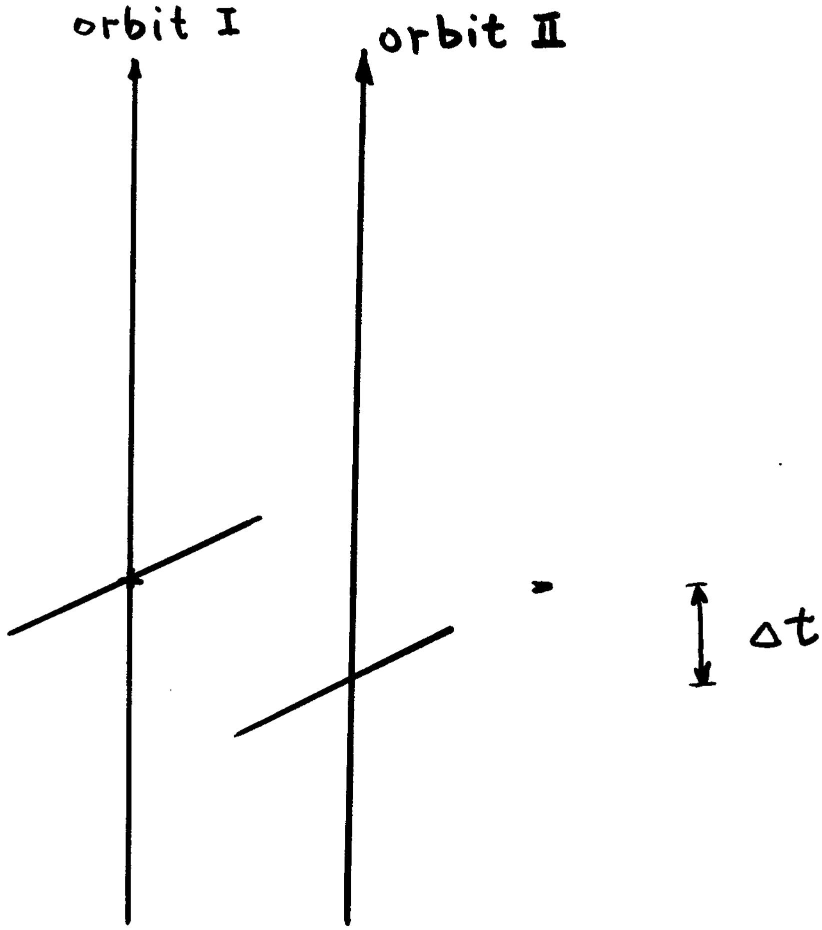
1. Measurement of nonlinear momentum compaction factor α_1



$$\beta^2 \dot{B}\, \Delta t = -\left(\alpha_1 + \frac{1}{2}\beta^2\right) B\, \frac{\Delta p}{p}$$

- using "pencil" beam with small $\Delta p/p$;
- vary $\Delta p/p$ by displacing the radial orbit;
- determine transition timing (Δt) by measuring the minimum beam loss when varying the time of phase switching.

$$\frac{\Delta C}{C} = [1 + \alpha_1 \delta + \alpha_2 \delta^2 + \cdots] \cdot \frac{\delta}{\gamma_{T_0}^2}$$


orbit I
orbit II
Δt

Beam loss vs. syn. phase switching time

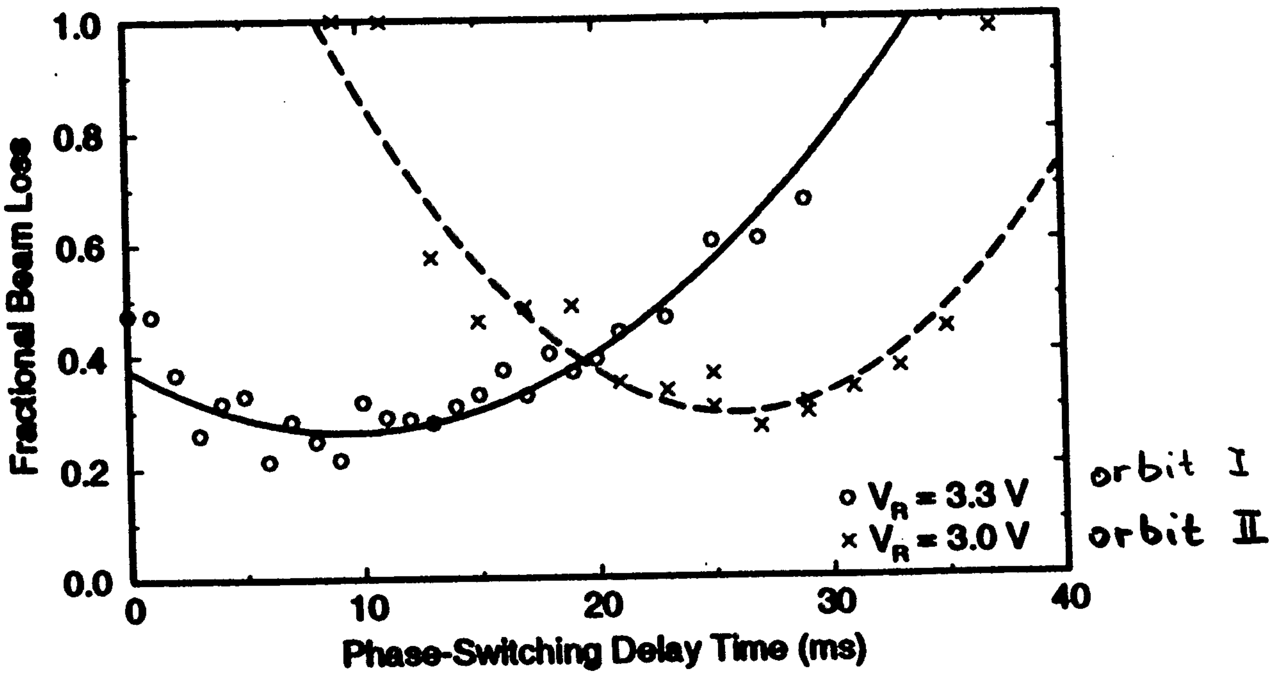


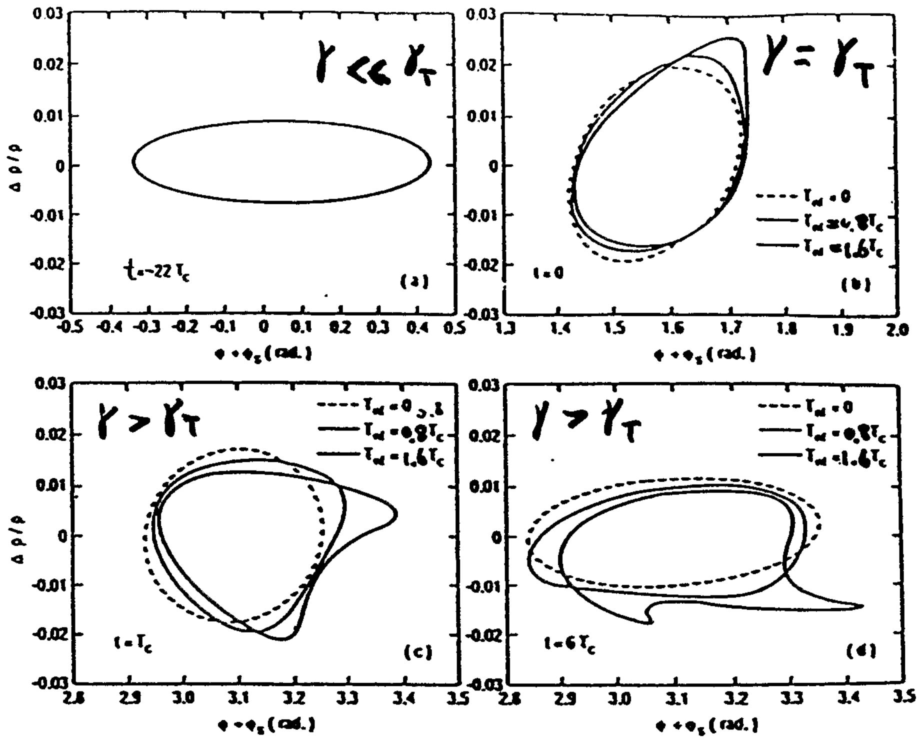
Table 1: Measured AGS γ_t, α_1, and momentum aperture at various γ_t-jump quadrupole (I_Q) and sextupole (I_S) settings.

(I_Q, I_S) (A)	(0, 0)	(1700, 0)	(1700, 100)
γ_{t0}	8.45	10.12	10.12
α_1	2.5	90	16
$\Delta p/p\|_{ap}$ ($\times 10^{-3}$)	±7.9	±4.7	±4.3

momentum aperture

nominal γ_T jump sext. on

2. Effects of chromatic nonlinearity (α_1)



non-adiabatic time:

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

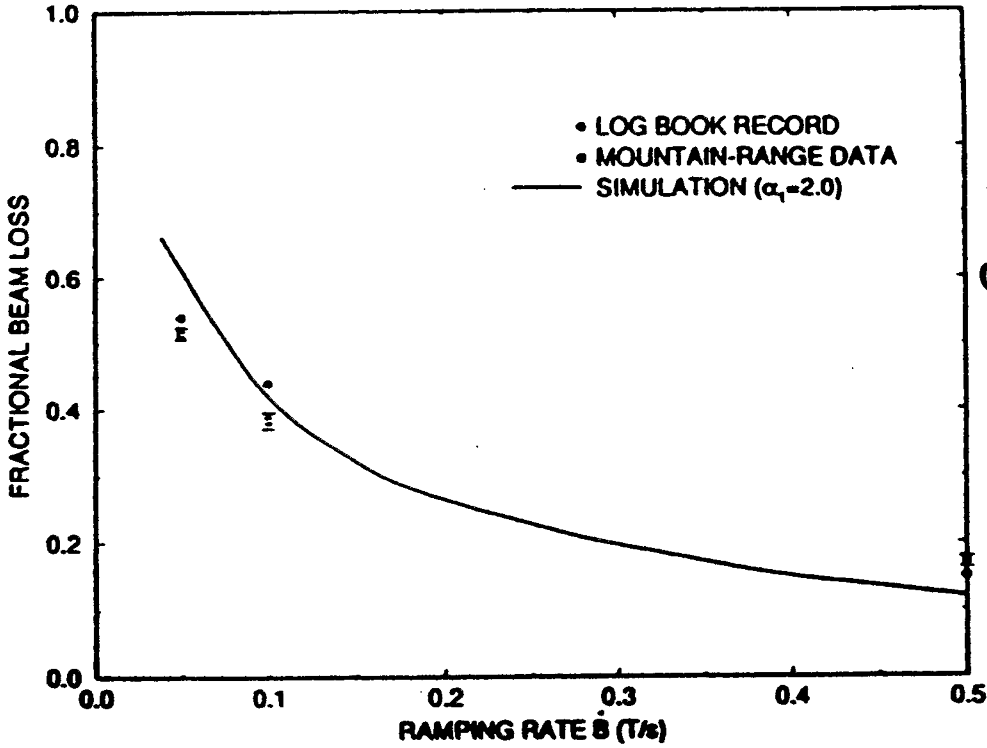
nonlinear time:

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

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

(Growth in longitudianl beam emittance)

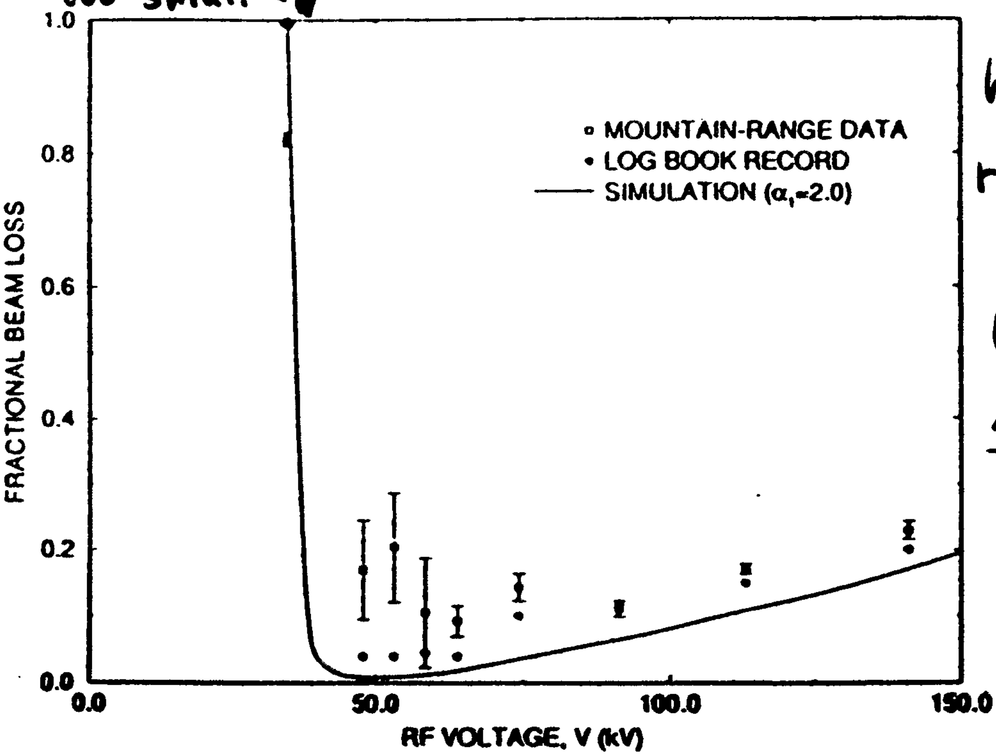
* Beam loss vs. crossing rate $\dot{B}$



faster crossing ra[te] ⇓ smaller loss

* Beam loss vs. peak rf voltage

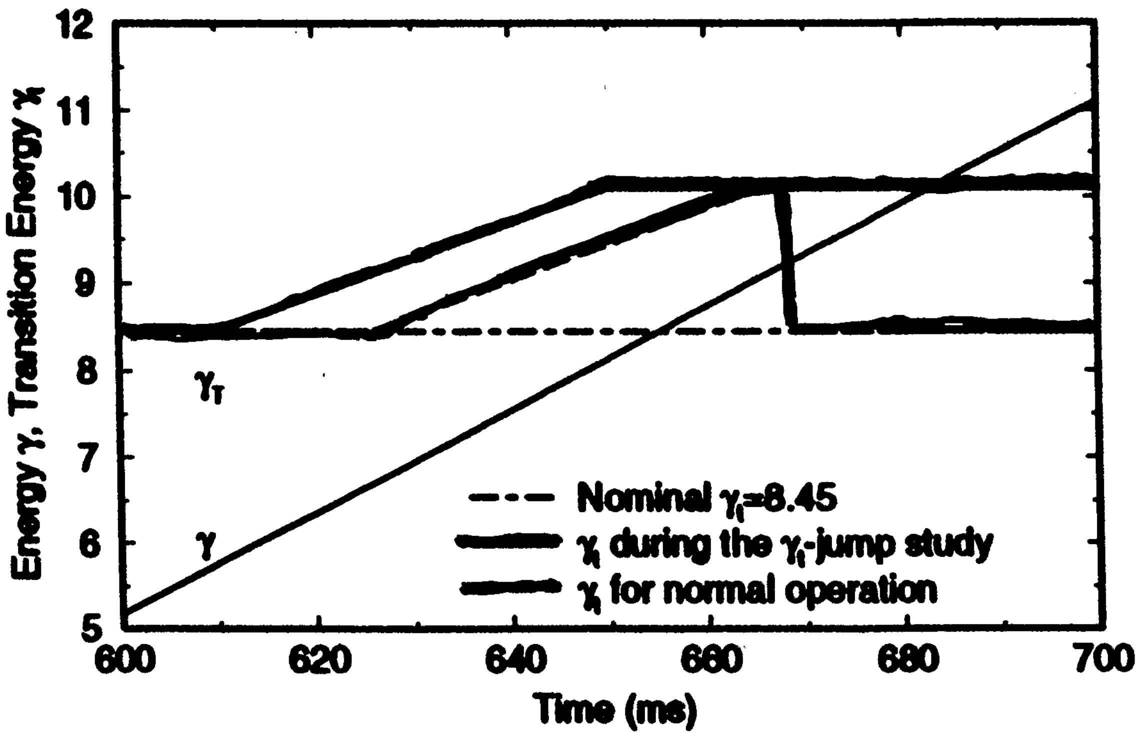
rf bucket too small ←



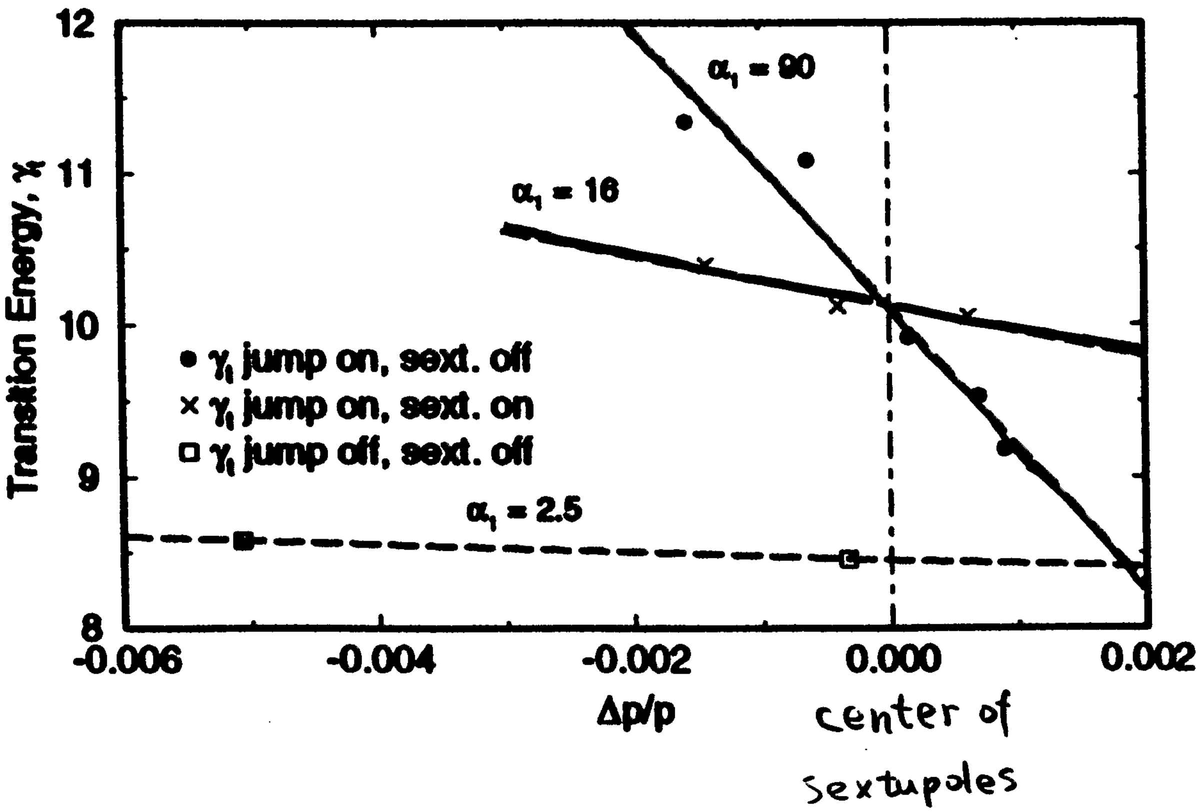
higher rf voltage ⇓ larger $\frac{\Delta p}{p}$ spread ⇓ larger los[s] due to α_1

3. γ_T-jump and nonlinearity enhancement

- γ_T-jump improves crossing efficiency by increasing the effective crossing rate
- γ_T-jump usually distorts lattice, enhancing α_1 and dispersion



4. reduction of nonlinearity using sextupoles



nominal operation : $\alpha_1 = 2.5$,

aperture $\frac{\Delta p}{p} = \pm 0.8\%$

γ_T jump lattice : $\alpha_1 = 90$

aperture $\frac{\Delta p}{p} = \pm 0.5\%$

sextupoles on : $\alpha_1 = 16$

aperture $\frac{\Delta p}{p} = \pm 0.4\%$

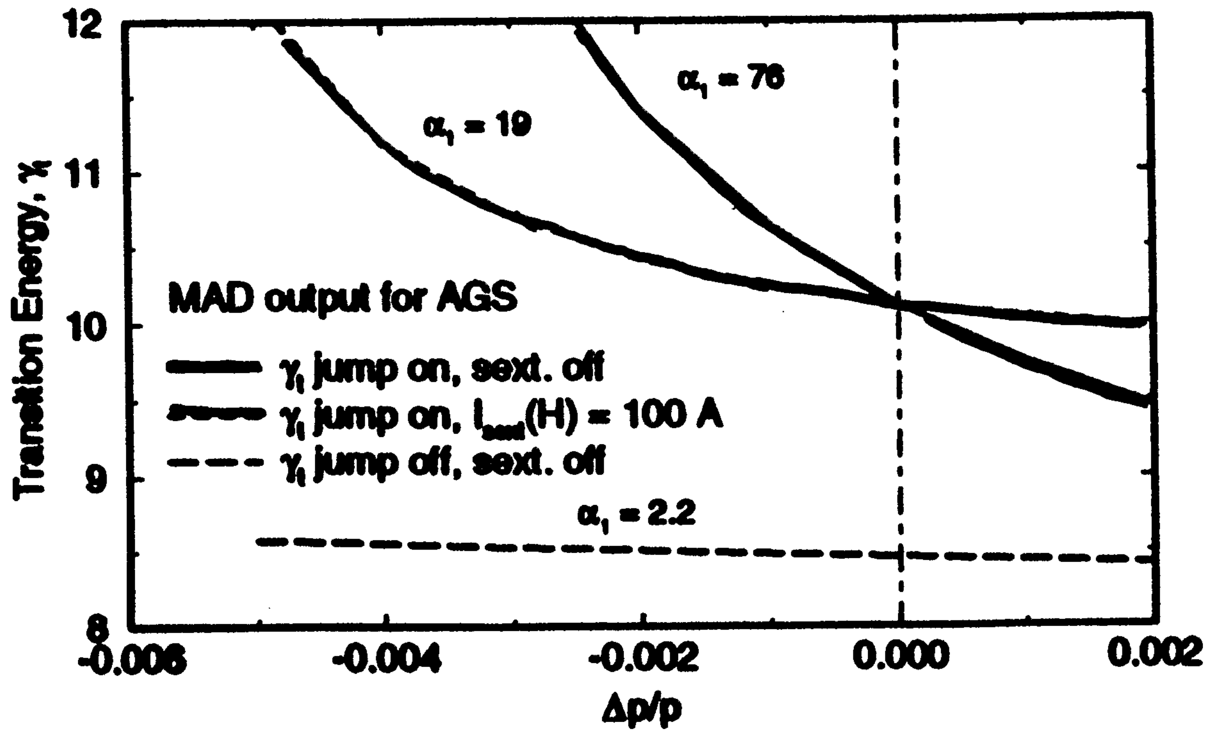
III. Comparison with MAD and TIBETAN Simulations

1. α_1 and dispersion evaluation using MAD

Table 2: MAD calculation of AGS γ_{t0}, α_1, α_2 and maximum dispersion $\eta_x|_{max}$ at the γ_t-jump quadrupole and sextupole settings corresponding to Table 1.

nominal γ_T-jump sext. on

(I_Q, I_S) (A)	(0, 0)	(1700, 0)	(1700, 100)
γ_{t0}	8.45	10.12	10.12
α_1	2.2	76	19
α_2	8.9	-2.7×10^3	-1.6×10^3
$\eta_x\|_{max}$ (m)	2.2	8.6	8.6



2. Longitudinal simulation using TIBETAN

- Using experimentally extracted α_1 and machine parameters, simulate transition crossing using TIBETAN under the same experimental condition
- Compare simulated mountain-range plots with experimental digitized beam profile data, using the same post-analysis codes (GT_ANALY)

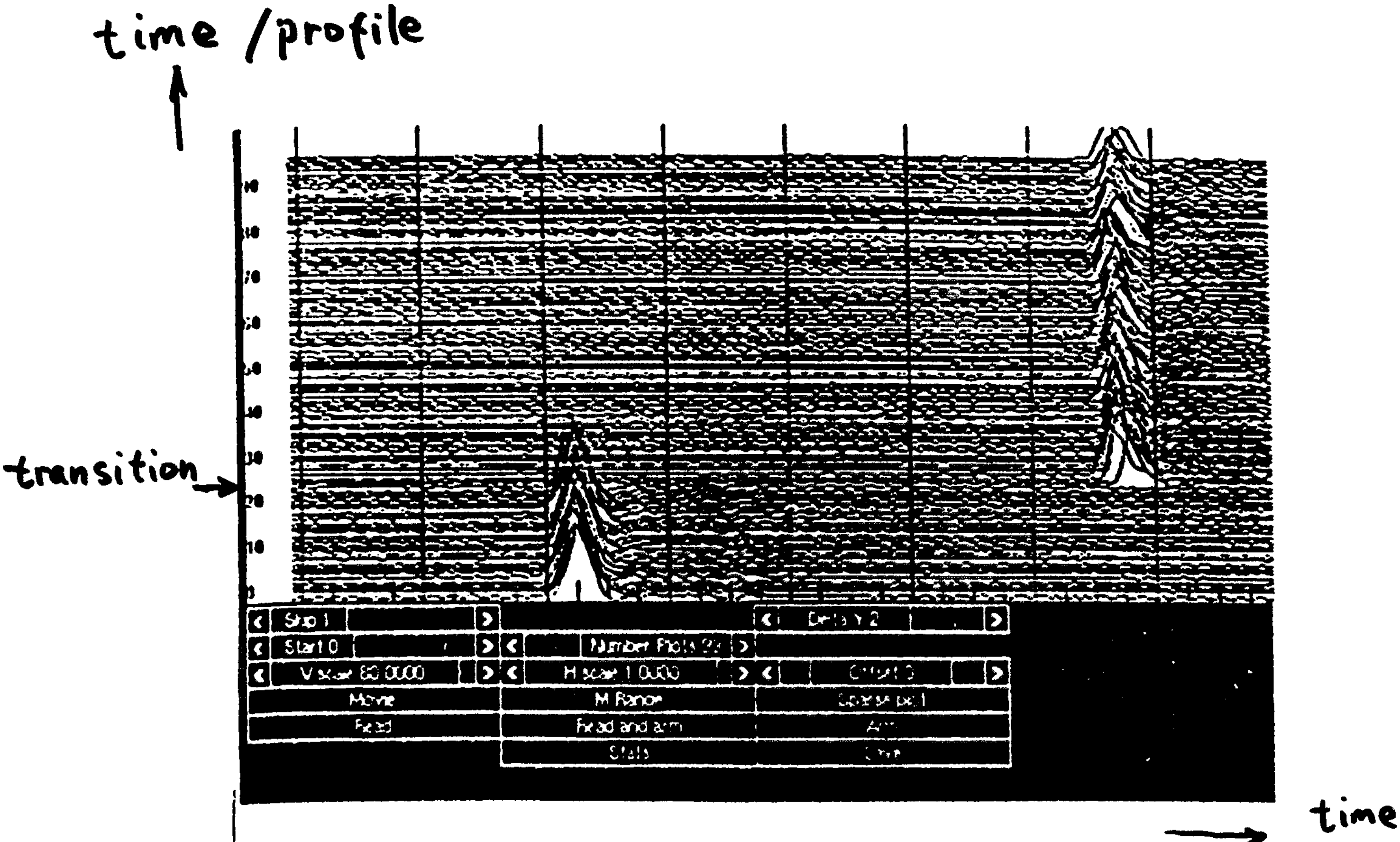


Figure : Typical digitized beam-profile data.

IV. Conclusions

- Although γ_T-jump in AGS improves transition crossing efficiency for high intensity beams, it enhances chromatic nonlinear effects (α_1).

- The sextupoles can be excited to greatly reduce α_1, hence improving longitudinal crossing at transition. However, the current scheme results in large dispersion.

- An optimization in γ_T-jump scheme and sextupole arrangement can greatly improve AGS operation at transition.

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