# High Intensity Beam Operation of the Brookhaven AGS

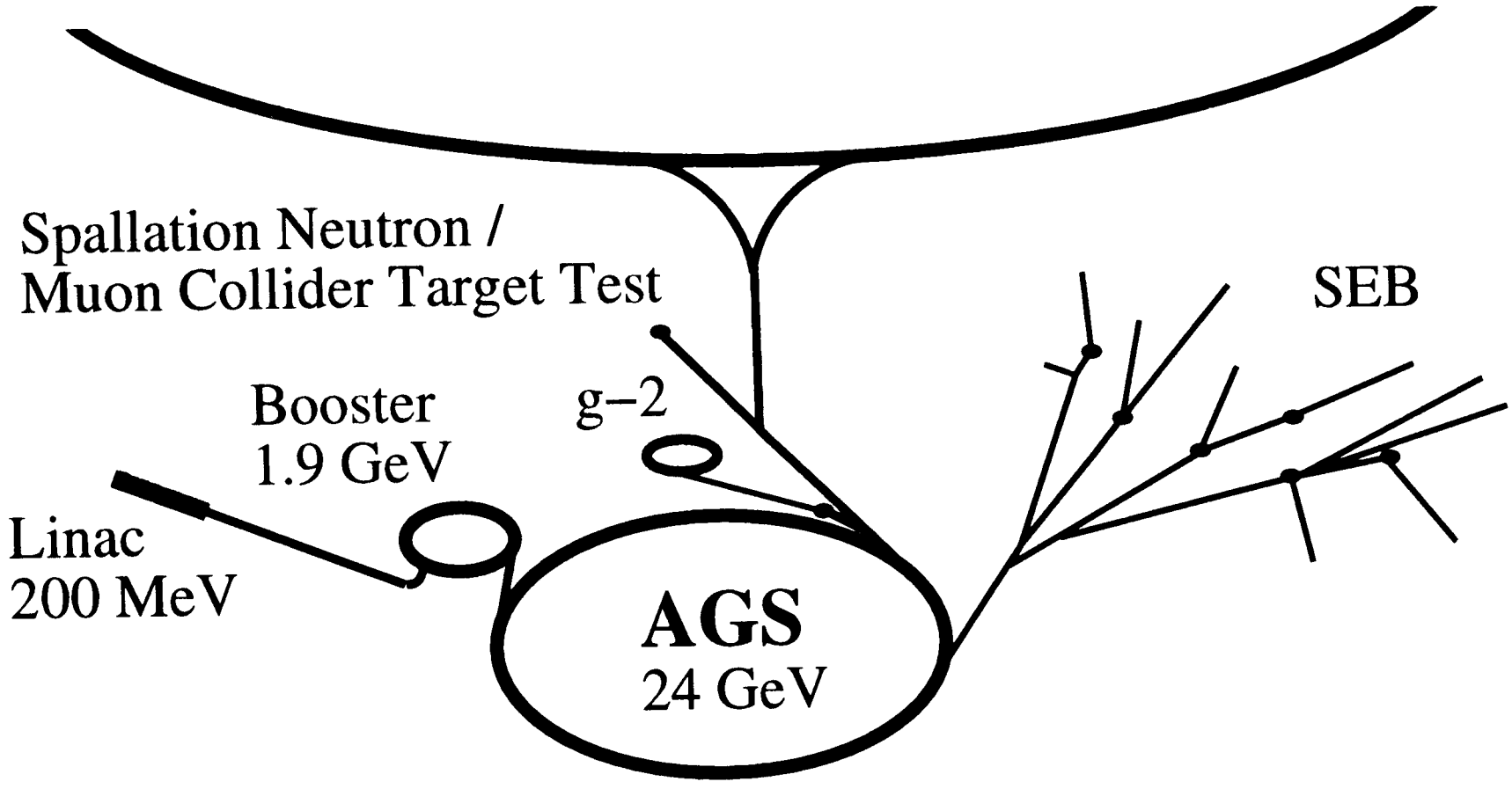
Recent High Intensity Performance and Intensity Limitations of the AGS, AGS Booster, and Linac

Planned and Possible AGS Intensity Upgrades

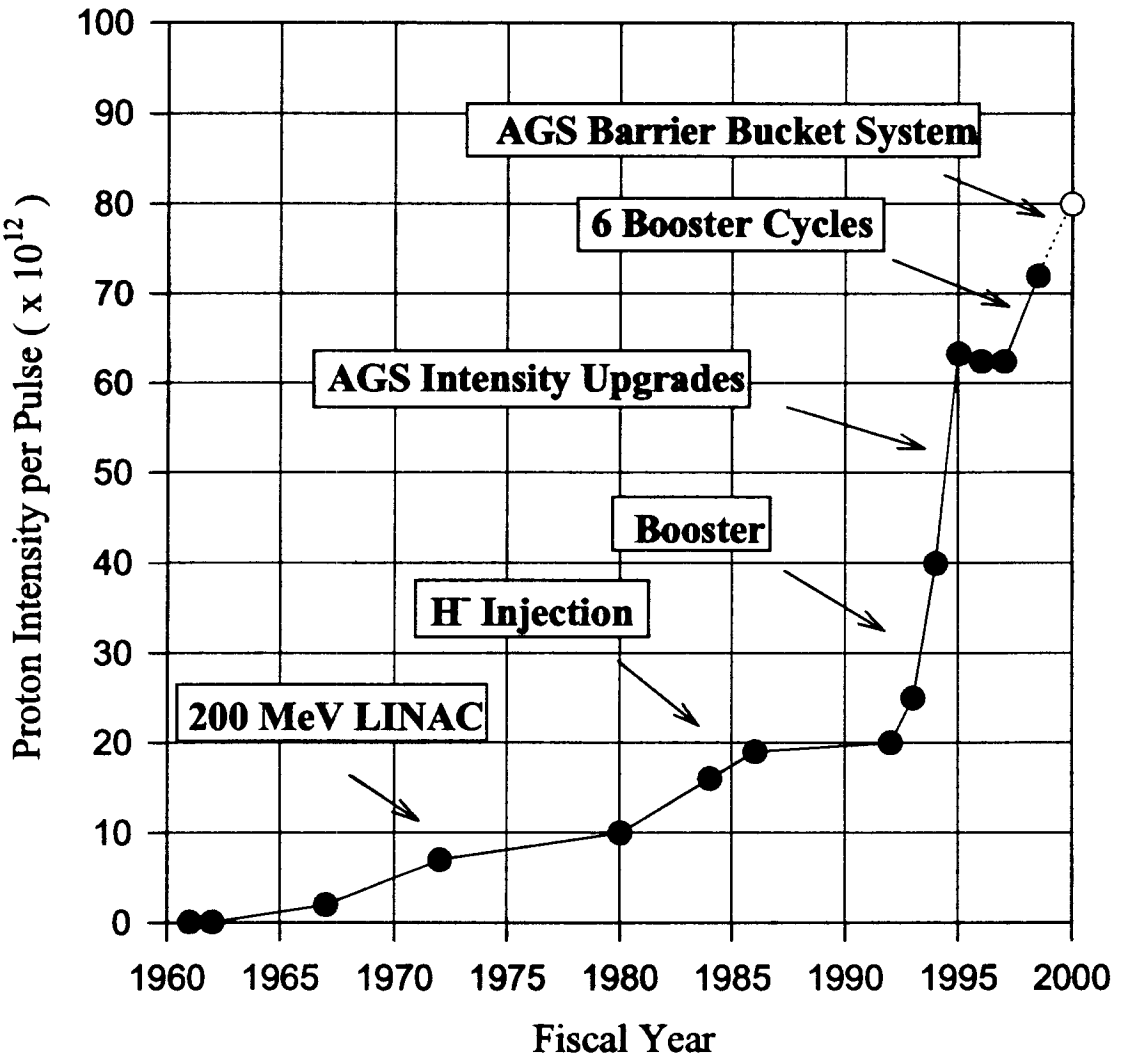
BROOKHAVEN
NATIONAL LABORATORY

Thomas Roser

# AGS–RHIC Complex



# AGS Proton Intensity History



# 200 MeV Linac Performance

- $120 \times 10^{12}$ $H^-$ per pulse at 7.5 Hz
- $H^-$ Source 35 keV 80 mA
  RFQ 750 keV 60 mA
  LEBT 750 keV 45 mA
  Tank 1 10 MeV 38 mA
  Tank 9 200 MeV 37 mA
- $\varepsilon_{norm,\ rms} = 2\ \pi$ mm mrad
- $\Delta E \approx \pm\ 1.2$ MeV
- RF Chopper at 750 keV

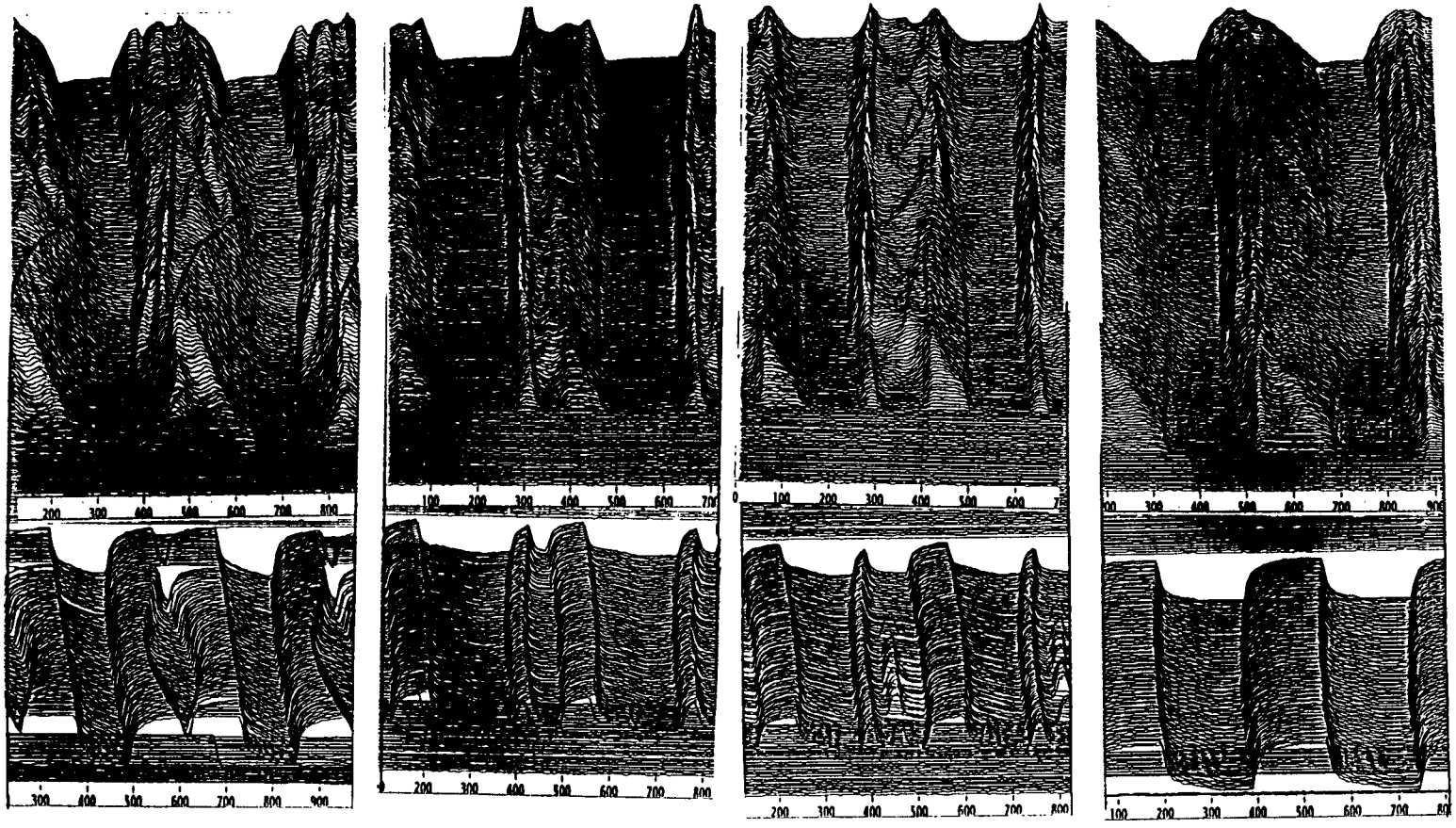
# Booster Performance

- $15 \times 10^{12}$ protons per pulse (record: $22 \times 10^{12}$ ppp)
- Injection: horizontal painting, vertical missteering,
  approx. 200 turns, chopped to 270 degrees,
  B dot = 3 T/s
- RF : 45 kV (h=1), 22 kV (h=2)
- B dot max = 9 T/s
- Bunch area: approx. 1.5 eVs
- Eddy current correction coils driven by back-leg windings

# Using the Fast Chopper for Painting Longitudinal Phase Space Distribution

**Mountain Range Of 1st ms of Bunch**

**Chopper Program Used for Painting**



# AGS "Comfort" Display

Main Dipole Field

Slow Extraction Spill

RF Voltage

Circulating Beam Intensity

Total Ring Losses

Peak Current

VHF Voltage

# Typical Efficiencies

| | 1996 | | 1997 | | 1998/99 | |
|---|---|---|---|---|---|---|
| | TP | % | TP | % | TP | % |
| Booster Input | 161 | | 145 | | 139 | |
| Booster Early | 107 | 66 | 84 | 58 | 103 | 74 |
| Booster Late | 90 | 84 | 80 | 95 | 86 | 83 |
| AGS Early | 67 | 74 | 66 | 83 | 70 | 81 |
| AGS Late | 61 | 91 | 59 | 89 | 65 | 93 |

# Major Loss in AGS Occurs in First 1ms

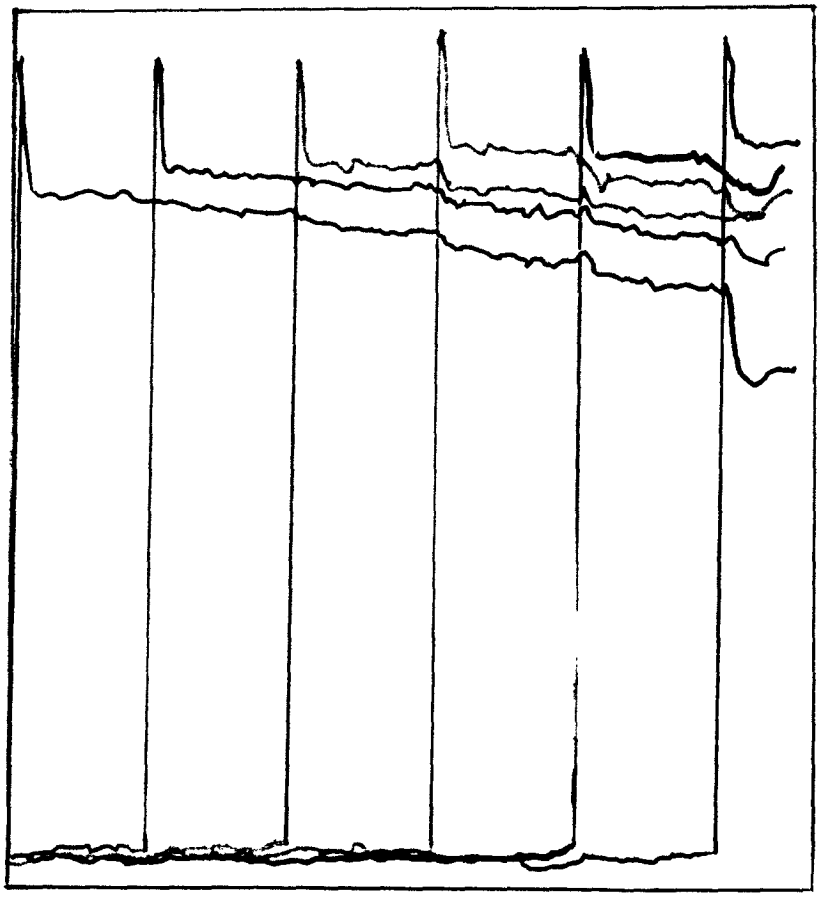
**Beam Current**

**And**

**Longitudinal Pick_up**

**Bunch_by bunch Intensity,**

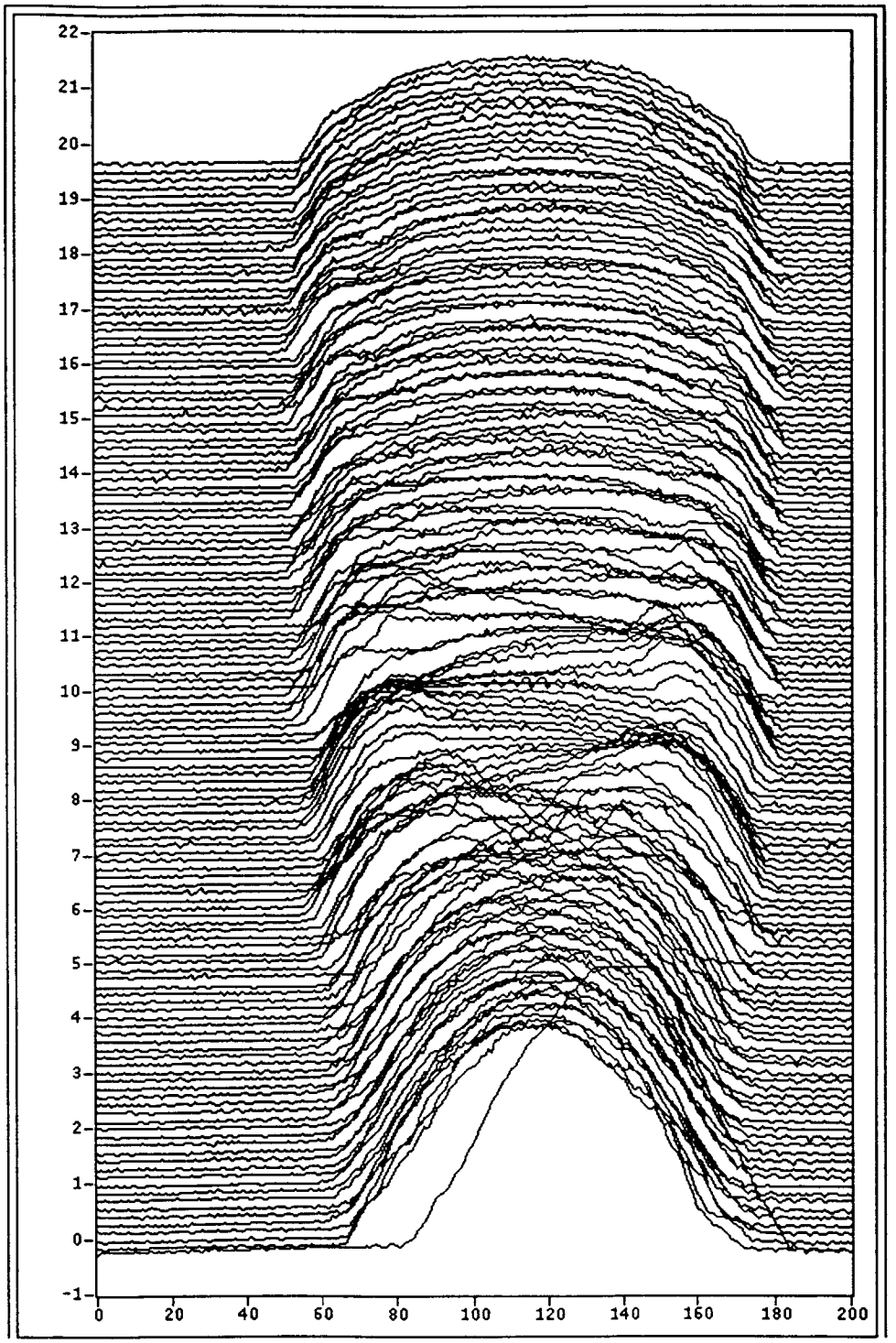
**Peaks sum to $9 \times 10^{13}$**



BUNCH STRETCHING USING A VHF CAVITY

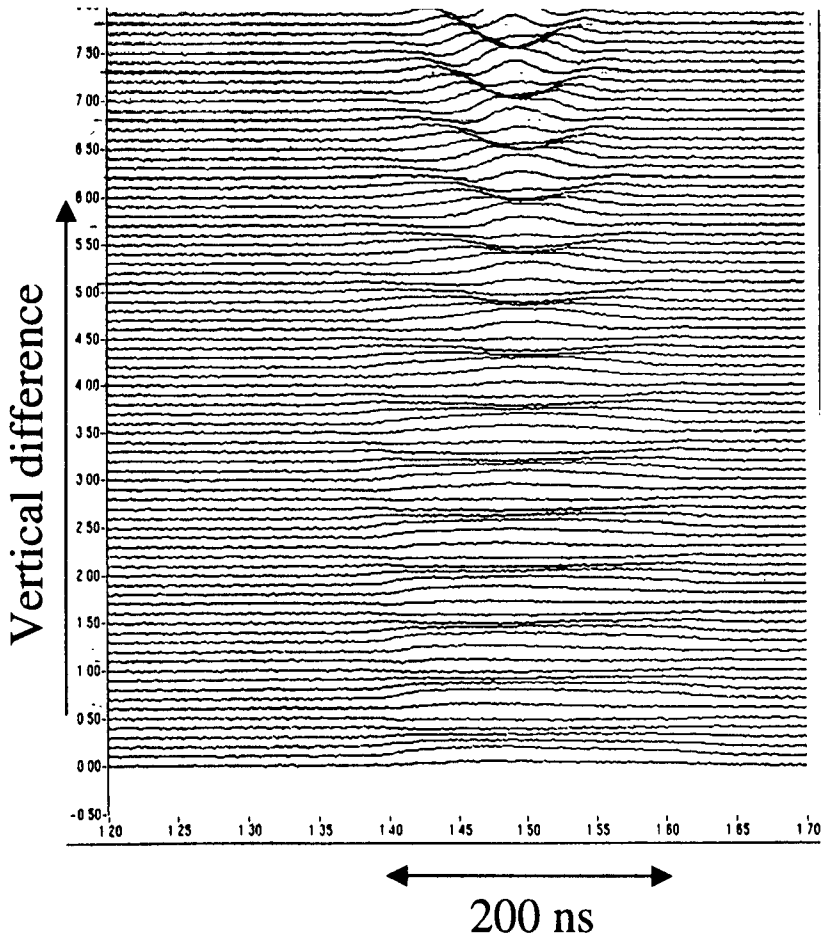
→ REDUCED SPACE CHARGE

Front Panel

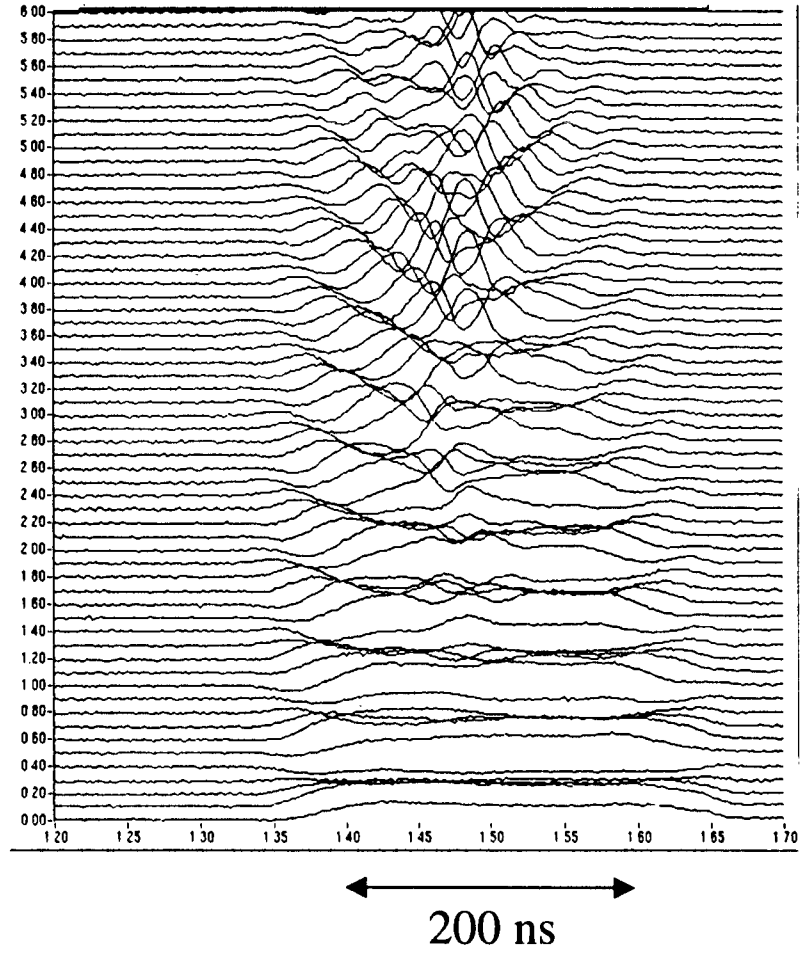


# Vertical Coherence at AGS Injection

Low Intensity




High Intensity



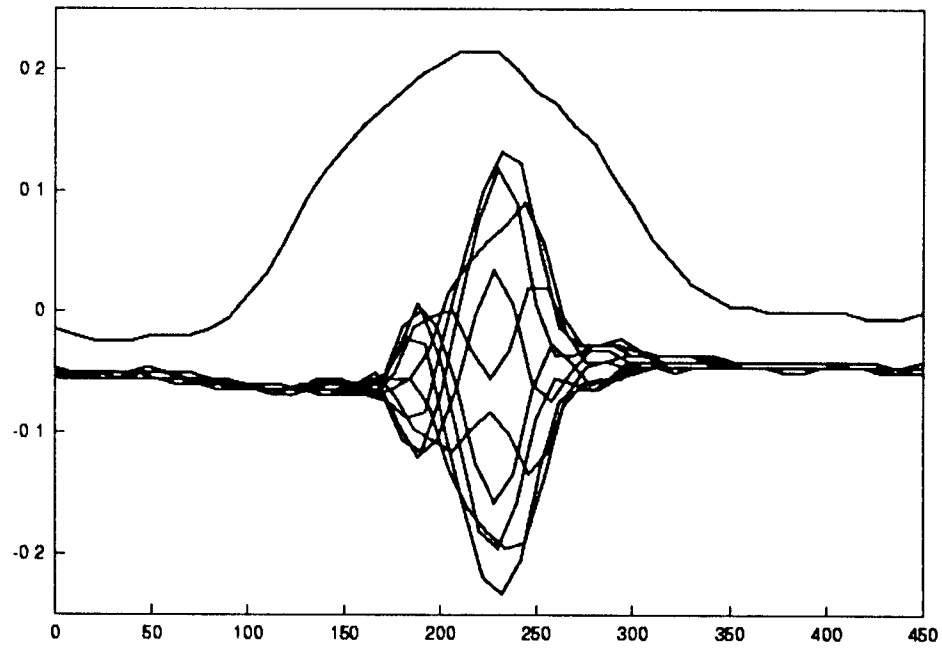
# Fast AGS Instability

Observed at AGS injection energy of 1.9 GeV

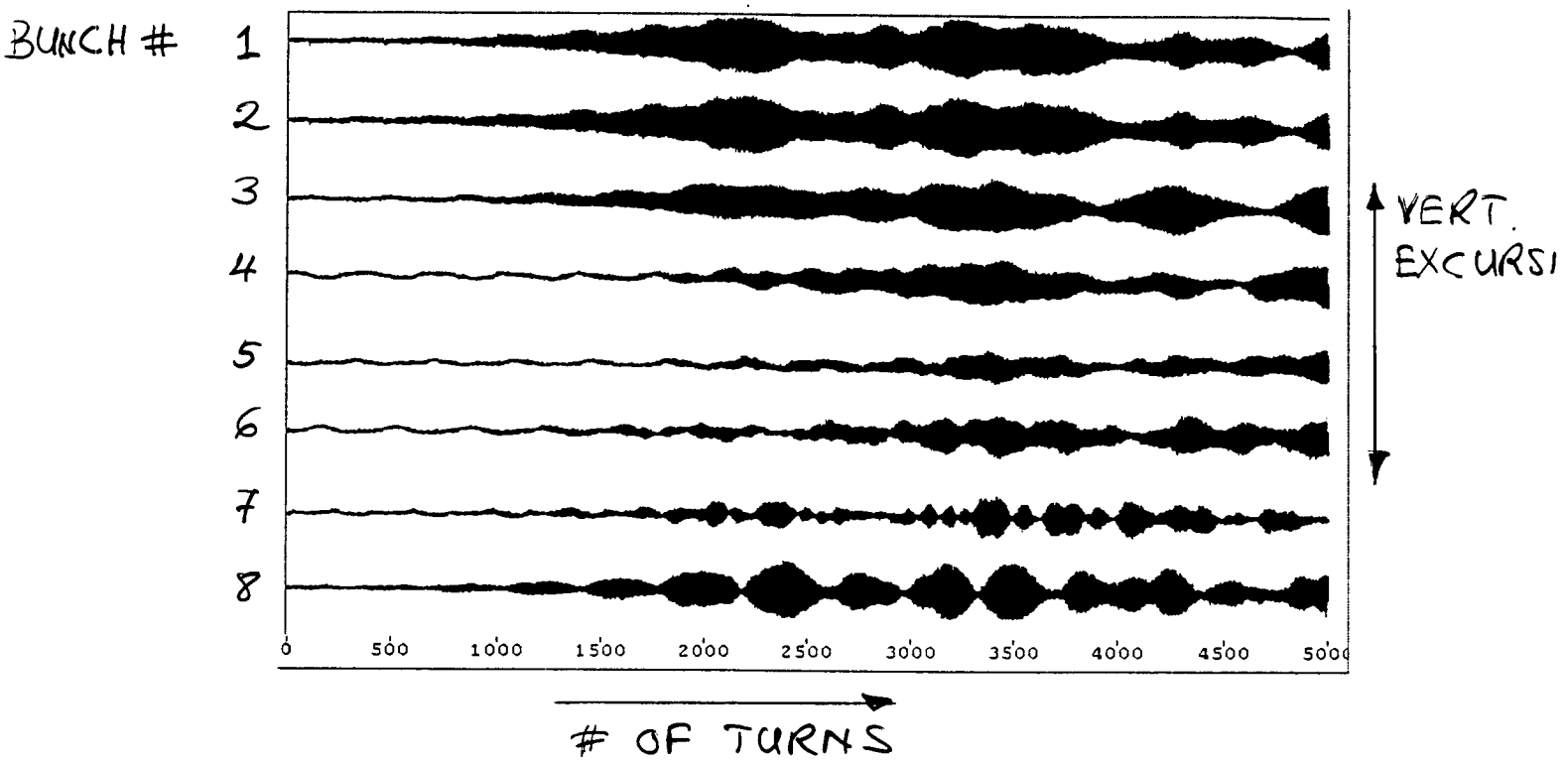
Single bunch with 12 TP

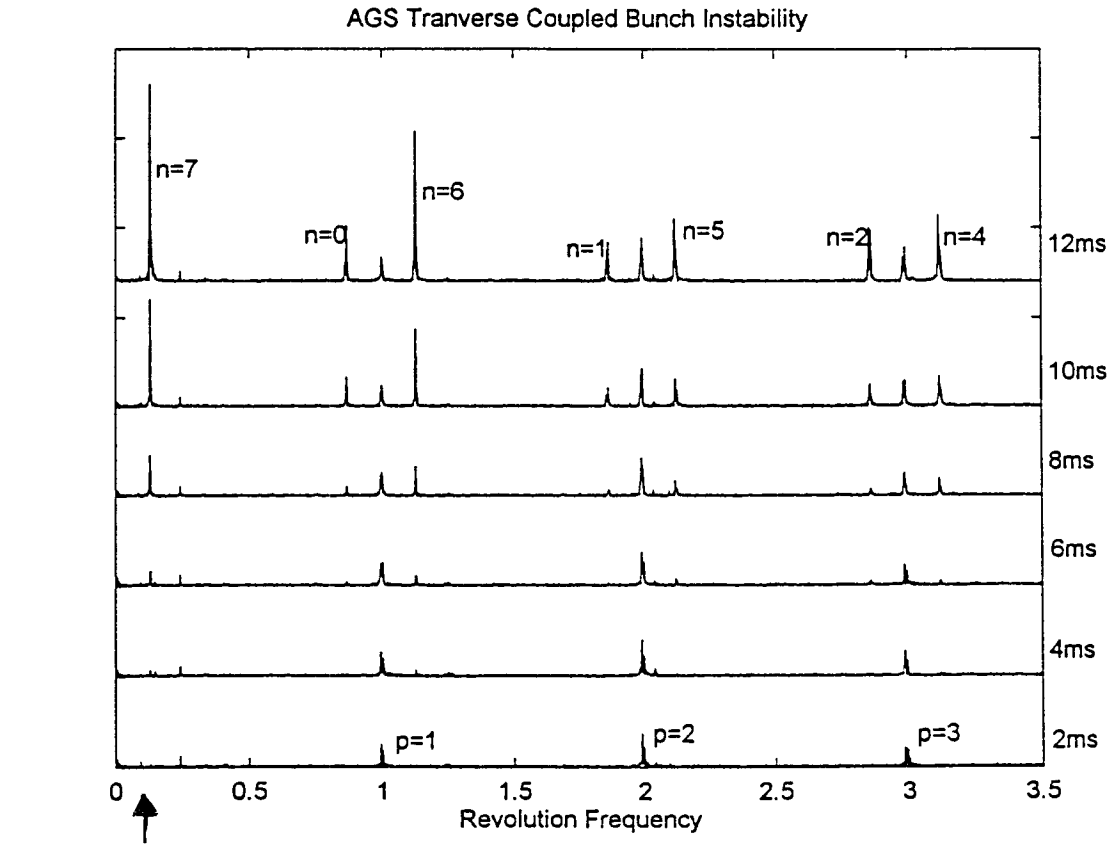
Beam loss until stable

Approx. 0.2 s growth rate



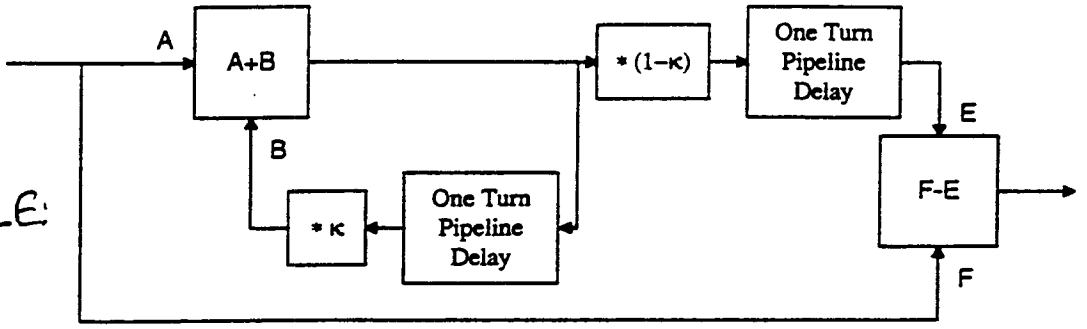
# TRANSVERSE COUPLED BUNCH INSTABILITY



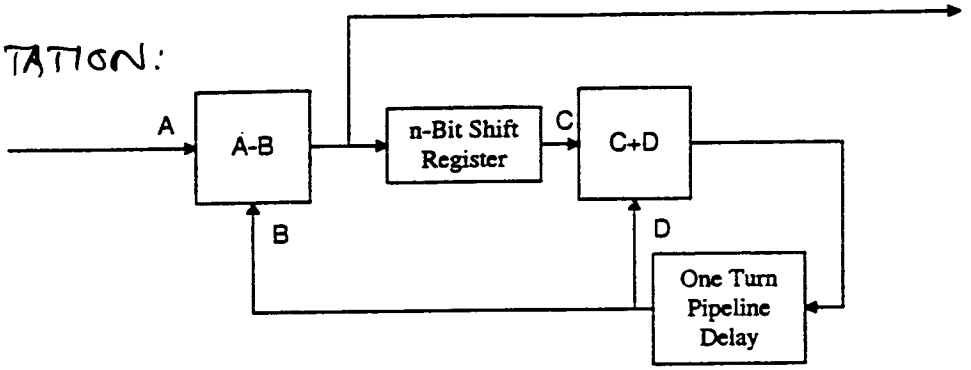
# DIGITAL RECURSIVE NOTCH FILTER

PRINCIPLE:

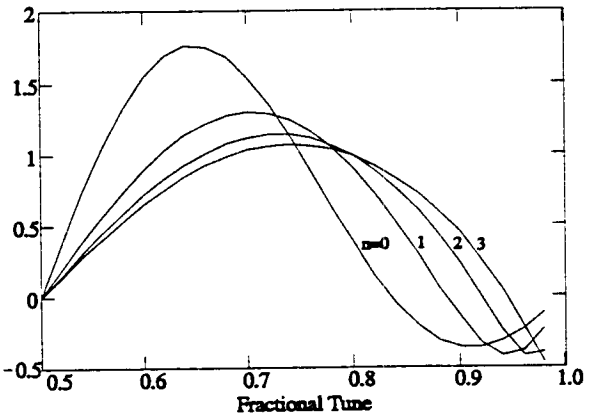


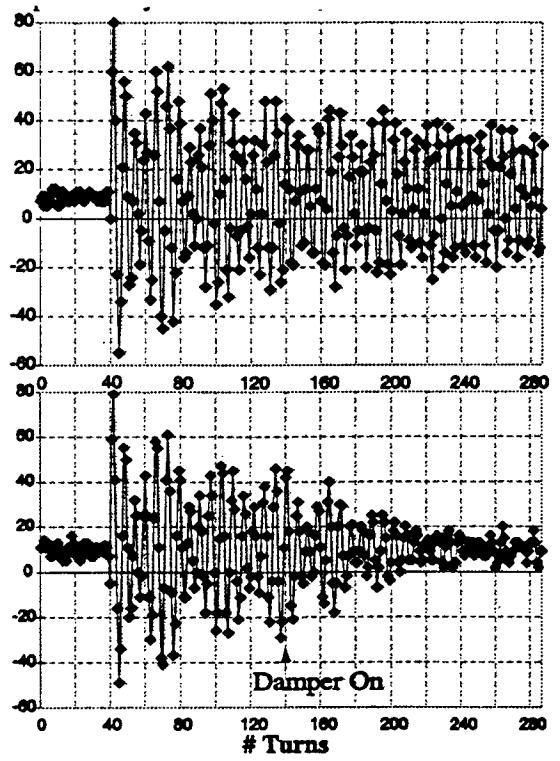

$$\kappa = \frac{2^n - 1}{2^n}$$

IMPLEMENTATION:




DAMPING EFFICIENCY VS. BETATRON TUNE



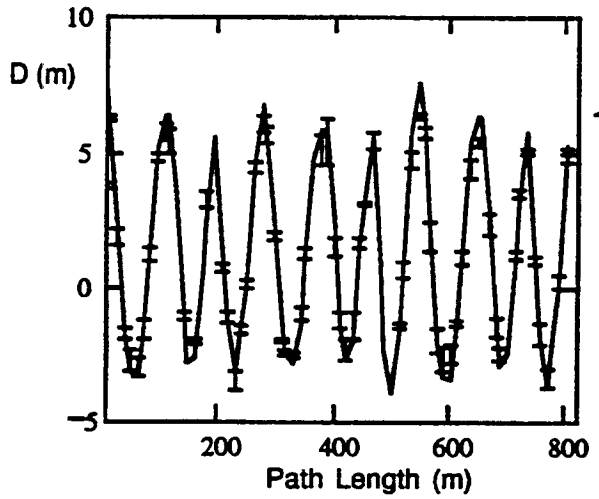




W/O DAMPE.

WITH DAMPE.

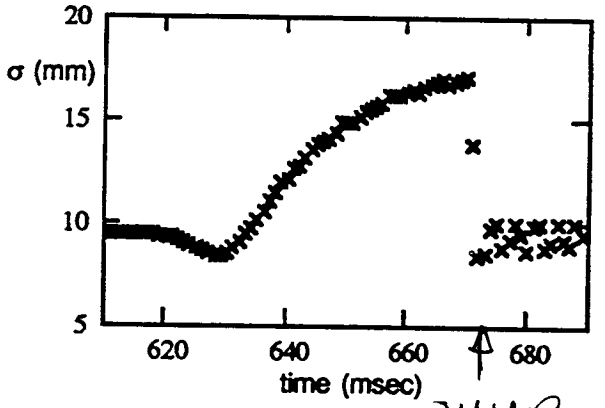
$\tau \approx 100$ TURNS

# AGS TRANSITION JUMP



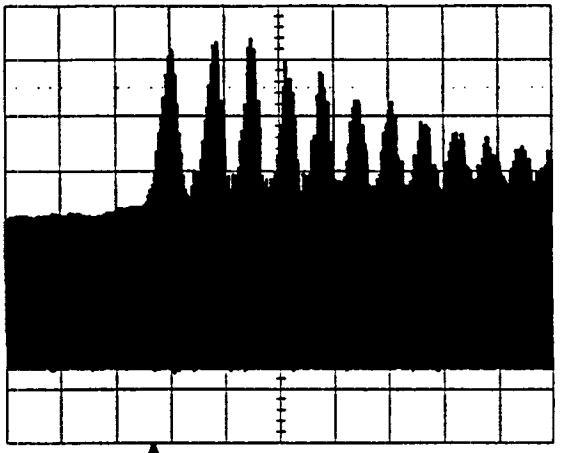

← DISPERSION DISTORTION

BEAM SIZE VS. TIME



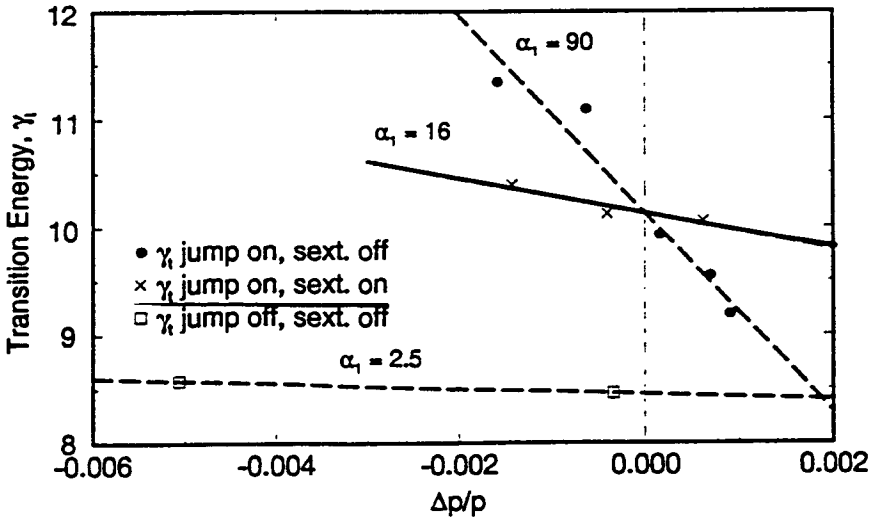

JUMP

QUADRUPOLE OSC.
FROM CHROMATIC MISMATCH



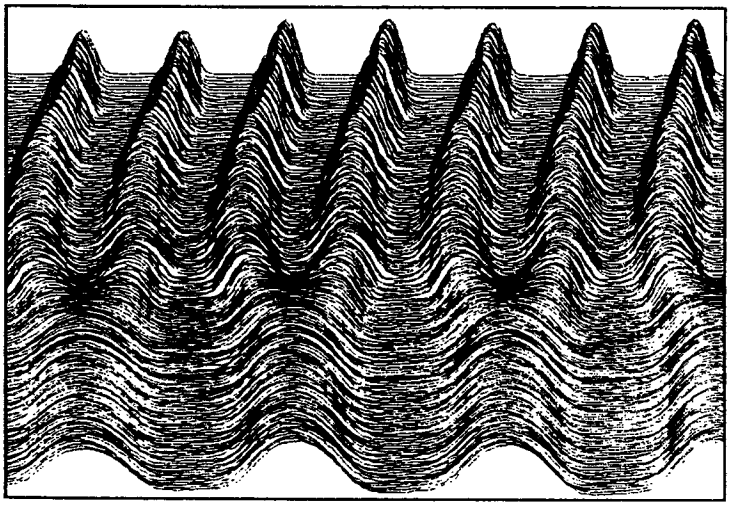
JUMP

MOMENTUM DEPENDENCE OF $\gamma_T$

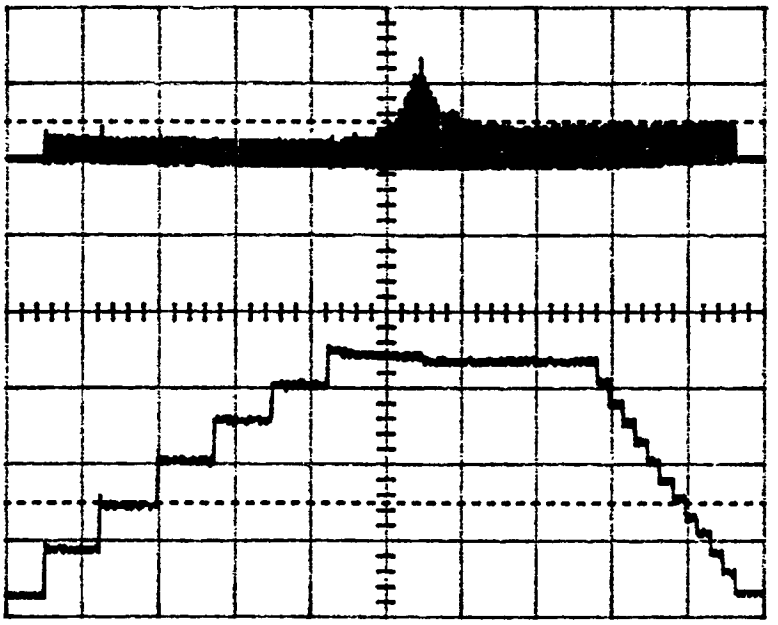


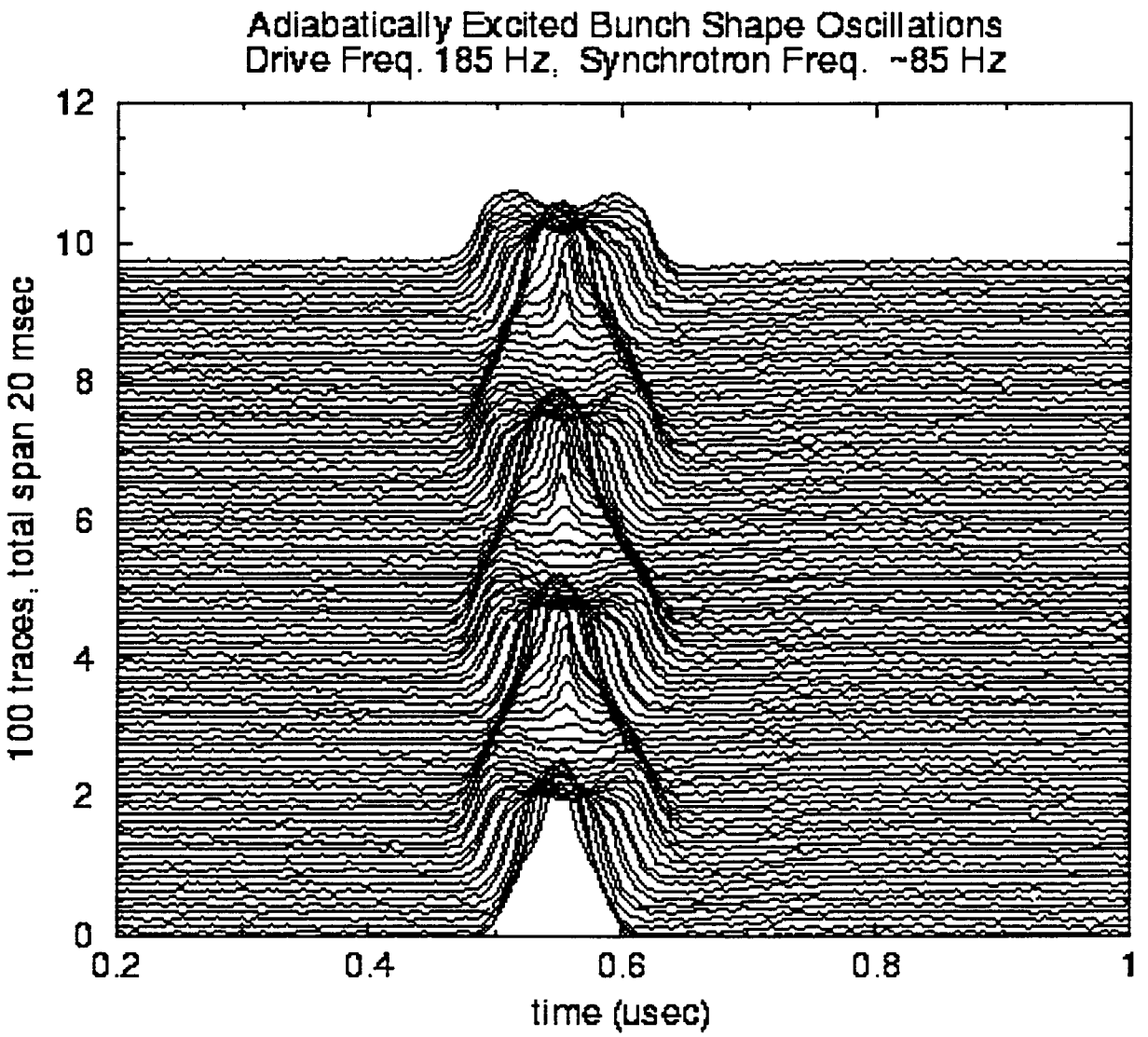
# g-2 Experiment Limited by Production Target Limit of 7 x$10^{12}$ protons/bunch

Six Bunches were Split into 12 by Adiabatic Ramping of h=6 and h=12 RF Voltage

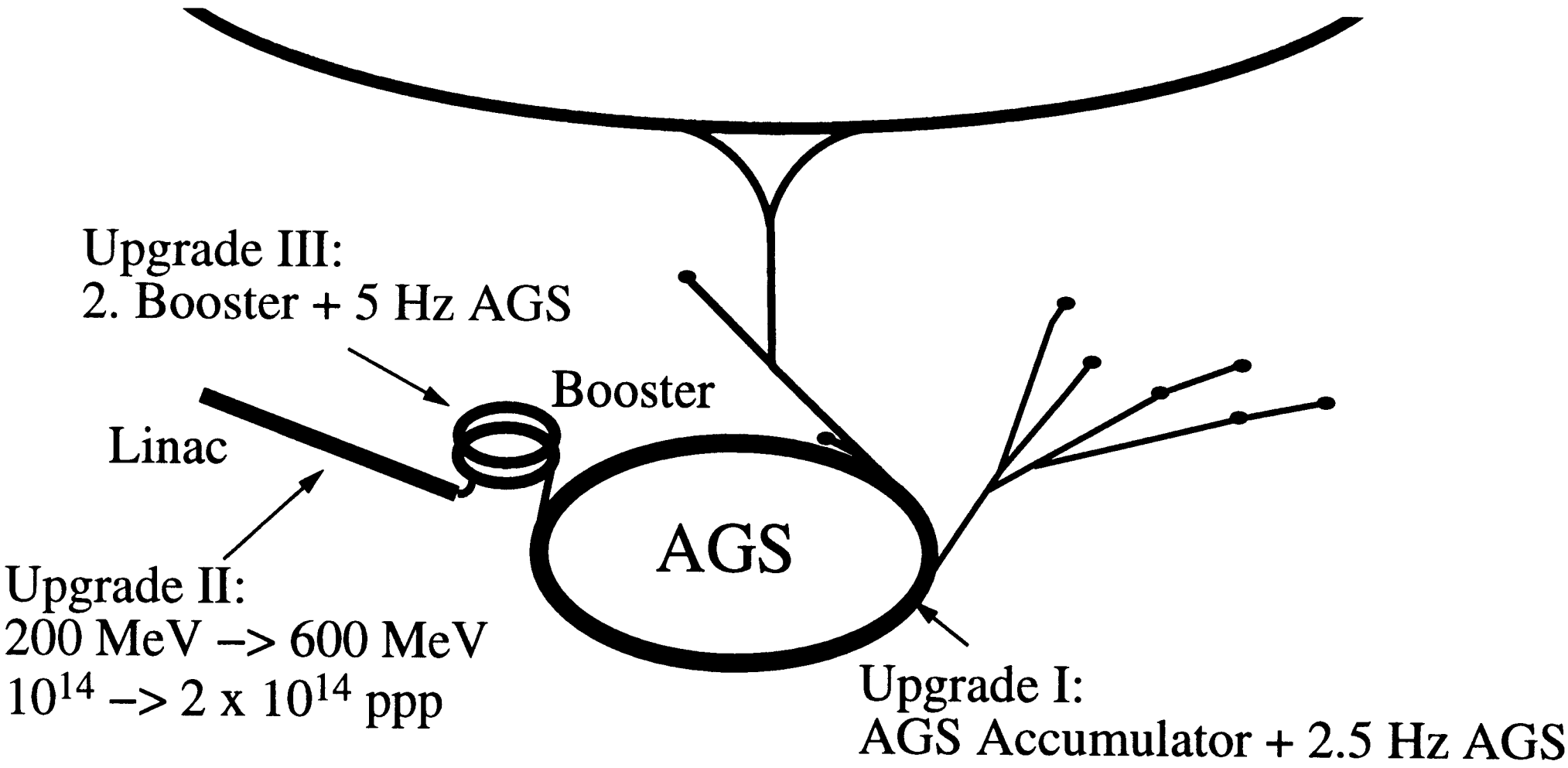


Splitting of 9 x $10^{12}$ bunches




Adiabatically Excited Bunch Shape Oscillations
Drive Freq. 185 Hz, Synchrotron Freq. ~85 Hz
100 traces, total span 20 msec
0
2
4
6
8
10
12
0.2
0.4
0.6
0.8
1
time (usec)

# AGS Upgrades



# Parameters for possible AGS upgrades

| | Present | Upgrade I | Upgrade II | Upgrade III |
|---|---|---|---|---|
| Linac intensity/pulse | $4 \times 10^{13}$ | $4 \times 10^{13}$ | $7 \times 10^{13}$ | $7 \times 10^{13}$ |
| Linac rep. rate | 7.5 Hz | 10 Hz | 10 Hz | 20 Hz |
| Linac energy | 200 MeV | 200 MeV | 600 MeV | 600 MeV |
| $\beta^2\gamma^3$ | 0.573 | 0.573 | 2.787 | 2.787 |
| Number of Boosters | 1 | 1 | 1 | 2 |
| Booster intensity/pulse | $2 \times 10^{13}$ | $2.5 \times 10^{13}$ | $5 \times 10^{13}$ | $5 \times 10^{13}$ |
| Booster rep. rate | 7.5 Hz | 10 Hz | 10 Hz | 10 Hz |
| Booster extr. energy | 1.9 GeV | 1.9 GeV | 2.5 GeV | 2.5 GeV |
| $\beta^2\gamma^3$ | 24.7 | 24.7 | 45.6 | 45.6 |
| Accumulator | No | Yes | Yes | Yes |
| AGS intensity/pulse | $7 \times 10^{13}$ | $10 \times 10^{13}$ | $20 \times 10^{13}$ | $20 \times 10^{13}$ |
| AGS rep. rate | 0.6 Hz | 2.5 Hz | 2.5 Hz | 5 Hz |
| Rf gradient | 10 kV/m | 15 kV/m | 15 kV/m | 30 kV/m |
| AGS extr. energy | 24 GeV | 25 GeV | 25 GeV | 25 GeV |
| Beam power on target | 0.17 MW | 1 MW | 2 MW | 4 MW |