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First RHIC Sextant Test ? Results and Accomplishment

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First RHIC Sextant Test — Results and Accomplishments

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RHIC Accelerator Physics

1. Introduction

2. Beam Test

   * Beam Quality Measurements

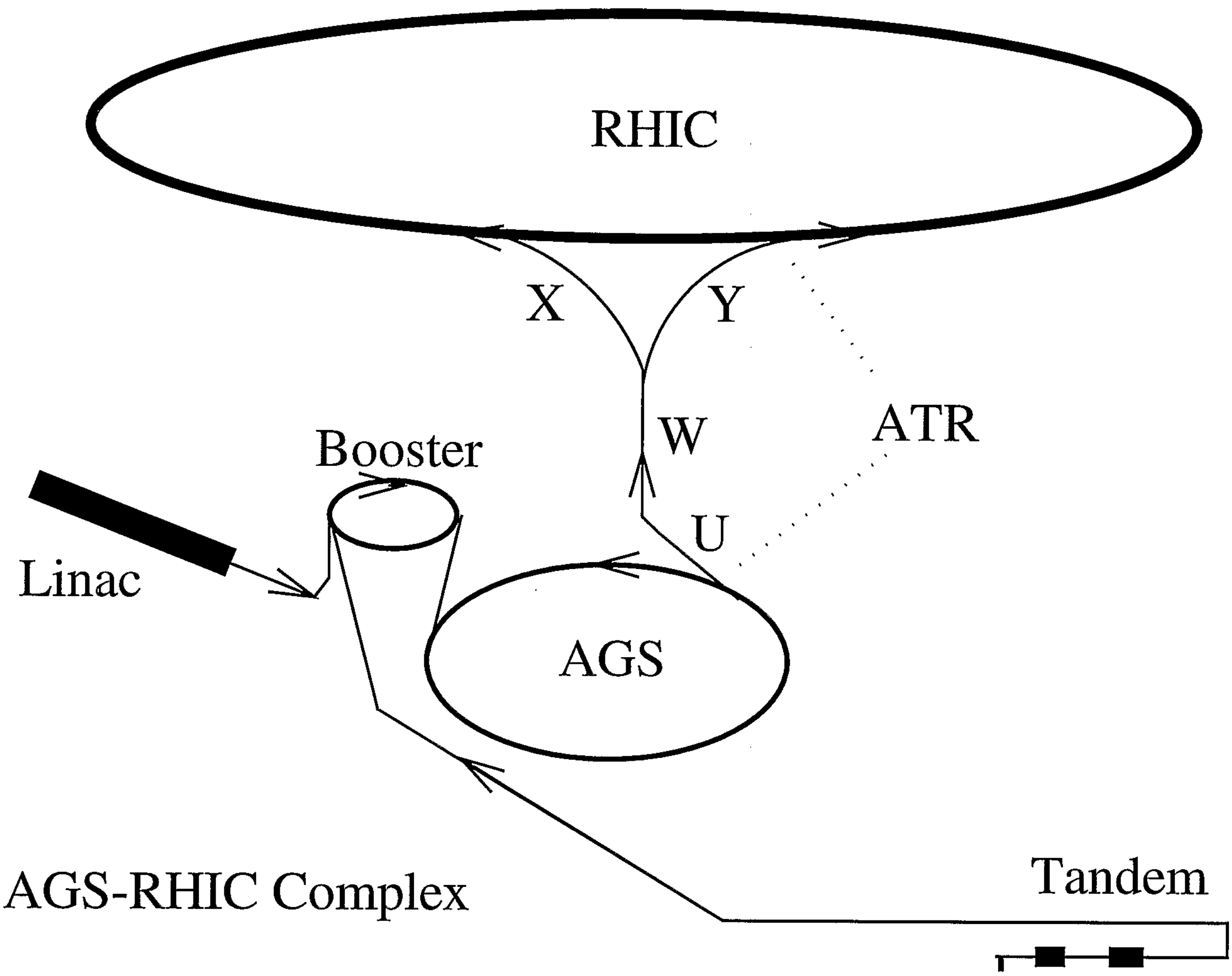
   * Machine Lattice Studies

   * System Performance and Stability

3. System Test

4. Conclusions

Schematic layout of the RHIC complex.



- Full sextant test: (Au) beam and system
- Dec. 96 — Feb. 97

1. Introduction

Sextant Test milestones:

- Preparation & AGS Study (Dec. 9 — 22, 1996):
  - AGS extraction condition & beam parameter optimization
  - software debugging
  - system test
- ATR Study (Jan. 10 — 21, 1997):
  - Jan. 10: beam injected into ATR
  - Jan. 11: beam hit ATR beam dump in < 8 hours
- Sextant Beam Test (Jan. 22 — Feb. 2, 1997):
  - Jan. 20: cool down starts
  - Jan. 24: Sextant commission granted
  - Jan. 25: safety done, lines unlocked
  - Jan. 26, 14:09 — beam hit Sextant dump in ~ 30 hours
- System Test without beam (Feb. 3 — 28, 1997):

$*$ Once passing the Lambertson, the beam traversed the Sextant and hit the dump without activating any correctors

$*$ Total beam study ~ 1 week

Sextant Test scope:

- Beam to the dump: establish nominal conditions
- Beam test:

  Beam Quality Measurements

  Machine Lattice Studies

  System Performance and Stability

  - With $^{197}Au^{79+}$ beam in RHIC
  - Total 81 shifts, including 17 owl shifts

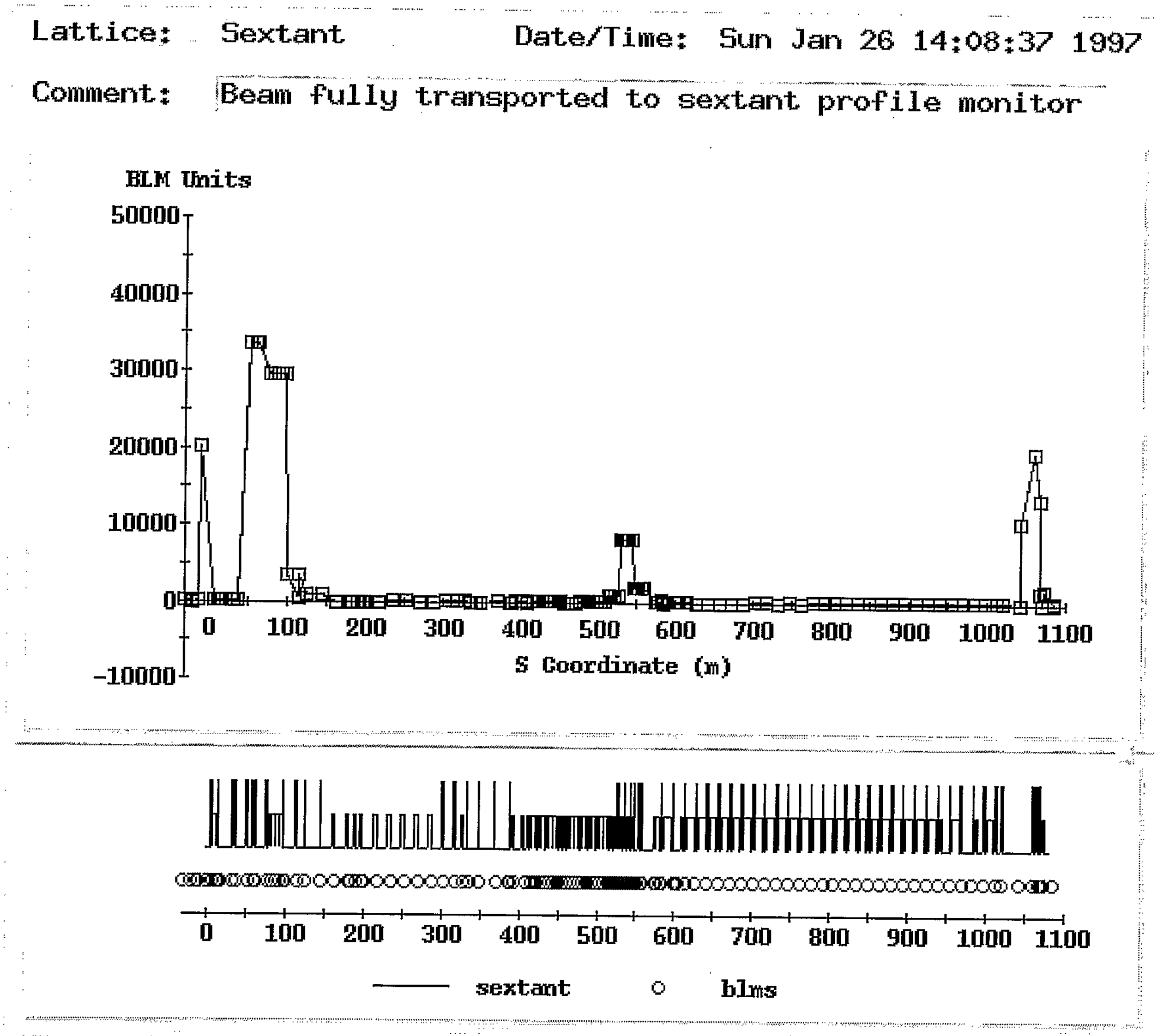
  RHIC Accelerator Physics Group
  AGS Main Control Room crew
  AGS/RHIC Controls Group ...

- System test:
  - including all accelerator systems

magnets and power supplies	instrumentation
beam permit and quench protection	injection
rf	cryogenics
vacuum	controls and database ...

- Radiation fault studies

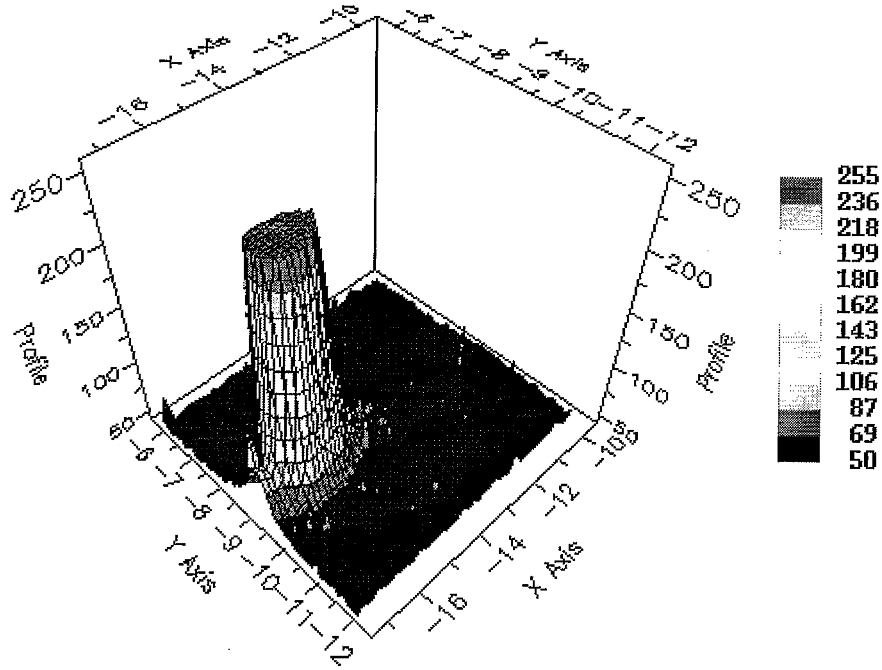
First beam in RHIC: Loss Monitor readings



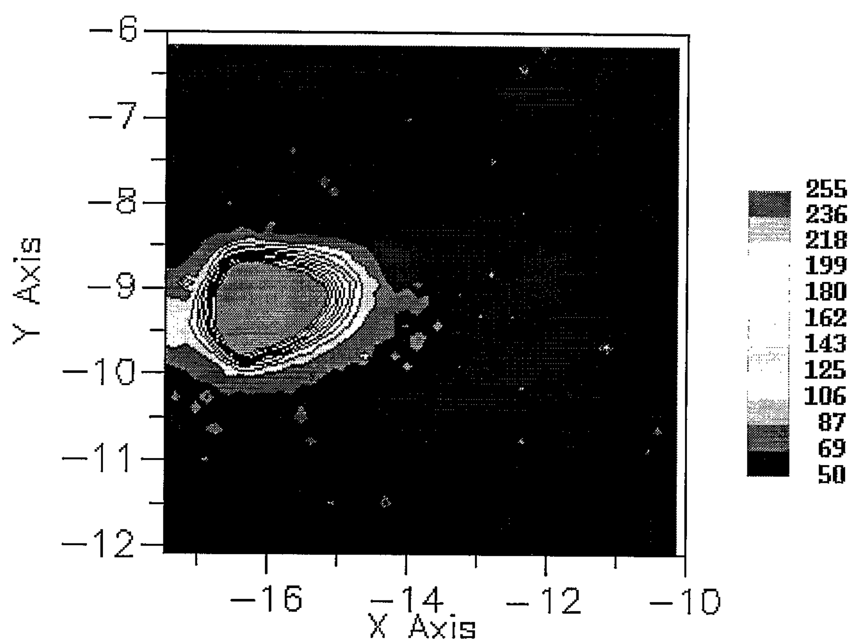
One of the first Beam Loss Monitor readings, showing loss at ATR striping flag (uf2), sextant entrance, and sextant dump.

First beam in RHIC: Profile Monitor readings

yo4-f3
Sun Jan 26 14:09:44 1997



Centroid X = -14.1188 Y = -8.86515 mm
Center X = -16.2776 Y = -8.82974 mm
Sigma Max = 1.08918 Min = 0.631376 mm with Theta = 0.0340329
Intensity = 1020872
Attenuation = 0%



2. Beam Test

2.1. Beam Quality Measurements

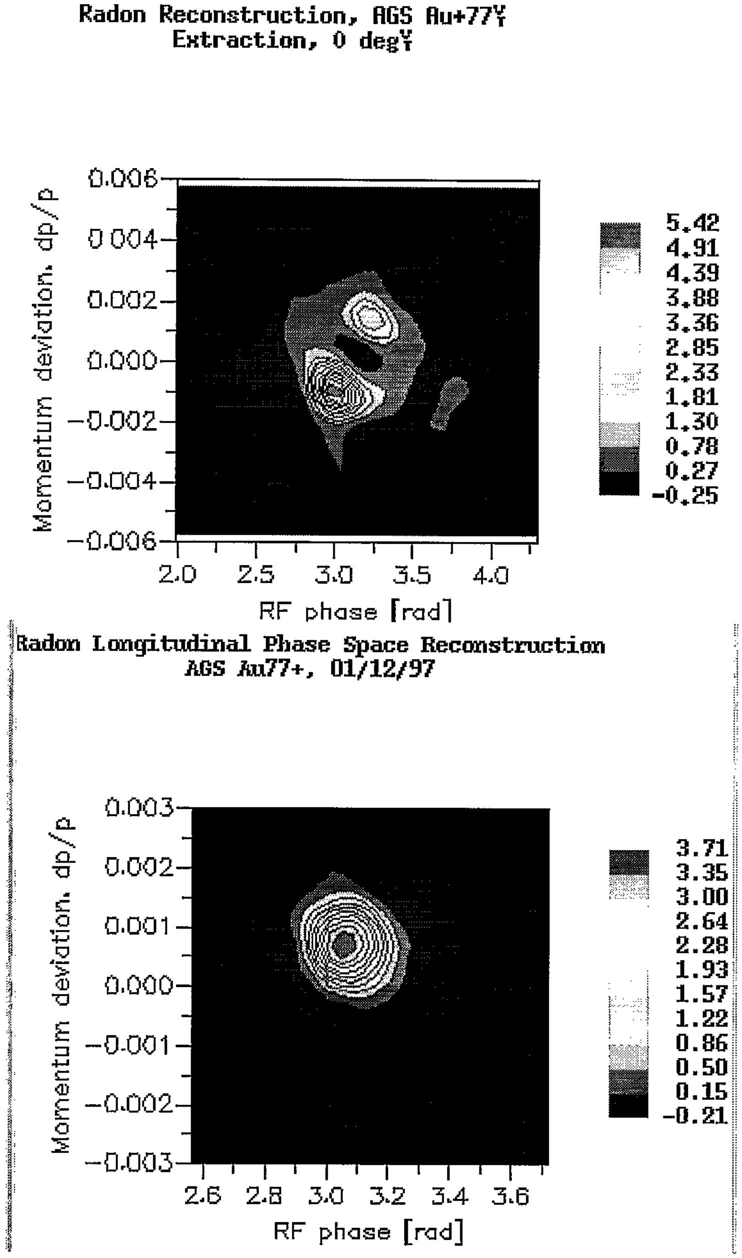
Goal: to achieve the nominal RHIC beam

Longitudinal emittance	$0.2 \sim 0.5$ eV·s/u
Transverse emittances	10 mm·mr
Intensity	10^9 ions per bunch
Energy (γ)	12.6
Shot-by-shot stability	

Beam parameter measured mostly in AGS

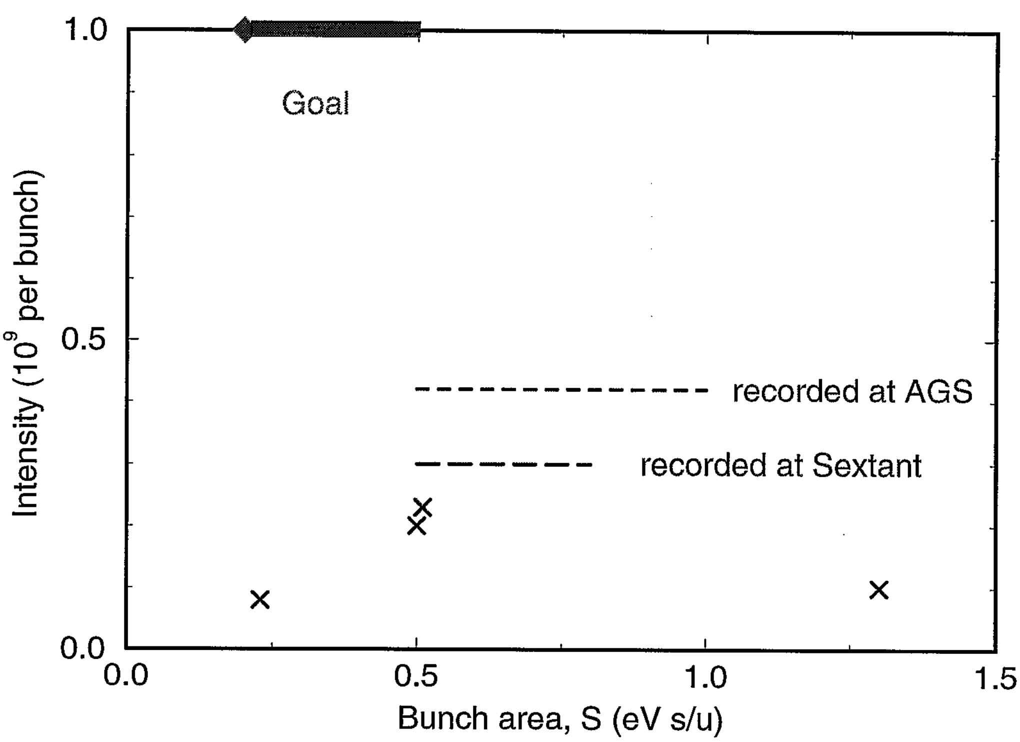
Confirmed by measurements in ATR & Sextant

Longitudinal phase-space reconstruction:



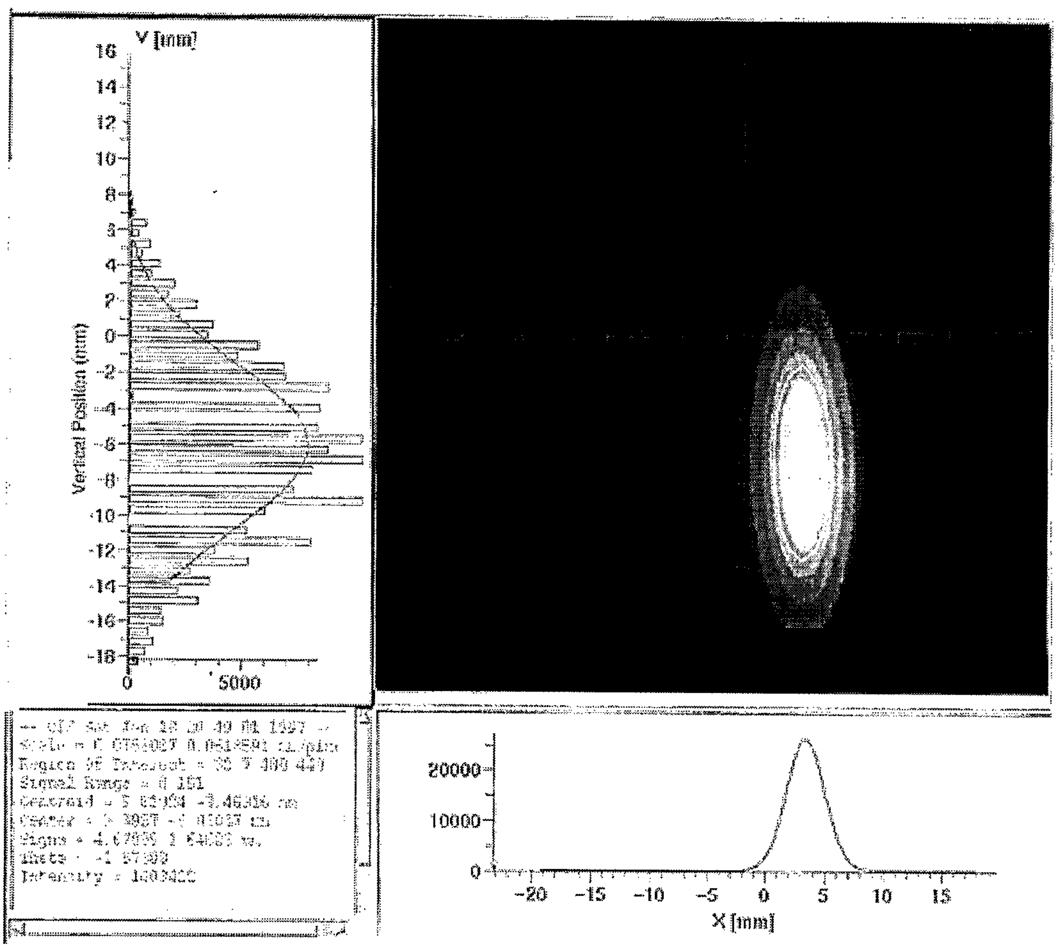
Tomographical reconstruction of the longitudinal phase space of a Au^{77+} beam in AGS on (a) Dec. 15, 1996 (S=1.5 eV·s/u) and (b) Jan. 12, 1997 (S=0.3 eV·s/u), showing improvement of merging at bunch coalescing.

- Energy: $\gamma = 12.15 \pm 0.1$
  - B field measured in AGS using Gauss clock plus Hall probe
  - confirmed with power supply setting in ATR bends
- Intensity: typical 2×10^8, up to 4×10^8 /bunch
  - measured consistently with Beam Current Transformers in AGS, ATR, and Sextant
- Bunch area: typical $S = 0.5 \pm 0.1$ eV s/u
  - AGS Wall Current Monitor profile
  - rf voltage calibrated with transition phase jump
  - cable bandwidth broadening subtracted ($\sim$ 2 ns measured)



Au^{79+} beam intensity and bunch area during the first Sextant Test.

- Transverse emittance: $\epsilon_{x,y} = 10 \pm 1$ mm mr
  - IPM measurement in AGS considering the momentum spread
  - Flag (Fluorescent Screen Profile Monitor) measurement in ATR & Sextant
  - Novel (electron collecting) IPM measurement in ATR
  - Automated archiving & on-line analysis



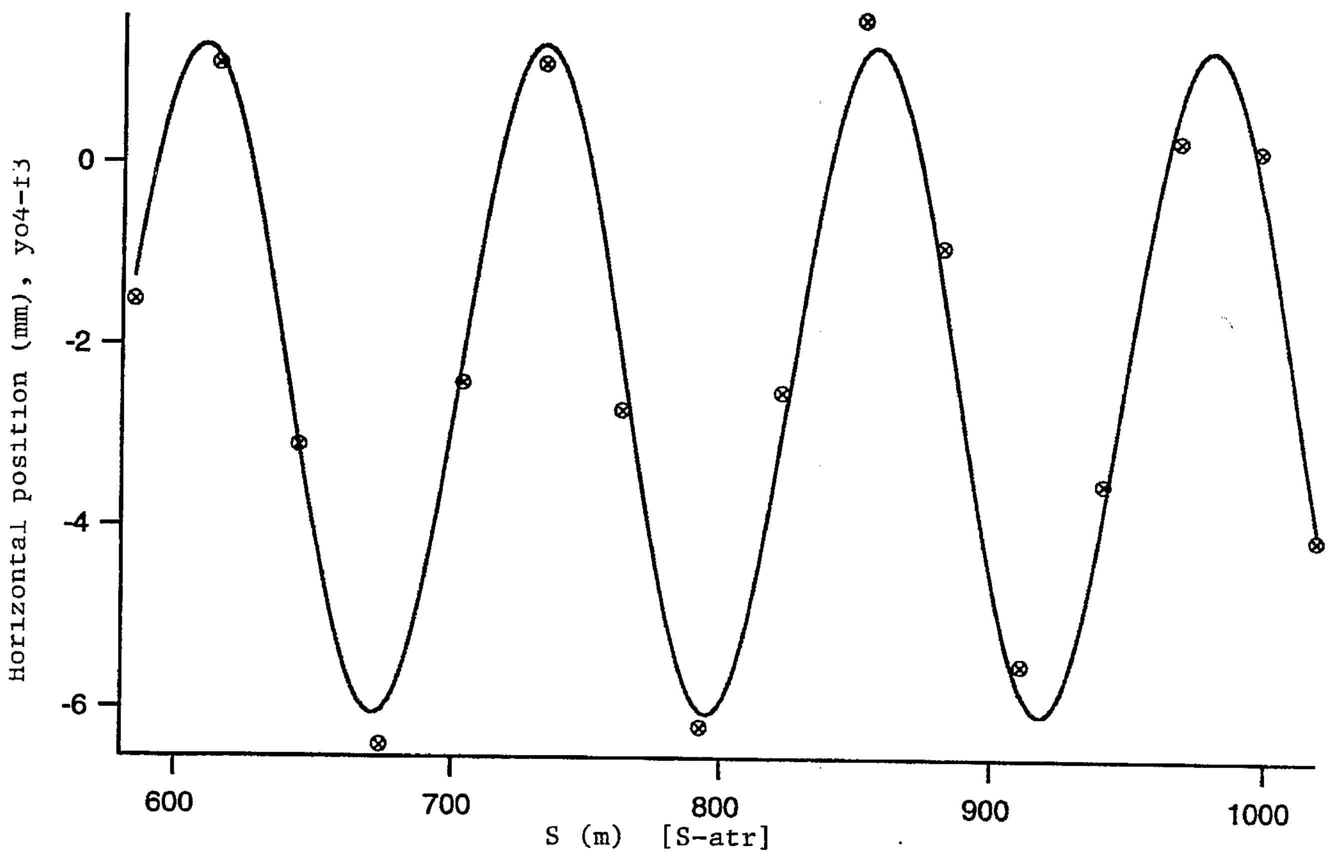
Transverse beam profile in W-line recorded on Flag wf3 and IPM.

2.2. Machine Lattice Studies

- Momentum aperture scan
  - Vary beam radial position in AGS to scan AGS extraction
  - Vary ATR and Sextant magnet power supplies to scan various bends
  - Bottle neck at AGS extraction when extraction bump is excited; minimum aperture $\Delta p/p \sim 1\%$
- Orbit correction
  - Automated orbit correction worked only for U and W line
  - Manual orbit correction elsewhere (BPM not reliable)
- Transfer matrix & difference orbit
  - Transfer matrix checked by the difference orbit method: comparison of orbit difference for an up stream kick
  - On-line lattice modelling in BPM application for comparison
- Dispersions in ATR and Sextant
  - Measured beam centroid position with Flags and BPMs while varying AGS radial position and recording frequency
  - AGS extraction condition changes, mismatched with ATR
- Optics (β, phase advance, chromaticity)
  - Phase advance measurement crucially done with the single flag in Sextant
  - Phase advance as functions of radial position and quad strength

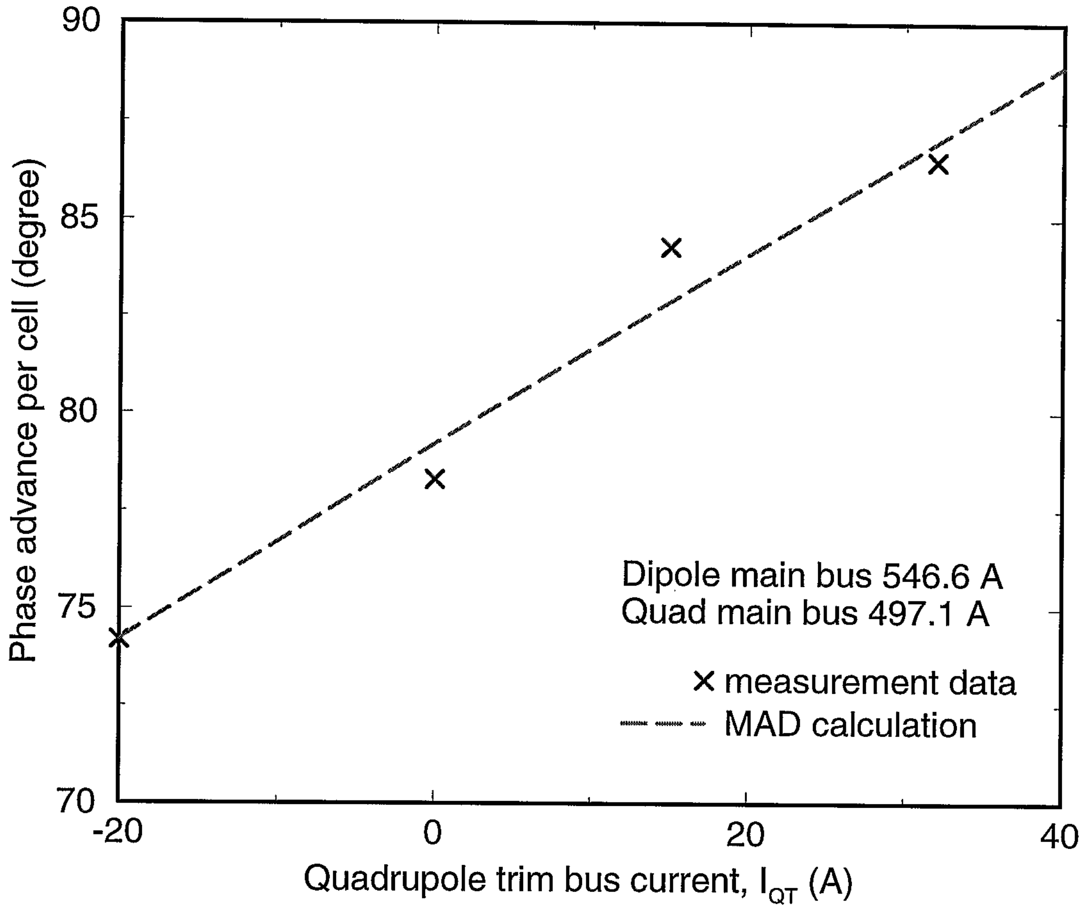
Poor men's way of phase advance measurement:

- BPM in Sextant not reliable
- Sequentially vary each horizontal & vertical dipole corrector strength
- Record beam centroid position on the only flag near Sextant dump,



Sextant phase advance measurement using corrector kicks and Flag position observation: beam centroid position vs. dipole corrector location excited at 1 A at injection.

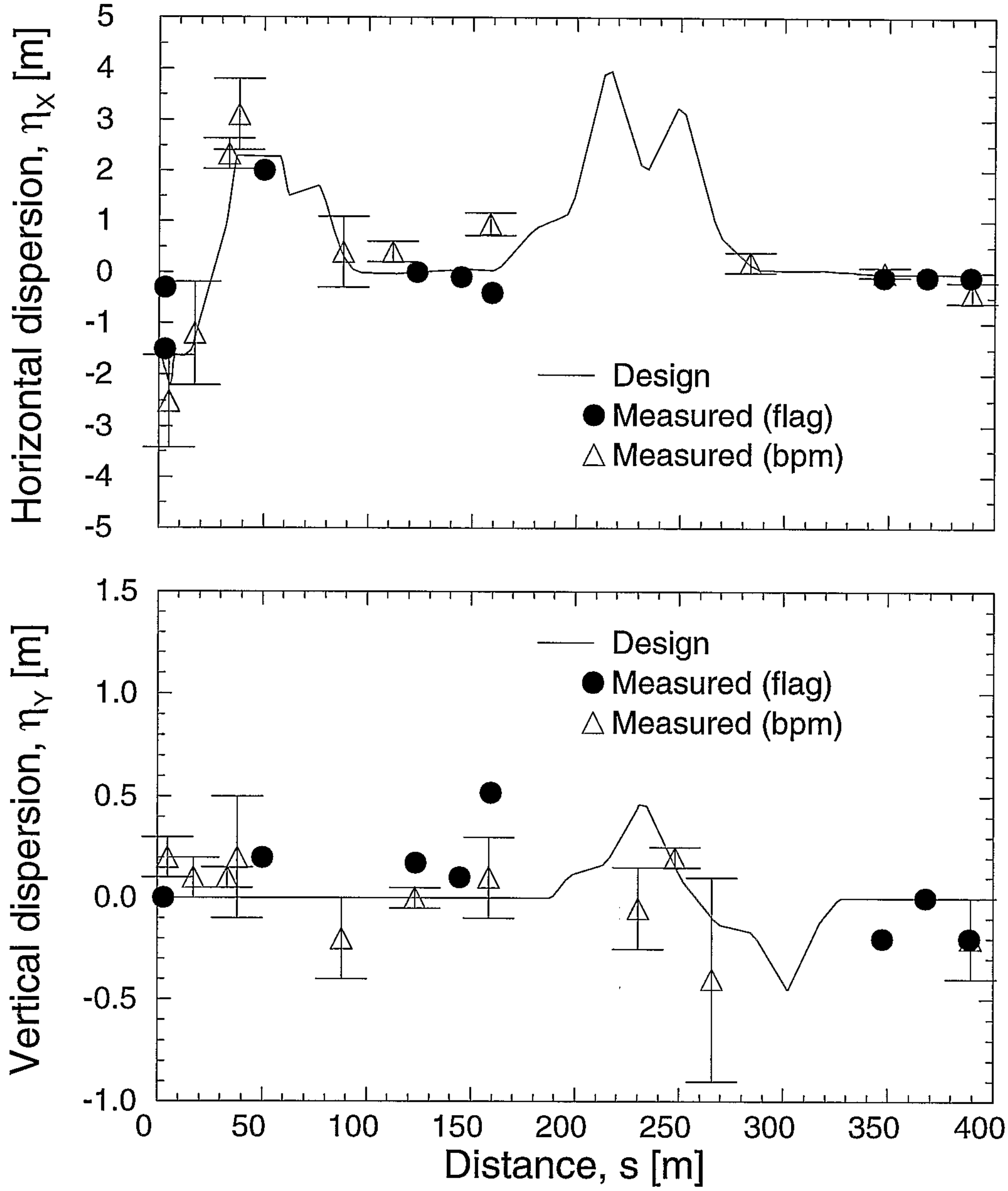
Phase advance vs. quad strength:



Comparison of beam measurement and MAD modelling (pre-installation bench measurement) on horizontal phase advance per cell as a function of arc focusing quad strength.

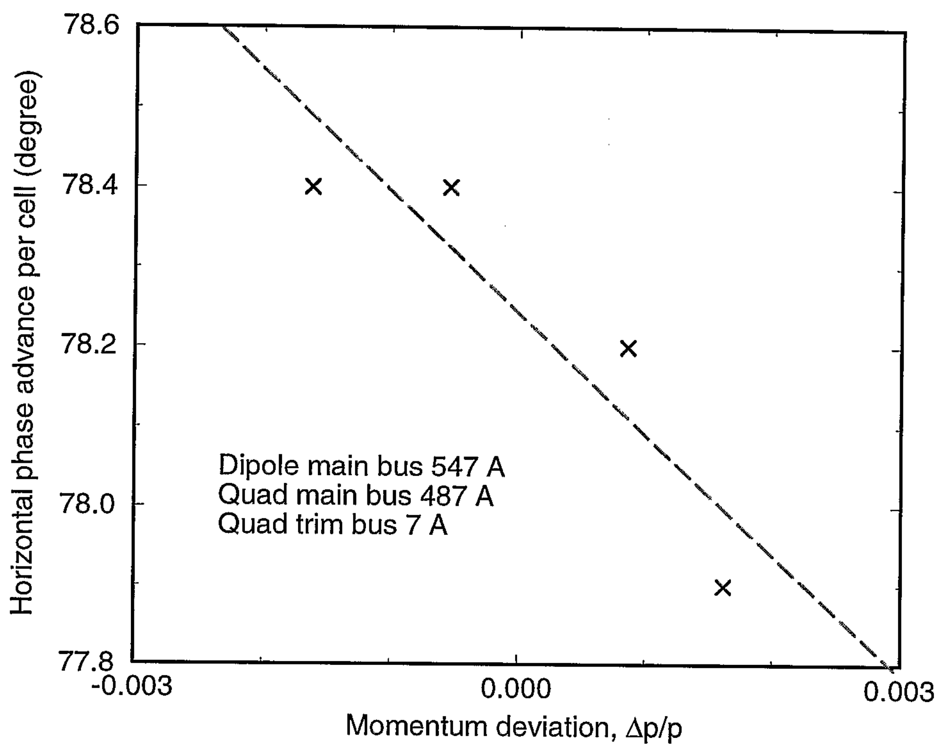
- Sextant power supply: 1 main dipole ($\sim$ 550 A), 1 main quad (QF and QD, $\sim$ 500 A), 1 trim quad (QF only, $\pm$30 A)
- MAD modelling using magnet Integral Transfer Function cold measured at 660 A; dead reckoned calculation
- Agreement within 0.6%

Dispersion measurement:



Dispersion in ATR measured by varying beam momentum in AGS.

Chromaticity measurement:



- measure phase advance for different radial orbits
- possible systematic error in AGS momentum calibration

Comparison on sextant natural chromaticity between measurement and MAD modelling: relative phase advance per unit momentum deviation.

ξ (measurement)	ξ (MAD)
-7	-5

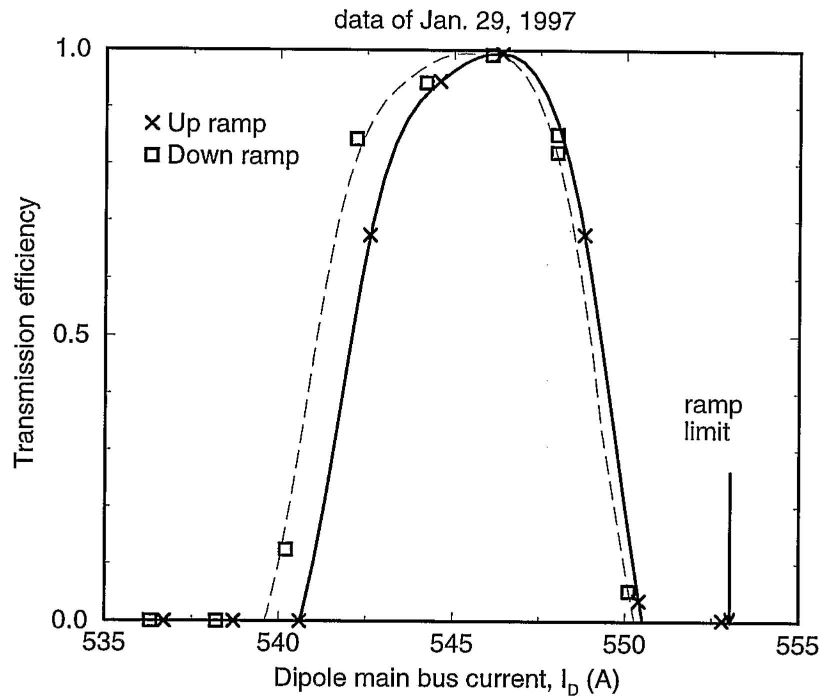
2.3. System Performance and Stability

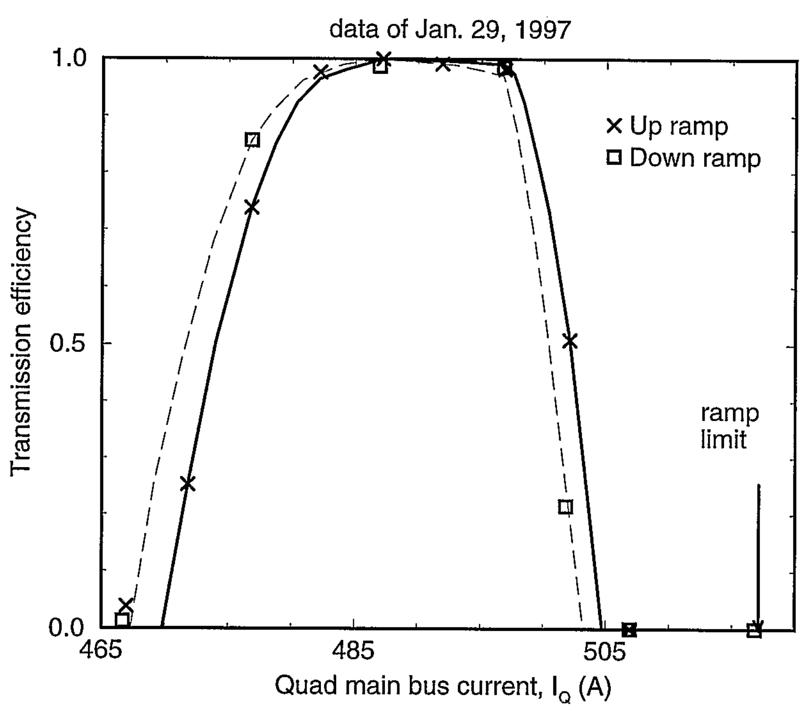
— Beam based accelerator system study:

- Beam instrumentation evaluation
- Injection position repeatability
- Kicker performance and kicker noise
- Multi-bunch stability
- Magnet hysteresis

...

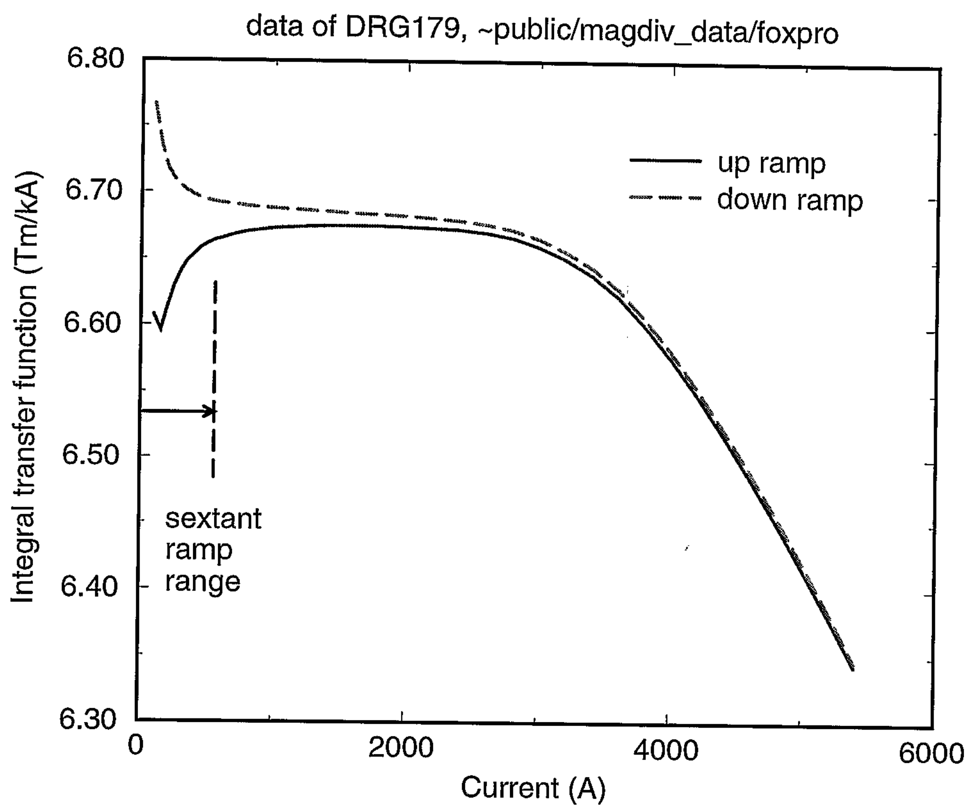
Magnet hysteresis:





Sextant dipole and quad hysteresis measurement by transmission efficiency scan.

Bench measurement:



Integral Transfer Function of an arc dipole at 660 A.

- Beam scan is limited by maximum allowable current ($\sim$ 600 A)
- In bench measurement, current is ramped to 5500 A

Comparison on sextant arc dipole hysteresis between beam measurement and bench (Integral Transfer Function) measurement.

Magnet	Δ_h (beam)	Δ_h (ITF)
Dipole	$\geq$ 1.1 A	1.8 A
Quad	$\geq$ 2.3 A	2.3 A

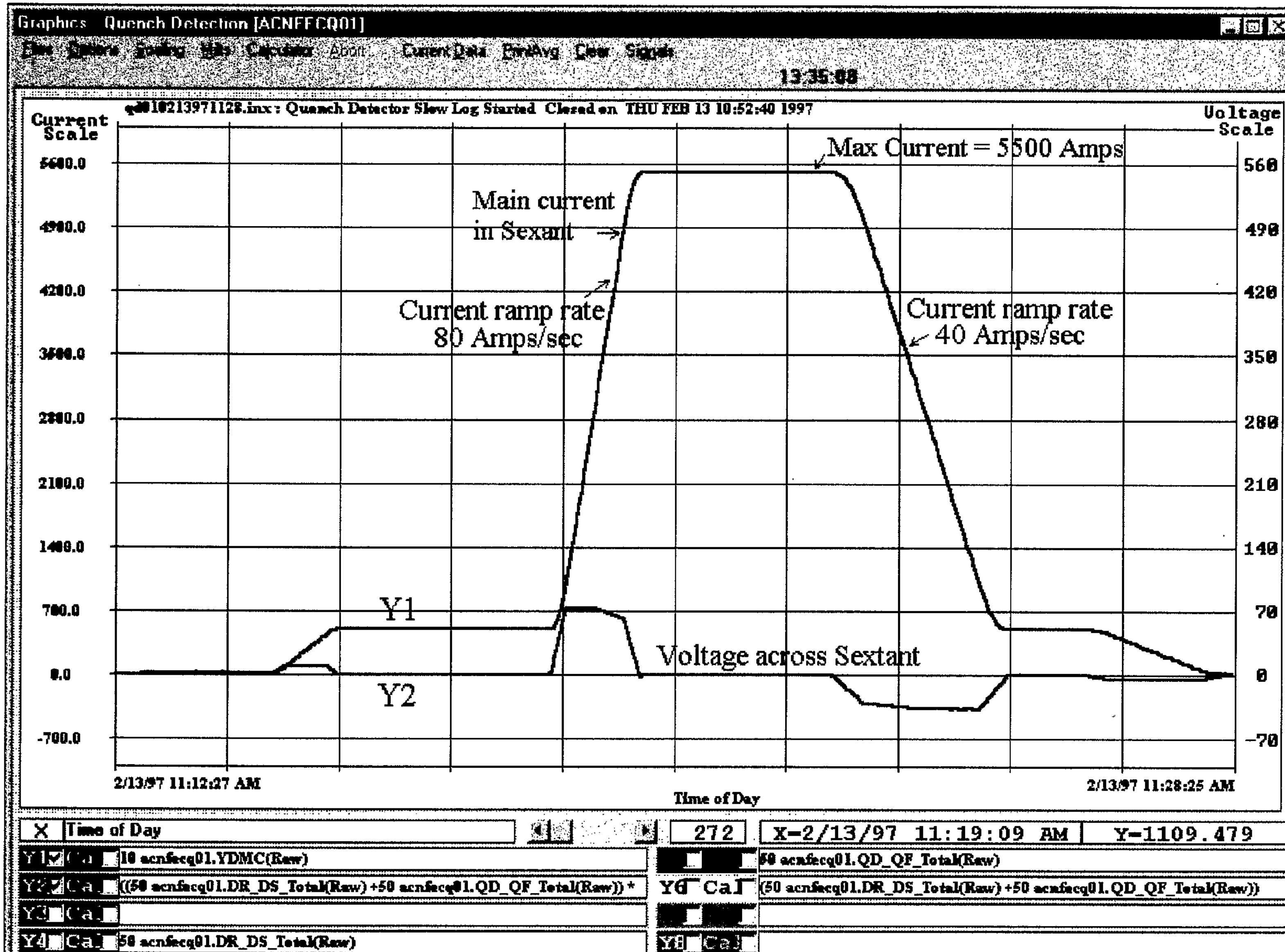
3. System Test

3.1. Magnets and power supplies

- Except for DX, all types of magnets are involved
- Magnets repeatedly ramped to 5,500 Amps, and kept at full current for 12 hours

  (nominal operating current 5 kA for 10 hours)
- Magnet ramping rate 10% higher than the nominal
- No quench for all magnets (previously 20% cold tested)

  (except for intentional quench induced by heaters)
- Bench measurement of magnet Integral Transfer Function confirmed by beam measurement with 0.6% accuracy



Current and voltage waveforms during a RHIC sextant test current cycle.

3.2. Instrumentation

- Beam Loss Monitors (BLM)
  commissioned in single pass & ring operation mode
  60 channel for ATR + 60 channel for Sextant
- Beam Position Monitors (BPM)
  total 24 planes
  ATR U and V line BPM satisfactory;
  worked for 4-bunch trains
  low level problems in Sextant BPM; not stable
  software communication bugs fixed after the Test
- Beam Current Monitors (BCM)
  4 in ATR, 1 in Sextant; all reliable
  worked for 4-bunch trains
- Beam Profile Monitors (Flags)
  8 in ATR, 1 in Sextant; all reliable
  worked for 4-bunch trains
- Ionization Profile Monitors (IPM)
  commissioned in ATR; excellent agreement with Flags

3.3. Cryogenics

- cool-down in 48 hours; stable through the Test
- warm-up in 24 hours with warm-up heaters

3.4. Vacuum

- helium leaks were observed in insulating vacuum volumes
- large leaks located and repaired; small leaks handled with turbopump stations

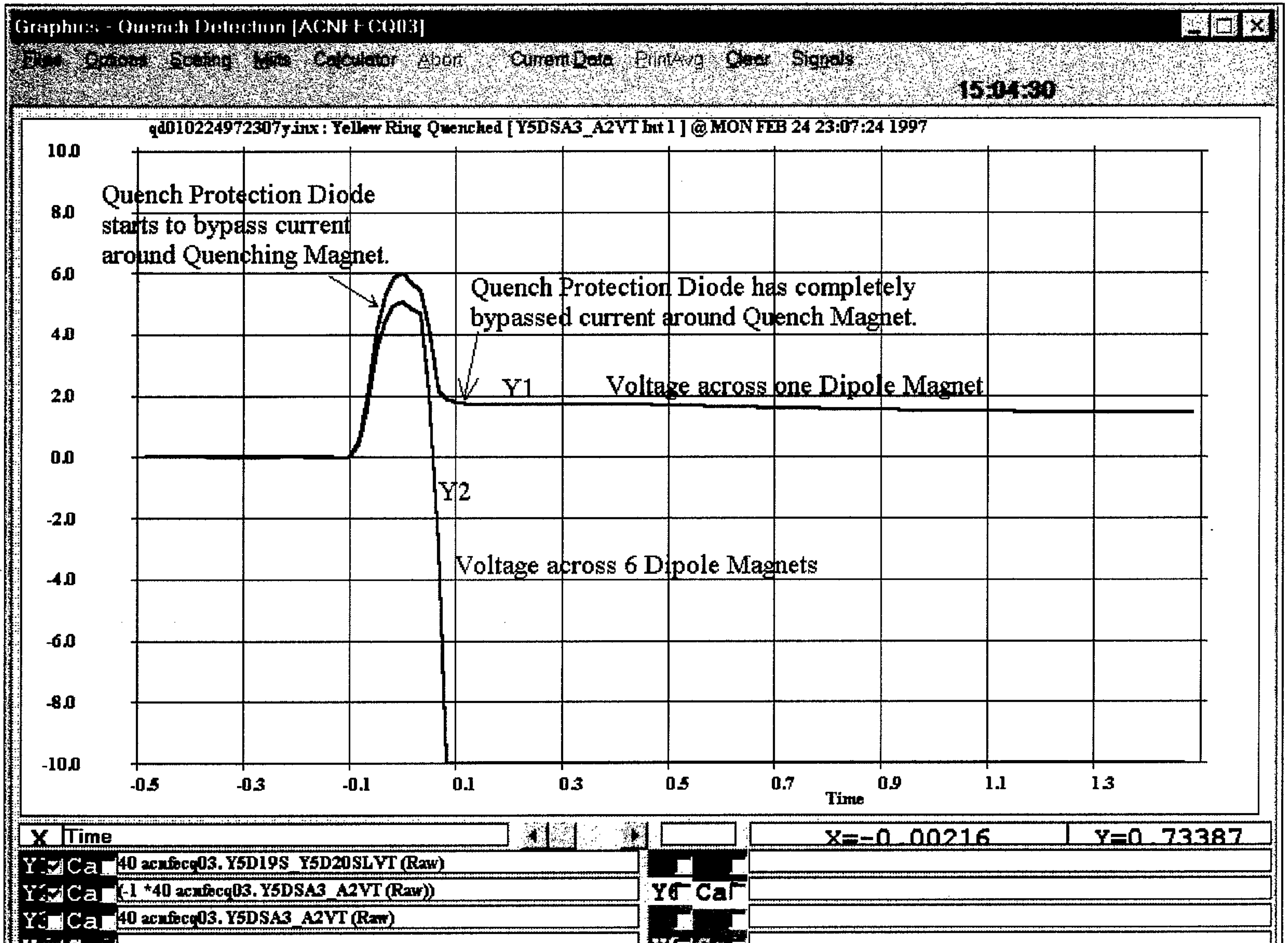
  actual pressure inside cold bore $< 10^{-11}$ Torr

  warm bore beam vacuums maintained at 10^{-9} Torr with ion sputter pumps

  insulating vacuum ranged from 10^{-7} to 10^{-3} Torr (at the leak); adequate

3.5. Beam permit and quench protection

- functioned properly in the Test
- disabled beam injection in the case of closed vacuum valves
- quench protection tested during the warm-up



Dipole Magnet Quench at 5500 Amps
Induced by Warm-up heater.

Figure 11

3.6. RF

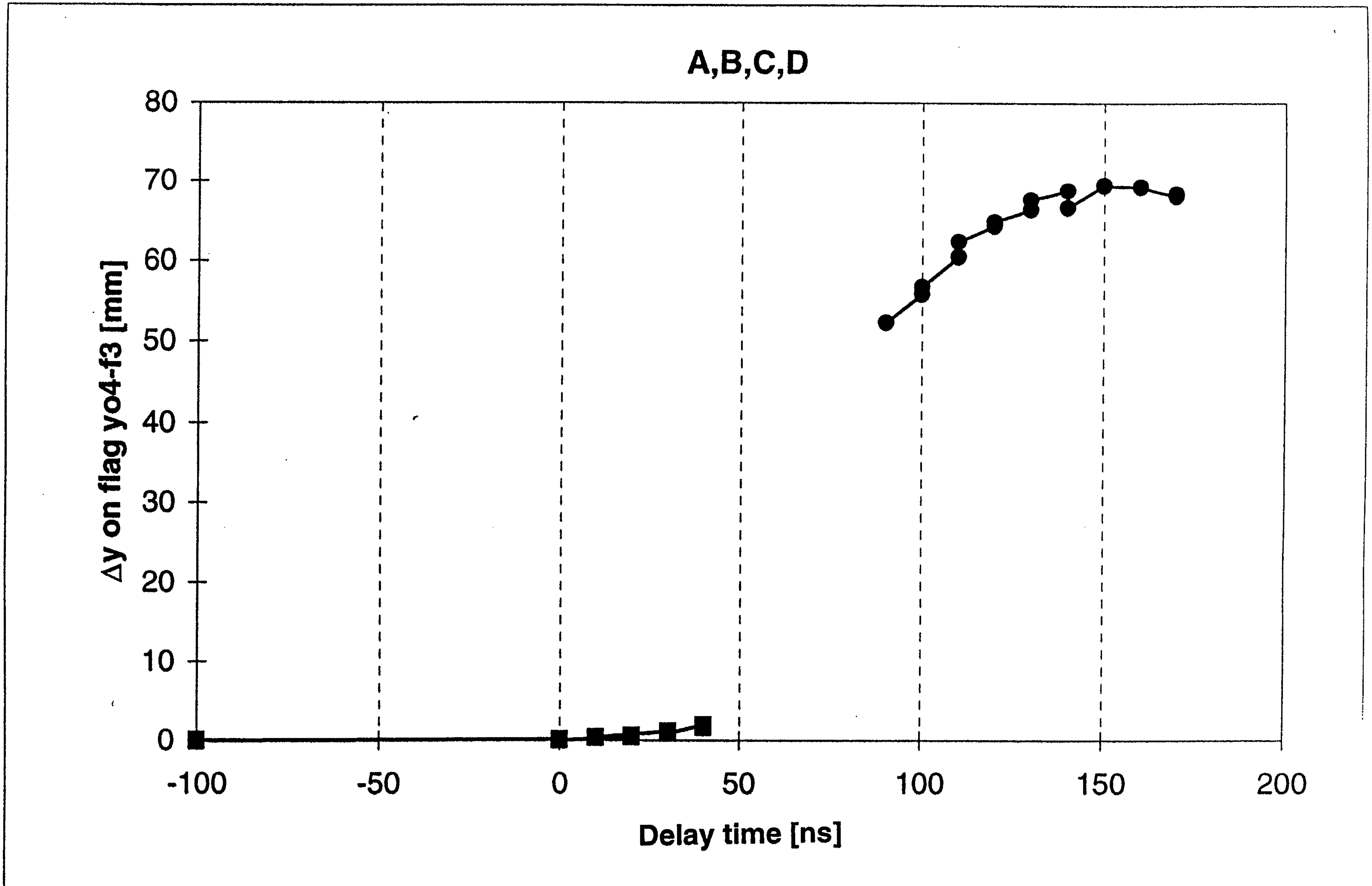
- A 197 MHz storage cavity was successfully run at 1.1 MV
  (nominal 1 MV)
- fully demonstrated the driver amplifier, power amplifier, cavity chain, and beam-system synchronization

3.7. Injection

- all requirements on the injection kicker are met:
  timing, strength, rise time
- shot-to-shot stability tested for multi-bunch injection
- initially using a dipole corrector; later using a kicker

3.8. Controls and database

- design validated during the beam test, integrating all other systems



A,B,C,D
80
70
60
50
40
30
20
10
0
Δy on flag yo4-f3 [mm]
-100
-50
0
50
100
150
200
Delay time [ns]

4. Conclusions

- A major milestone - the First Sextant Test - was passed successfully commissioning all major accelerator systems.

- Beam emittances reached the design value; beam intensity reached 40% of the nominal value.

- Machine lattice was verified; agreement between beam and bench measurement on phase advance within 0.6% accuracy.

- Sextant Test was an excellent practice for the full commissioning in 1999.