

# A Survey of the Capabilities of the Upgraded TeV BPMs

Rob Kutschke, CD/EXP

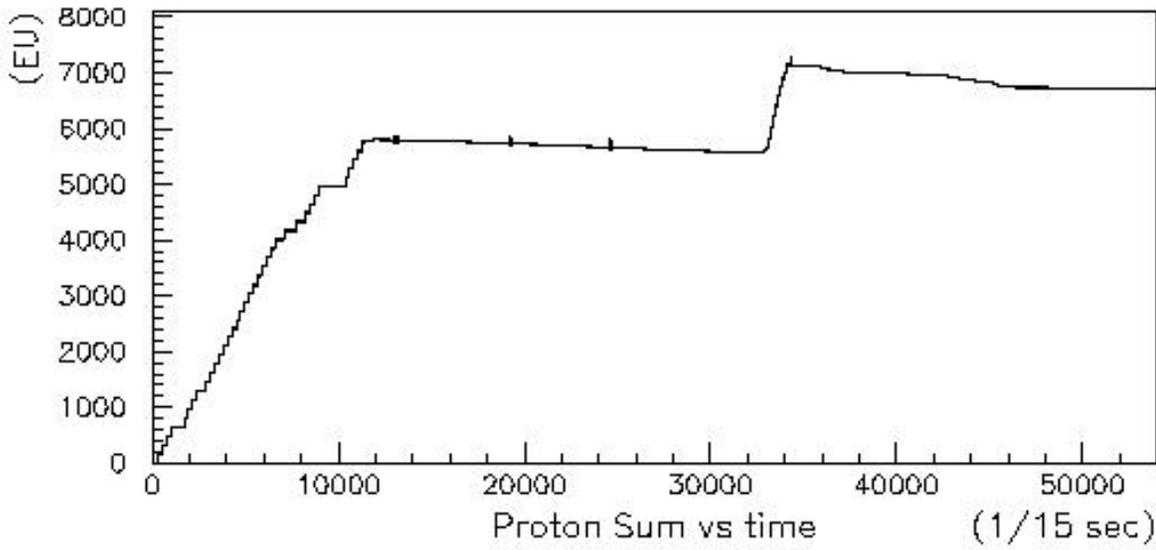
Run II Meeting

March 24, 2005

# This Talk Will Show:

- Closed orbit.
  - Average of all bunches over many turns.
  - Can see both protons and anti-protons.
- Injection TBT
  - Triggered by injection.
  - Either single bunch or uncoalesced beam.
  - Can see: synchrotron motion, betatron motion, quadrupole oscillations of bunch in the bucket, HV coupling, plus some instrumental artifacts.
- TBT
  - Triggered by request.
  - Will show 36x36 during normal HEP store.
    - Do NOT ping beam.
    - Can see the “15 Hz” motion.
- Using data taken at A3 in early January and February.

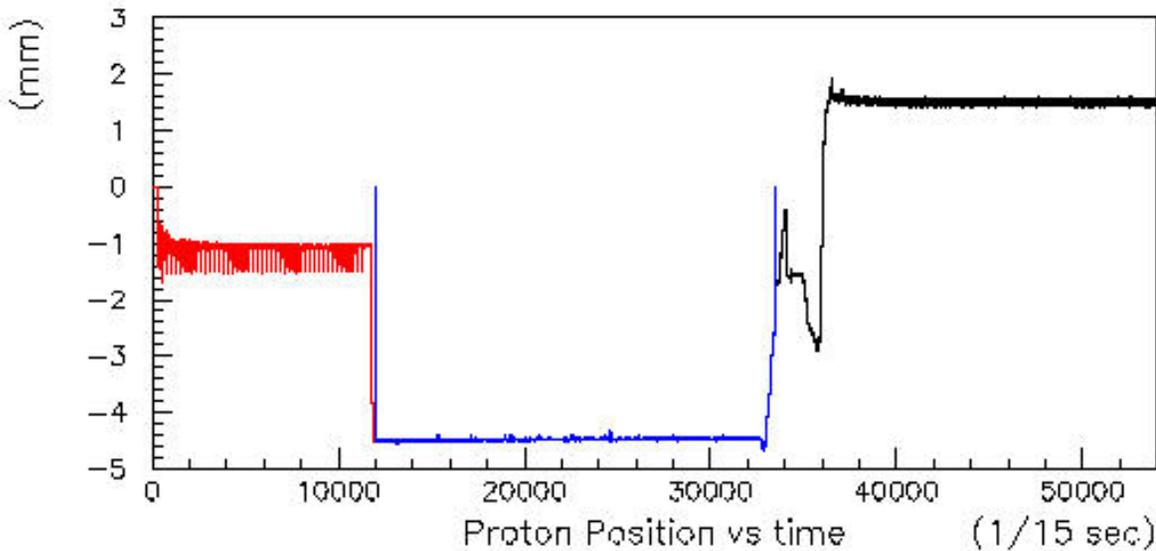
Closed Orbit HA32 Shot on Feb 18, 2005



$$Sum = |A| + |B|$$

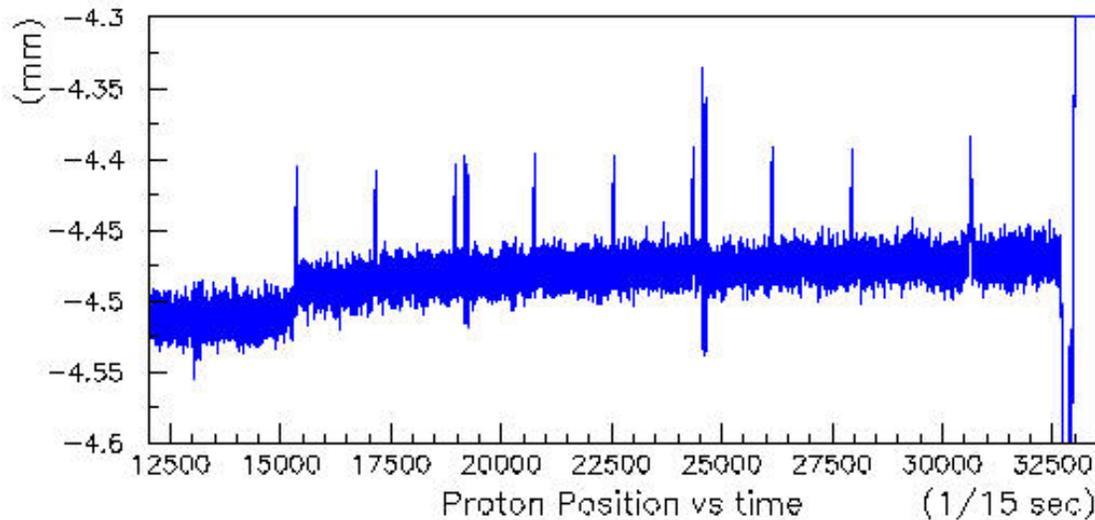
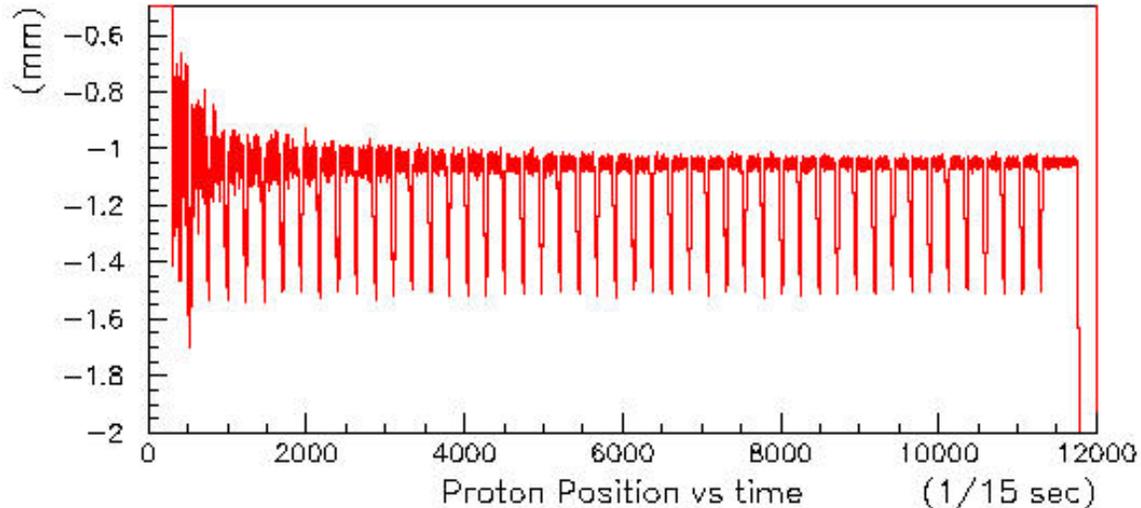
$$A = (I_A, Q_A)$$

$$B = (I_B, Q_B)$$



$$P = 26 \frac{|A| - |B|}{|A| + |B|}$$

Closed Orbit HA32 Shot on Feb 18, 2005

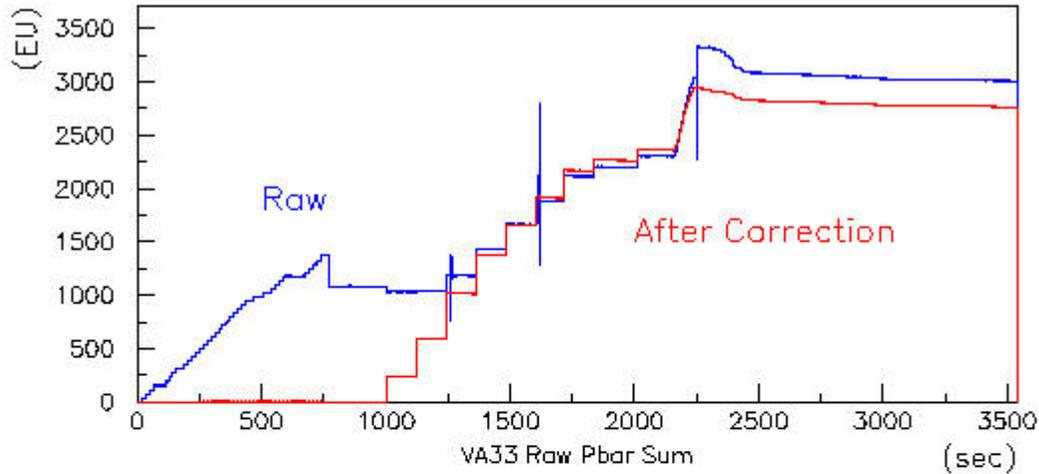


Detail during **proton injection** and **anti-proton injection**.

Can see injection bumps during proton injection.

During pbar injection can see injections, cogging and a small instrumental effects.

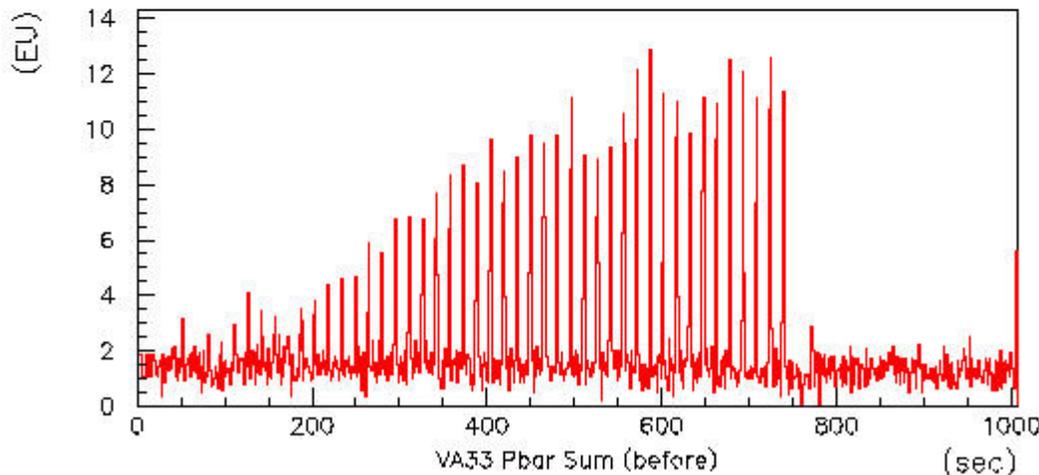
Closed Orbit HA32 Shot on Feb 18, 2005



Cancellation of proton contamination on Pbar cables:

$$A'_{Pbar} = A_{Pbar} - aA_P - bB_P$$

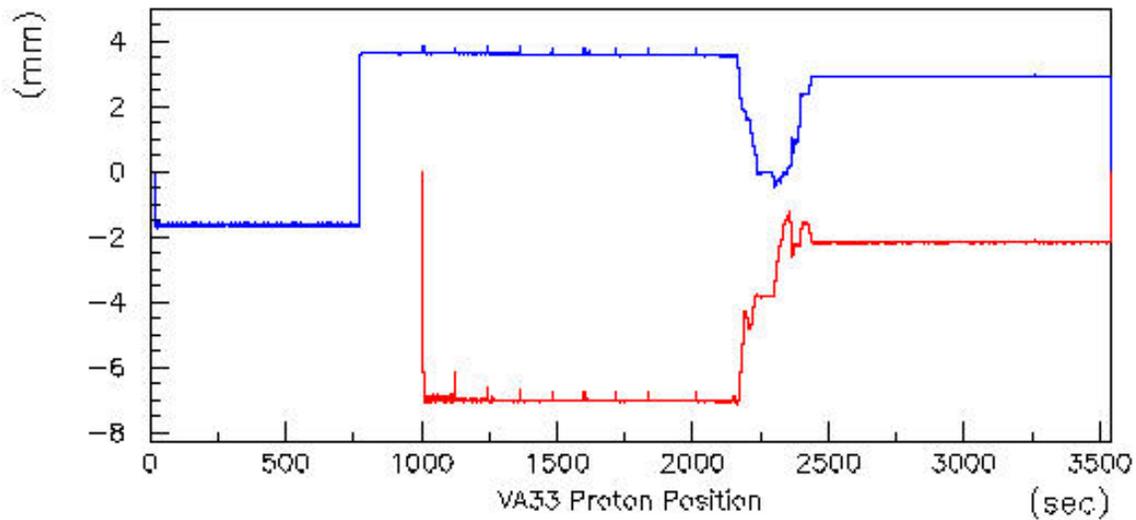
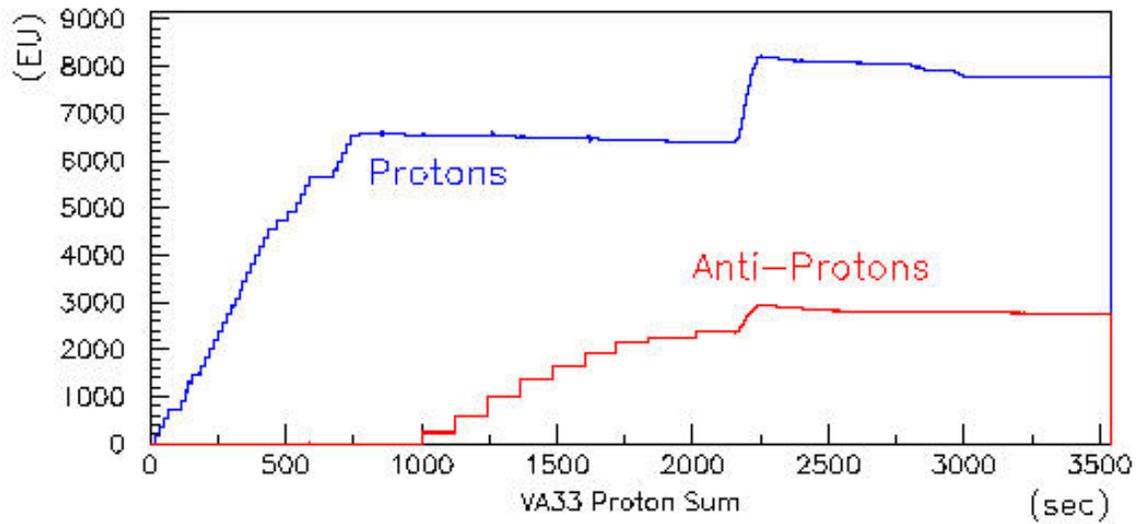
$$B'_{Pbar} = B_{Pbar} - cB_P - dA_P$$



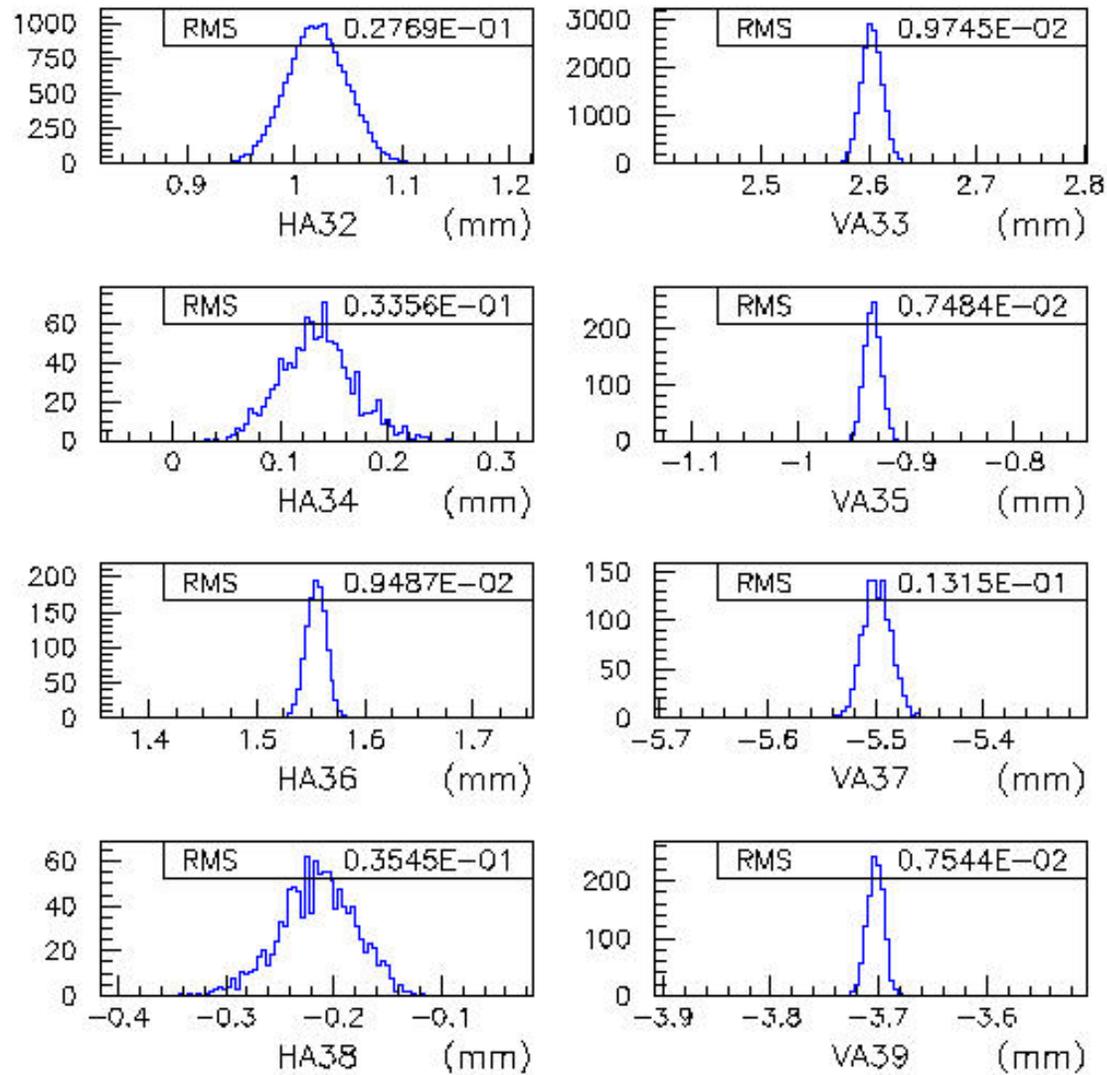
a,b,c,d determined empirically using the opening of the helix.

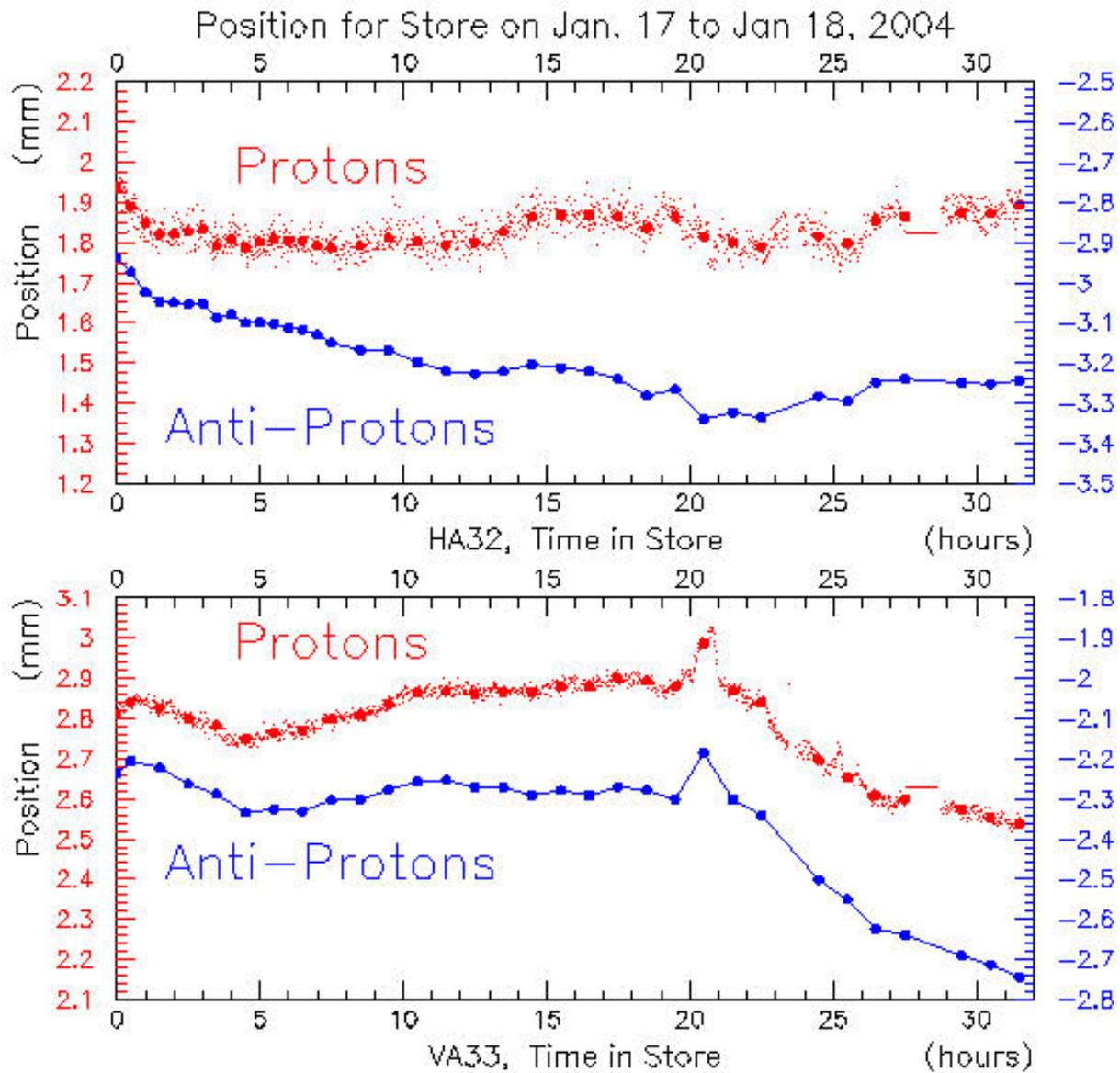
Using corrected values, compute sum and position as for protons.

Closed Orbit HA32 Shot on Feb 18, 2005

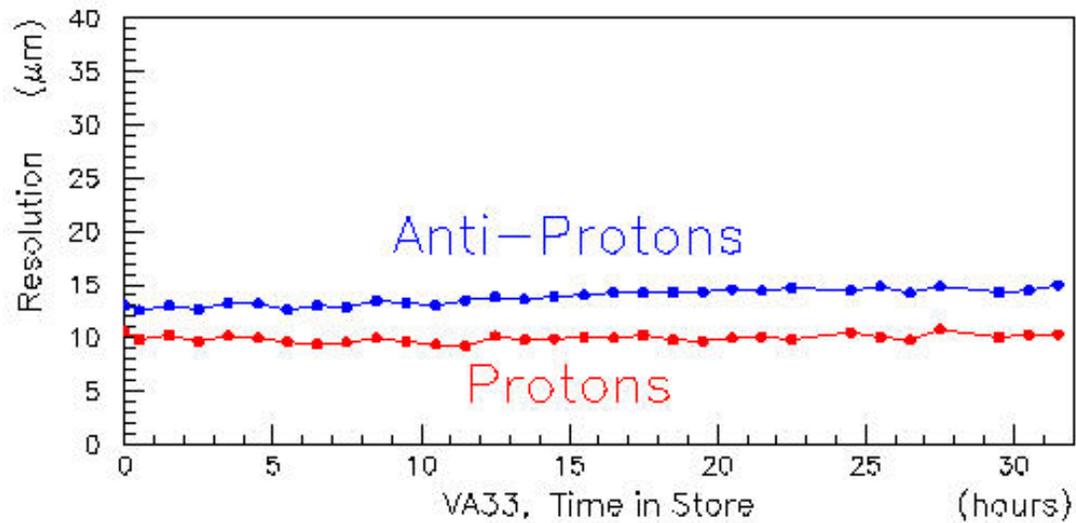
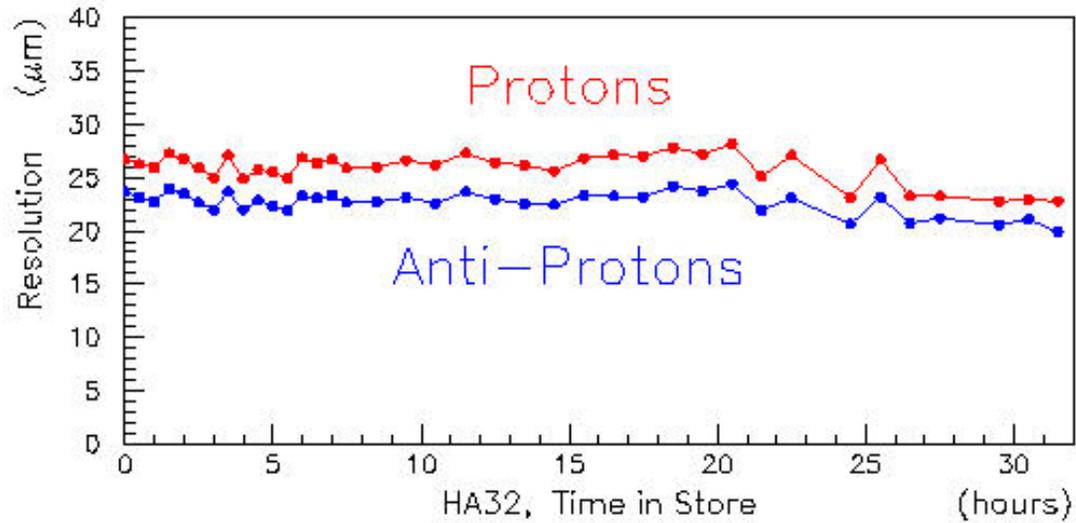


# Resolution for A3 BPMs, Feb 14, 2005





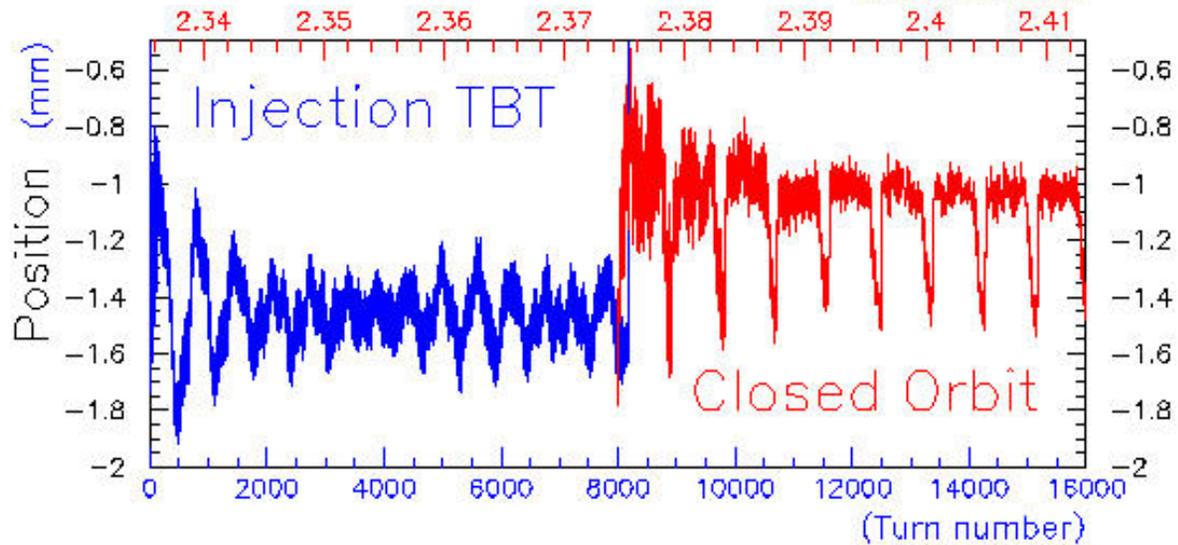
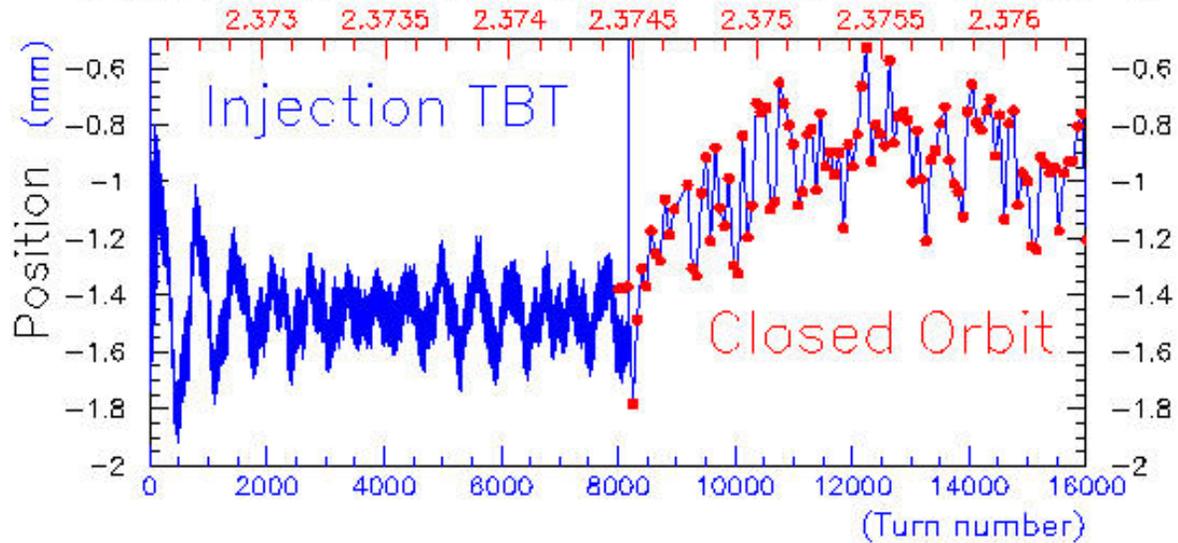
Resolution for Store on Jan. 17 to Jan 18, 2004



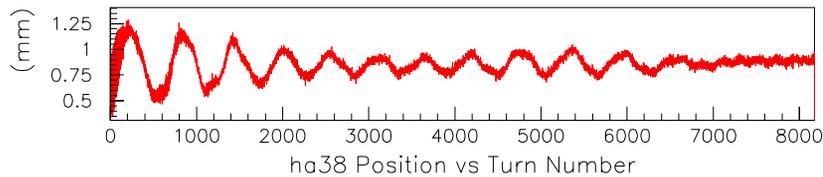
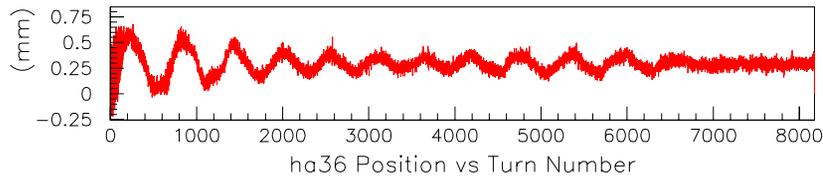
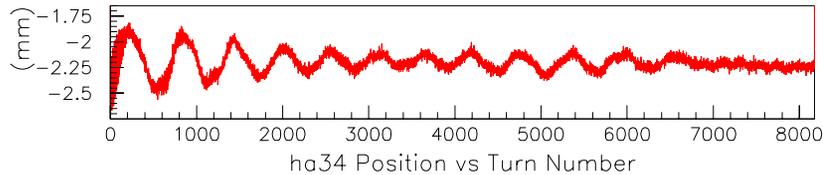
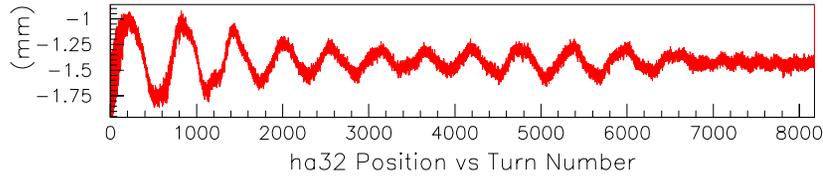
# Injection TBT

- Triggered by injection.
- Either single bunch or uncoalesced beam.
- Check that it gives same answer as closed orbit.
- Can see: synchrotron motion, betatron motion, quadrupole oscillations of bunch in the bucket, HV coupling, plus some instrumental artifacts

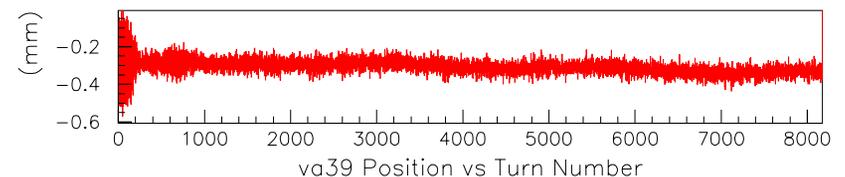
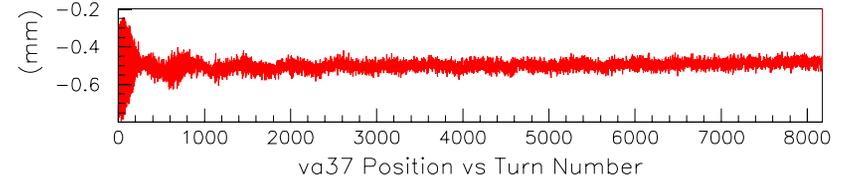
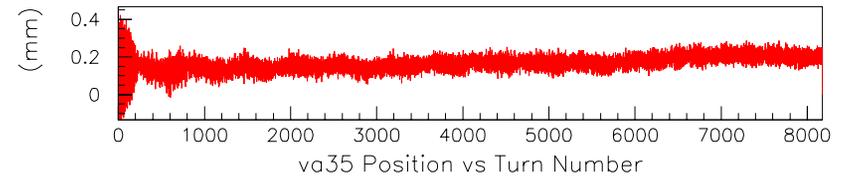
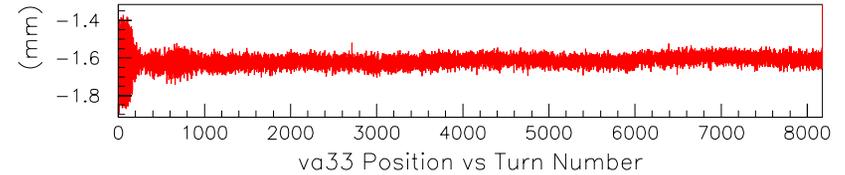
Injection on HA32, Single Bunch, Feb 21, 2005, 2:22:25 AM



Position for H BPMs in A3, Feb 6/05, Coalesced



Position for V BPMs in A3, Feb 6/05, Coalesced



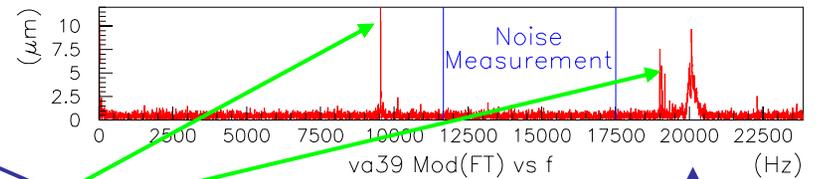
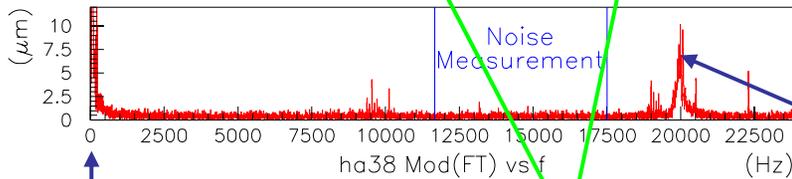
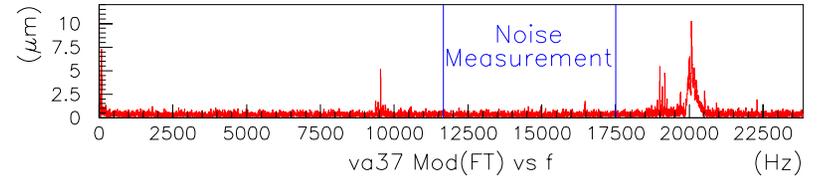
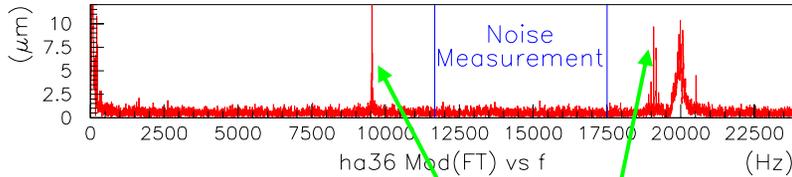
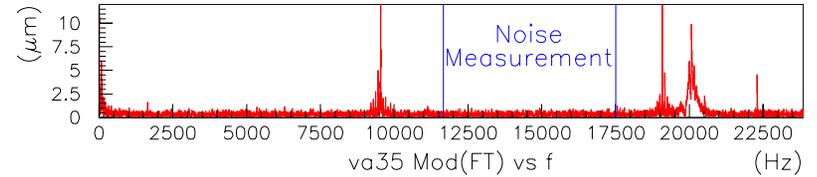
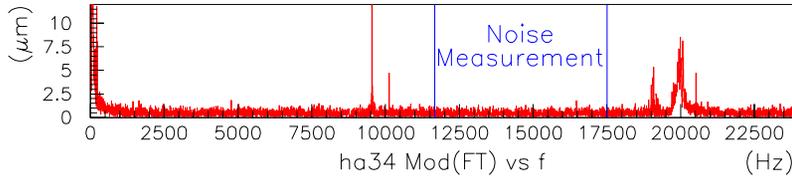
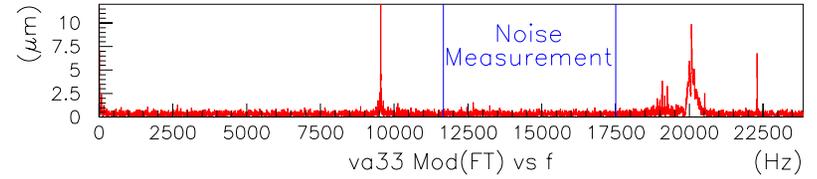
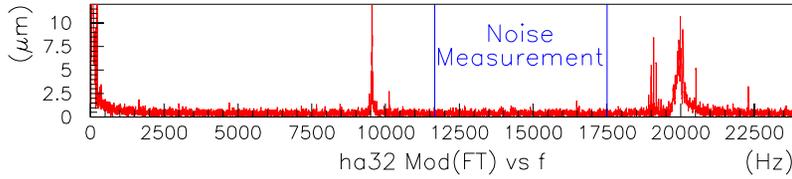
1.1 mm full vertical scale

0.6 mm full vertical scale

- Injection TBT; 150 GeV; 8192 turns.
- One coalesced bunch. HEP shot after all tuning.

Detail of Mod(FT) for H BPMs in A3, Feb 6/05, Coalesced

Detail of Mod(FT) for V BPMs in A3, Feb 6/05, Coalesced



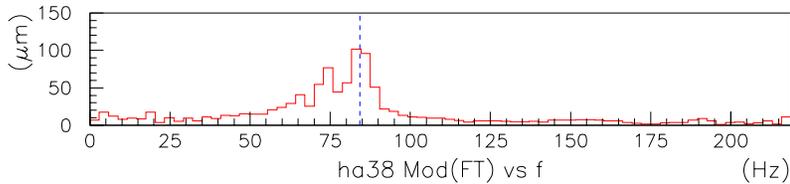
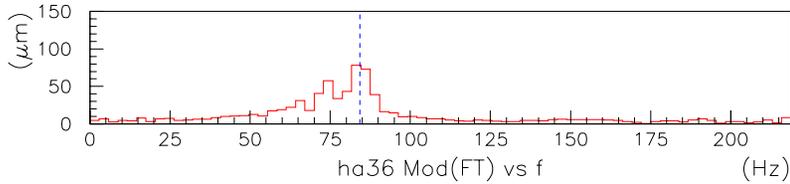
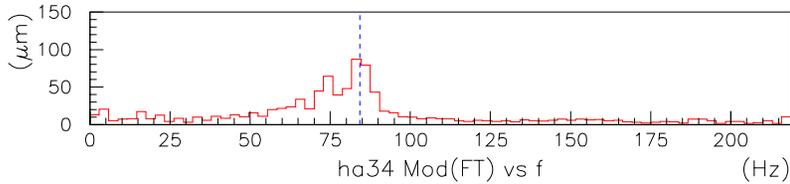
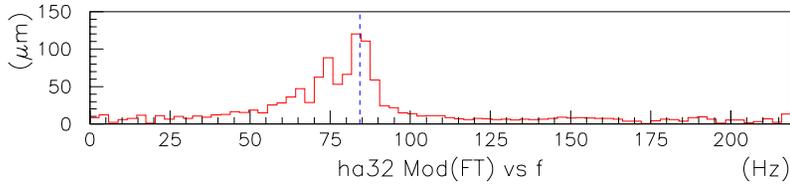
1113 / 5 Artifacts

Bin Size:  $\sim 3$  Hz  
Resolution:  $0.3 \mu\text{m}/\sqrt{\text{Hz}}$

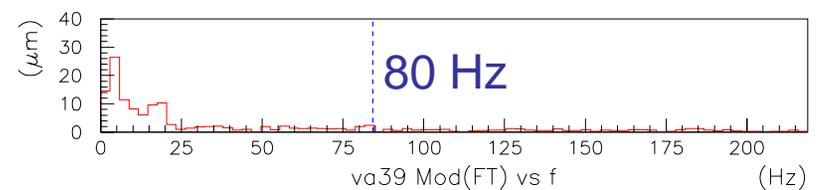
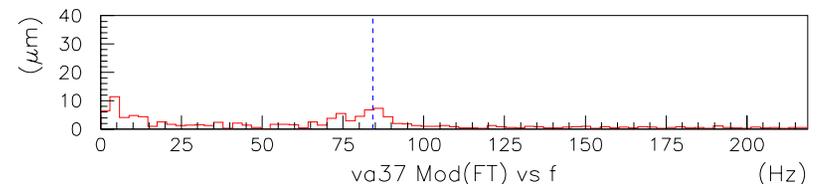
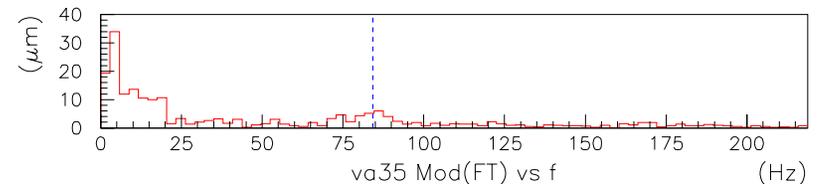
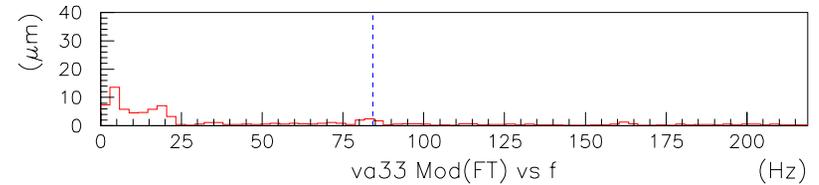
Synchrotron Line

Betatron Lines

Detail of Mod(FT) for H BPMs in A3, Feb 6/05, Coalesced



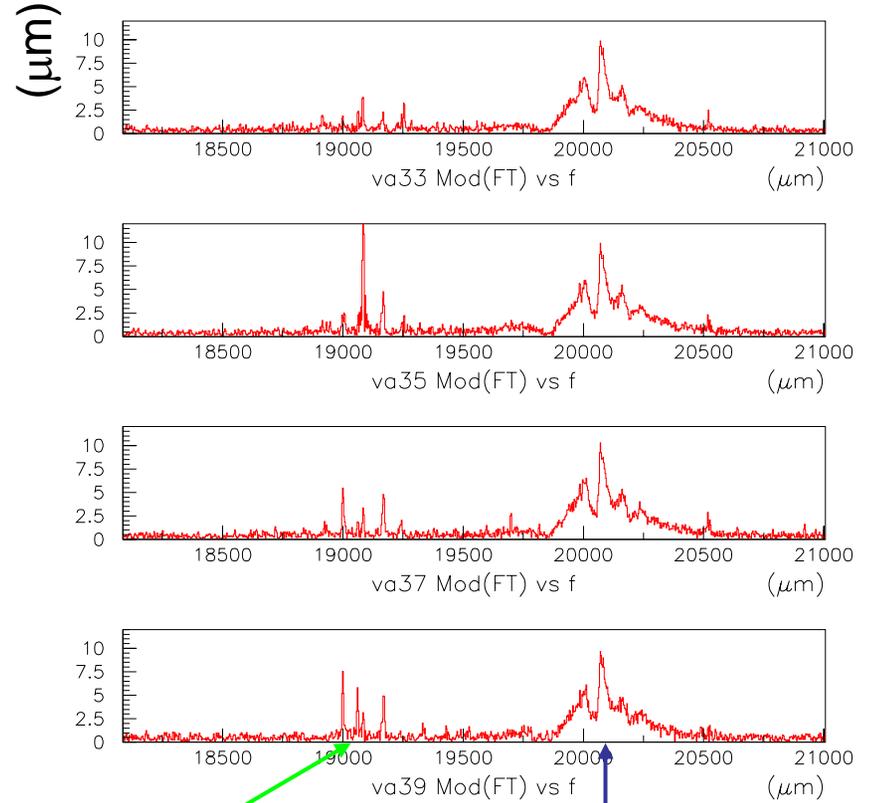
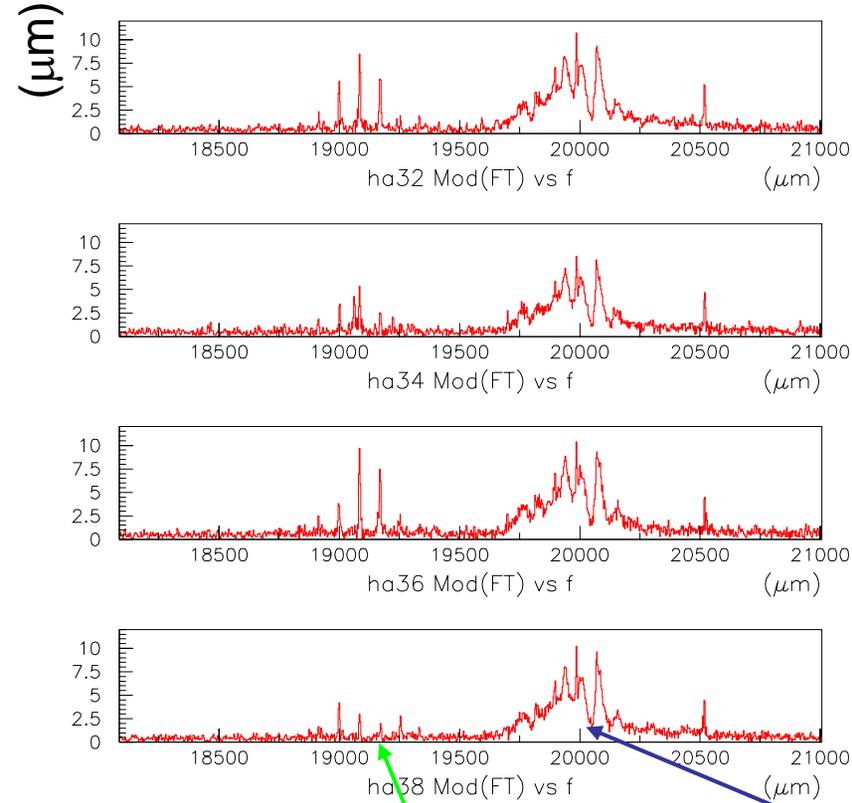
Detail of Mod(FT) for V BPMs in A3, Feb 6/05, Coalesced



- Synchrotron line present in H but not V.
- 150 GeV expected sync frequency: 80 Hz.

Detail of Mod(FT) for H BPMs in A3, Feb 6/05, Coalesced

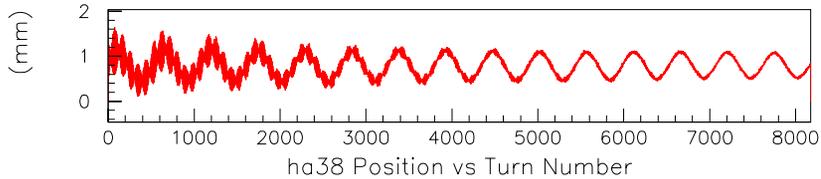
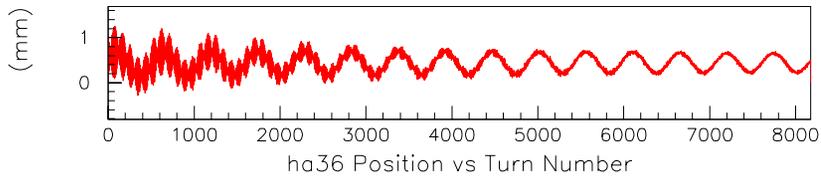
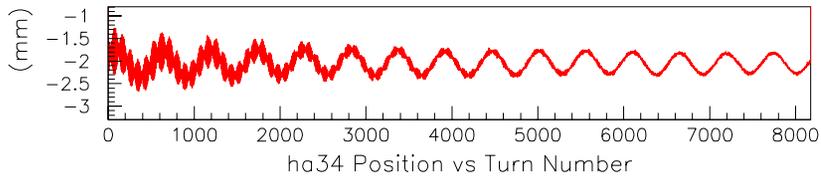
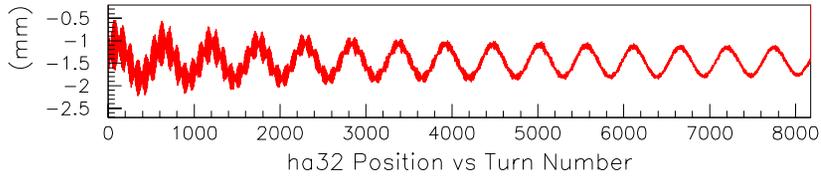
Detail of Mod(FT) for V BPMs in A3, Feb 6/05, Coalesced



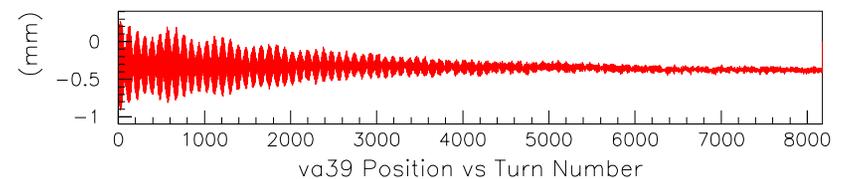
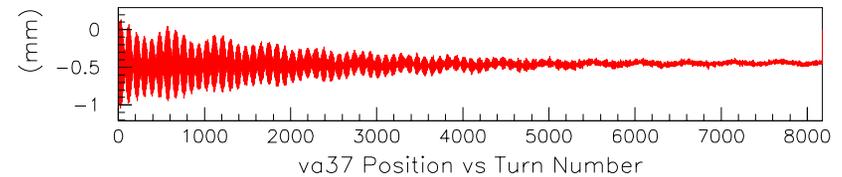
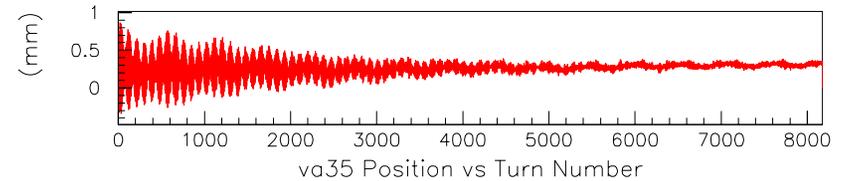
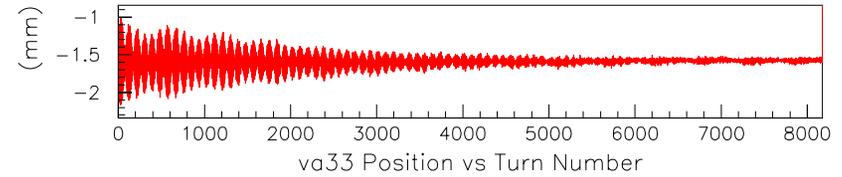
1113 / 5 Artifacts

Betatron Lines

Position for H BPMs in A3, Feb 7/05, Uncoalesced

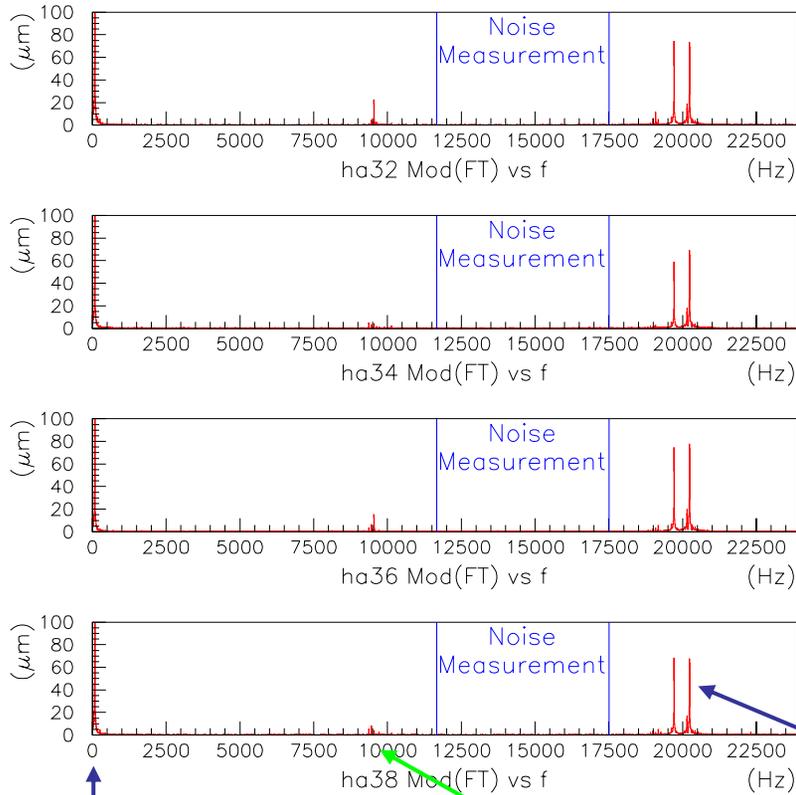


Position for V BPMs in A3, Feb 7/05, Uncoalesced

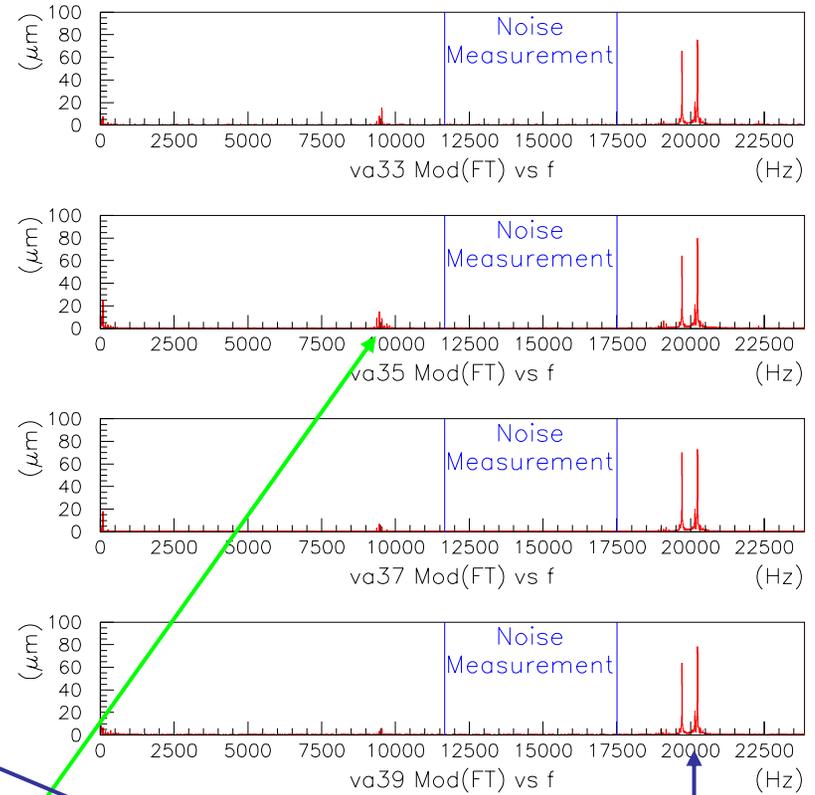


- Injection TBT; 150 GeV; 8192 turns.
- Uncoalesced beam. Tuneup shot with large injection mismatches.

Detail of Mod(FT) for H BPMs in A3, Feb 7/05, Uncoalesced



Detail of Mod(FT) for V BPMs in A3, Feb 7/05, Uncoalesced



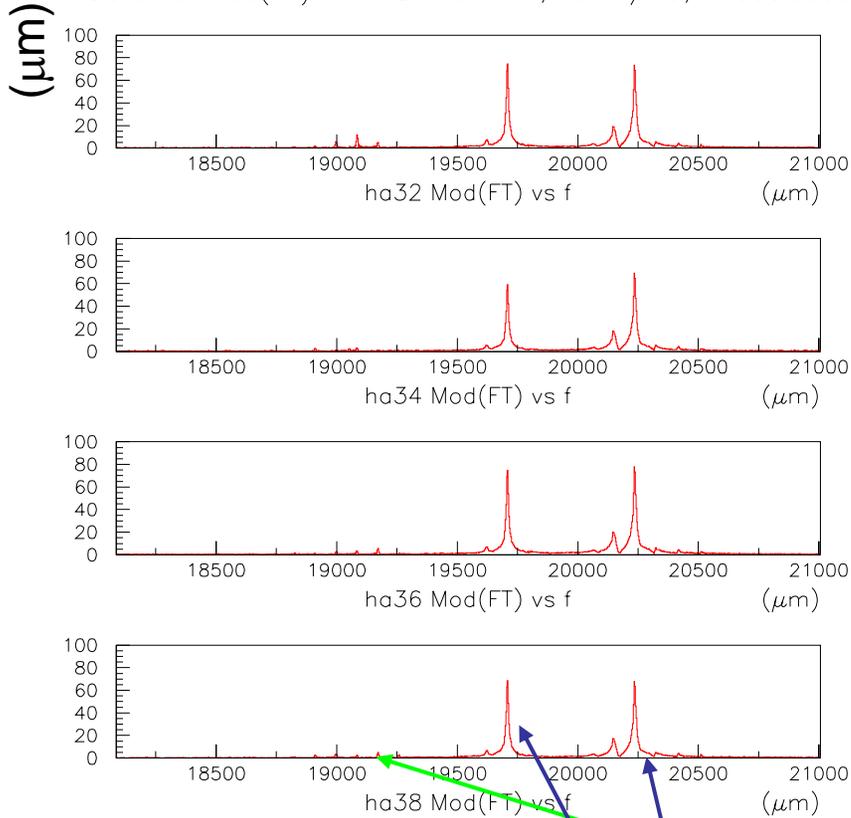
1113 / 5 Artifacts

Bin Size: ~3 Hz

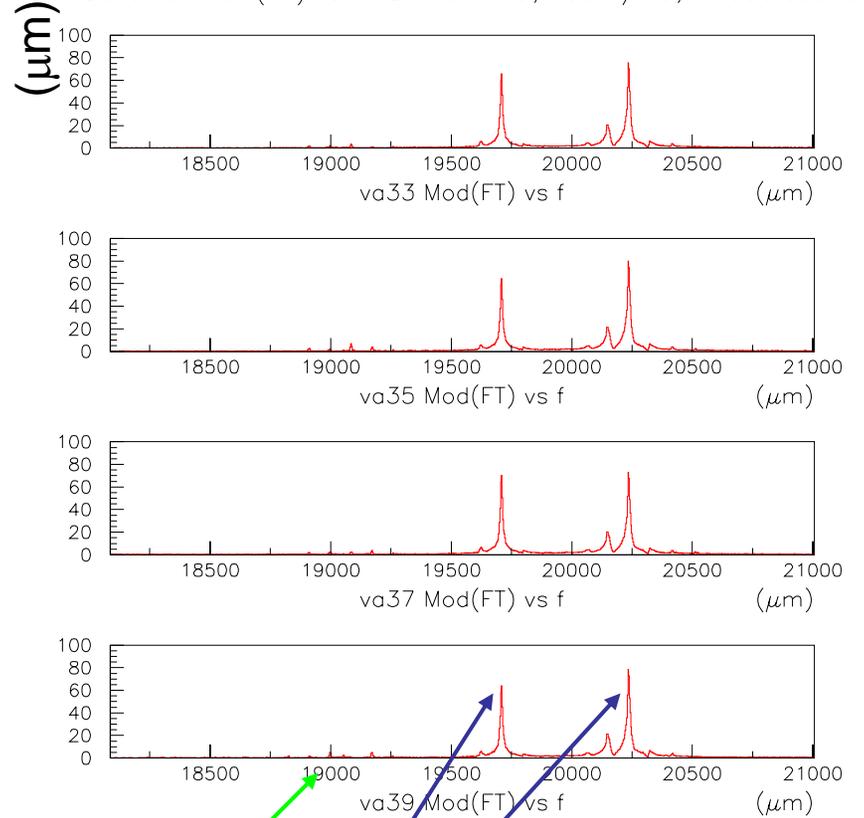
Synchrotron Line

Betatron Lines

Detail of Mod(FT) for H BPMs in A3, Feb 7/05, Uncoalesced



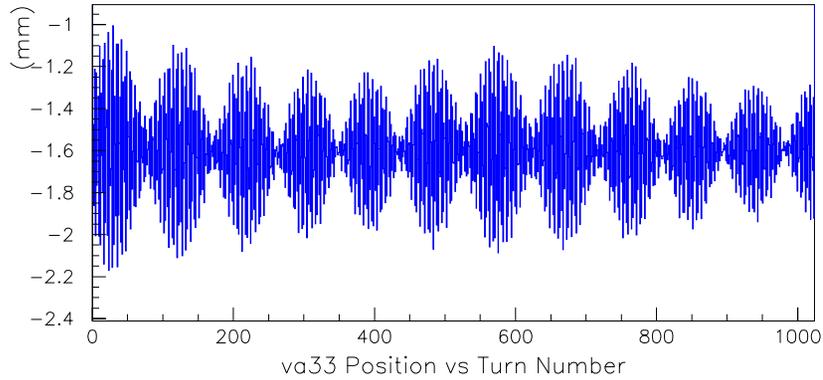
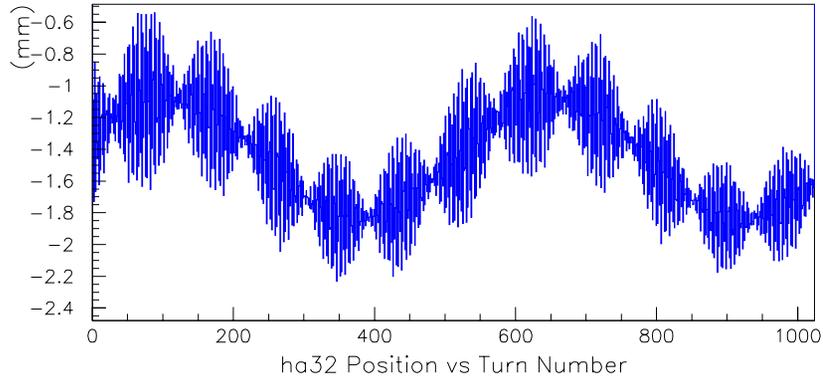
Detail of Mod(FT) for V BPMs in A3, Feb 7/05, Uncoalesced



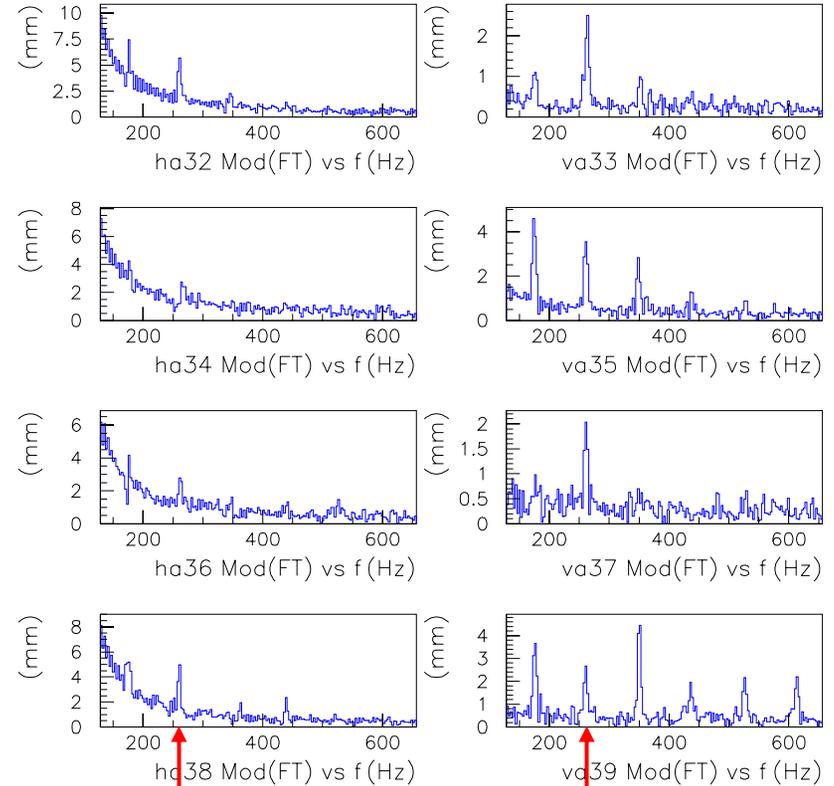
1113 / 5 Artifacts

Betatron Lines

Position for HA32 and VA33, Feb 7/05, Uncoalesced



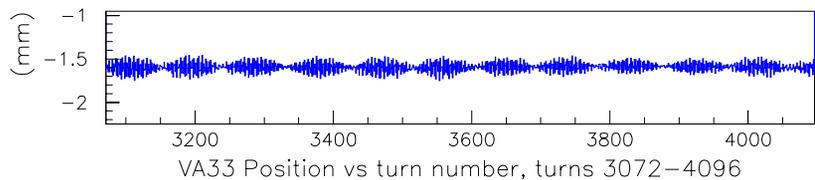
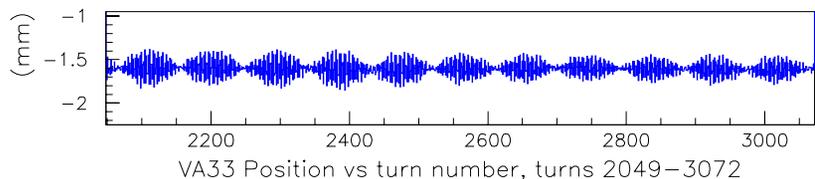
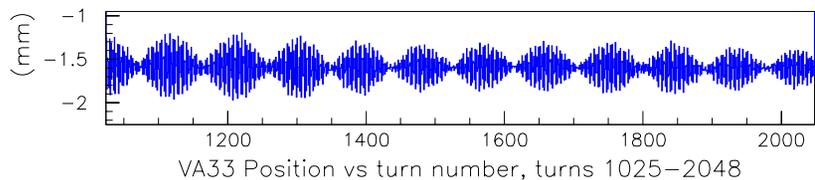
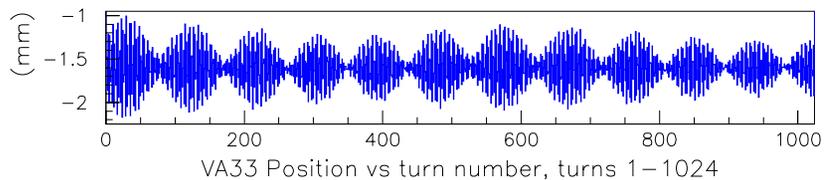
Fourier Transforms of Position Data, Feb 7/05, Uncoalesced



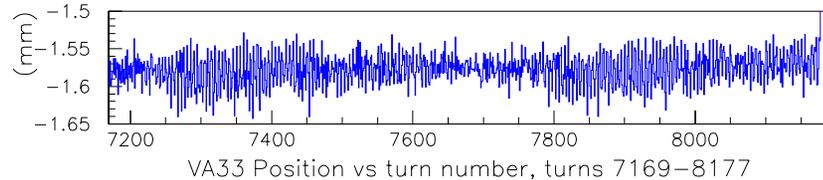
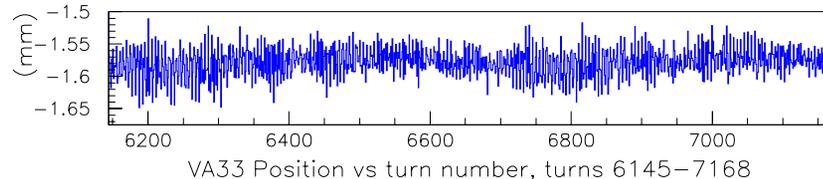
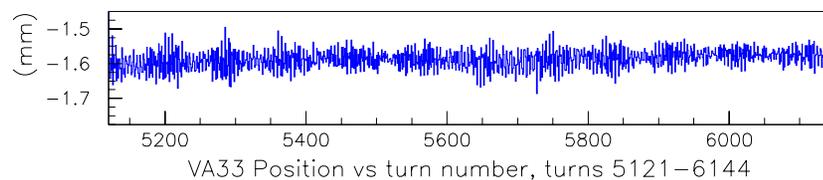
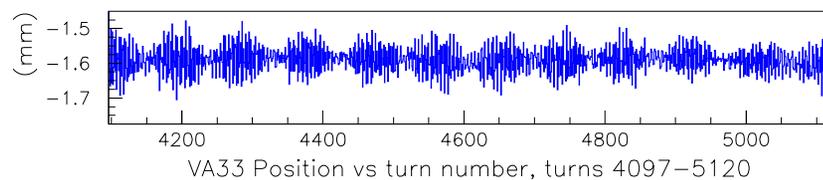
- HV coupling is clear.
- Frequency of envelope is about 260 Hz.

HV Coupling Frequency

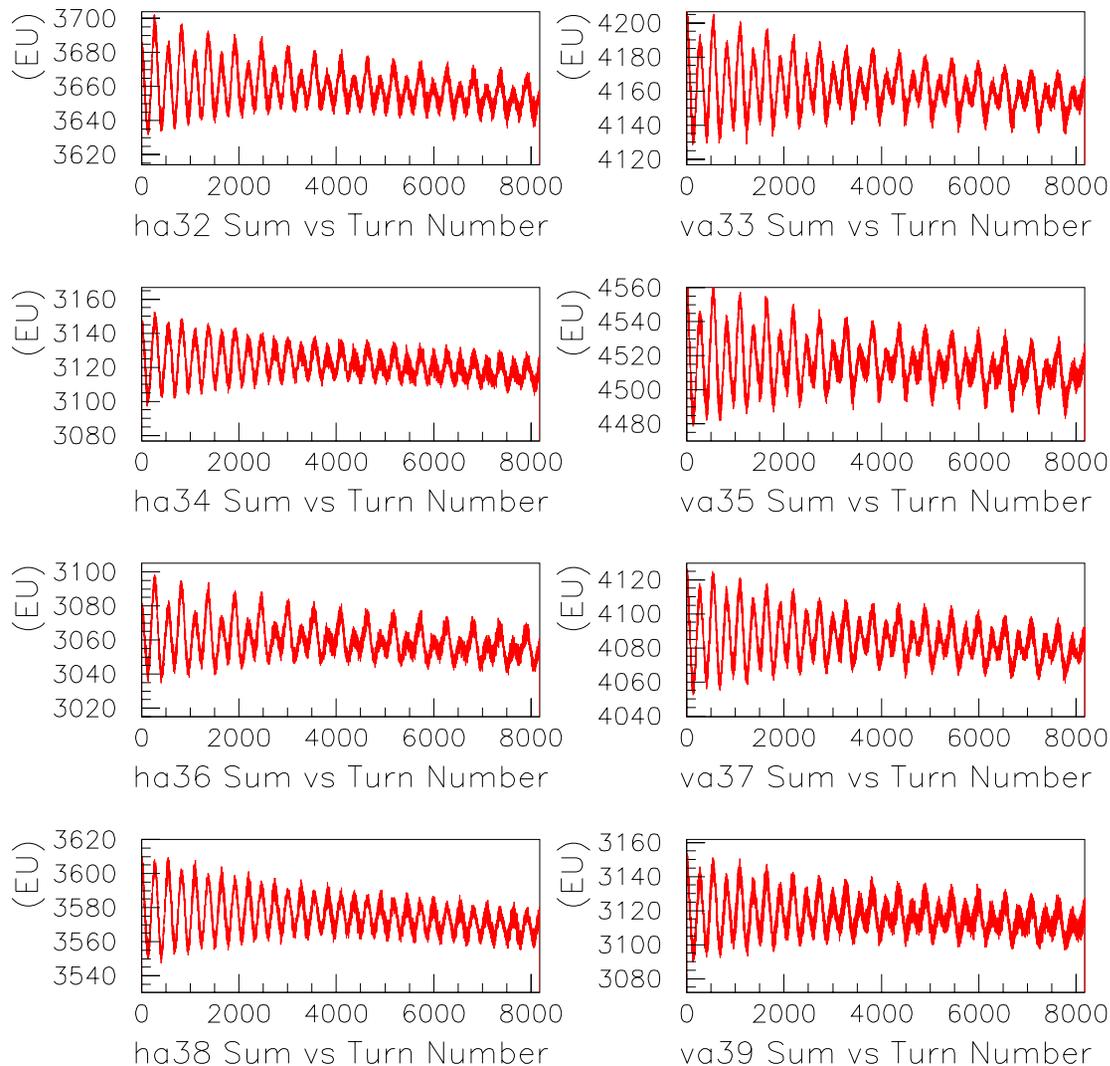
Position for VA33, Feb 7/05, Uncoalesced



Position for VA33, Feb 7/05, Uncoalesced

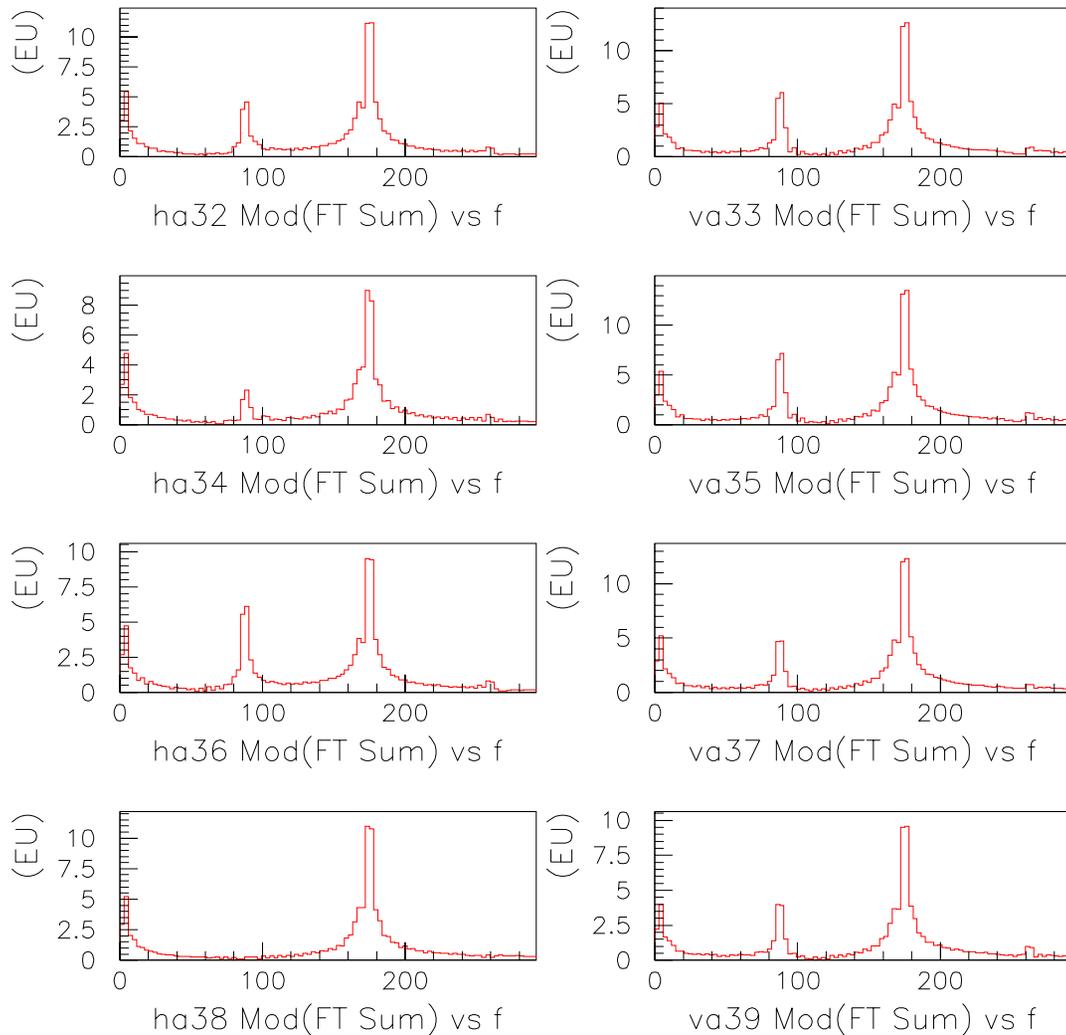


## Sum Signals for BPMs in A3, Feb 7/05, Uncoalesced



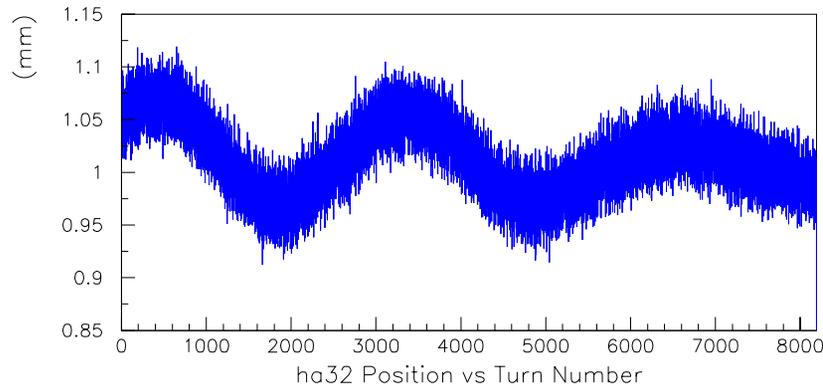
- Injection TBT.
- Sum signal (A+B)
- Same data as for positions.
  - Uncoalesced.
  - 150 GeV.
- Dominant frequency is different than in position data!

Detail of FT of Sum Signals for BPMs in A3, Feb 7/05, Uncoalesced

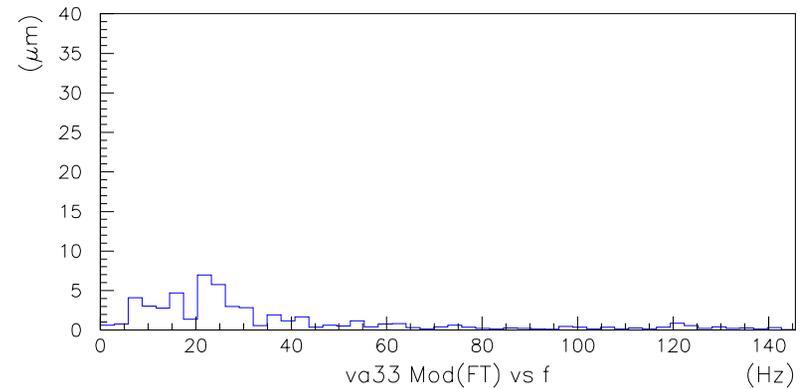
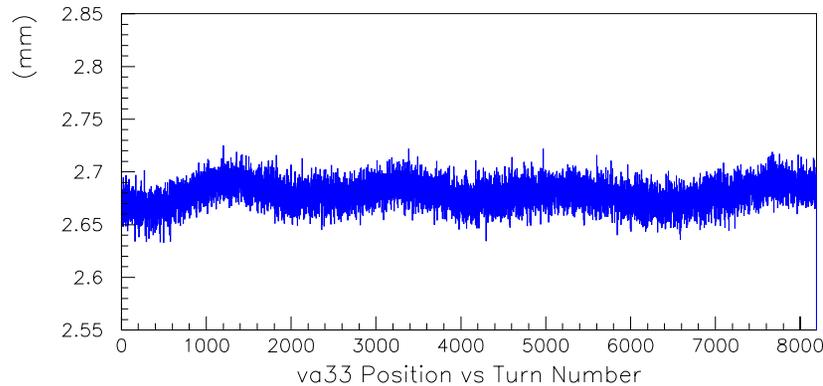
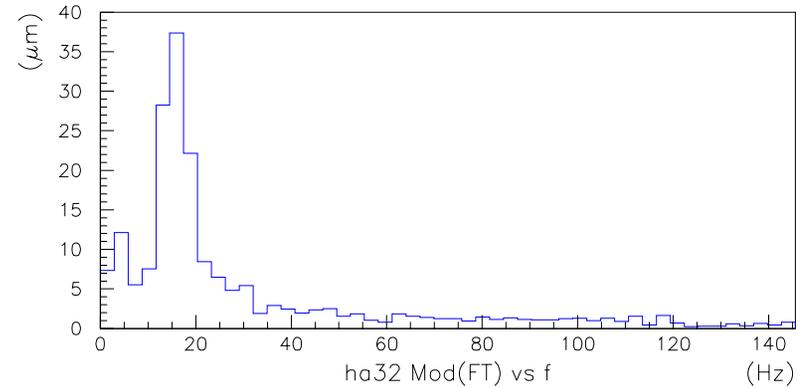


- Detail of Fourier transform.
- 150 GeV
  - $f_{\text{sync}} \sim 80$  Hz.
- Main structure at  $\sim 160$  Hz is quadrupole oscillation of bunches in their buckets.

A3 TBT data from Middle of HEP Store

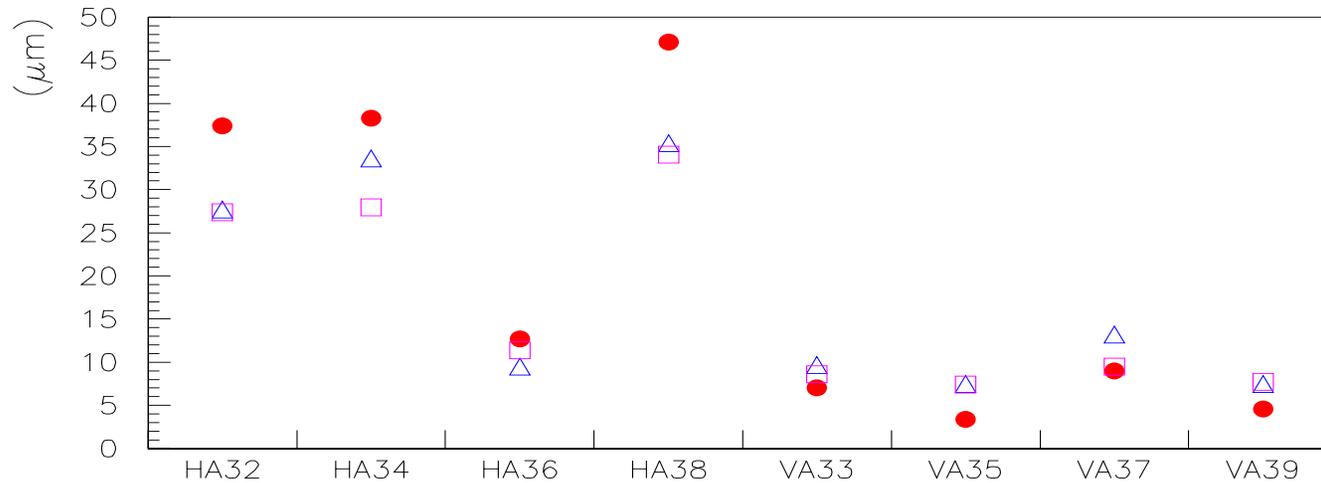


A3 TBT data from Middle of HEP Store



- TBT middle of HEP 36x36 store.
- 980 GeV;  $f_{\text{sync}} \sim 37$  Hz.
- Similar features on other BPMs.
- Closed orbit resolution correlates with size of 15 Hz oscillations.

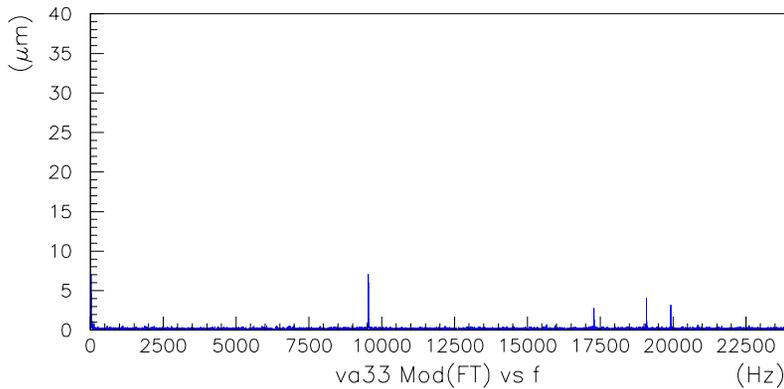
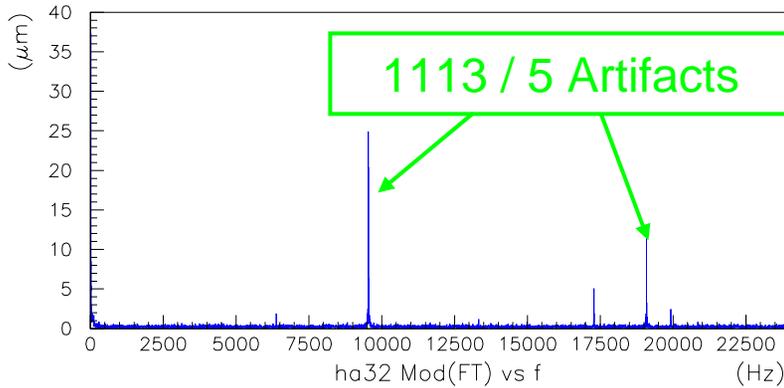
## TBT Amplitude and CO Resolution



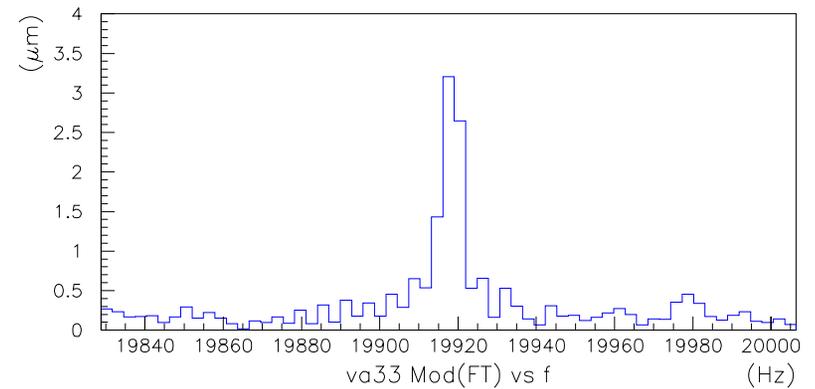
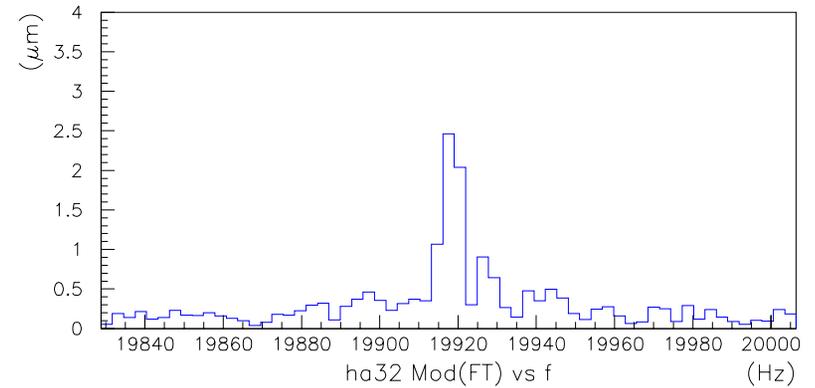
- Amplitude of TBT Motion
- △ RMS of Closed orbit Measurements
- Simple Model,  $\sqrt{0.5 \text{ TBT}^2 + 7^2}$

- Can observed TBT motion explain the variation in RMS of closed orbit measurements?
- In broad strokes yes. Still working on a quantitative model.

A3 TBT data from Middle of HEP Store



A3 TBT data from Middle of HEP Store



- Not sure why line at 19918 Hz is at the same frequency in both horizontal and vertical?

# Conclusions

- TBT and Injection TBT are working.
- We can cleanly see:
  - Synchrotron lines
  - Betatron lines
  - Quadrupole oscillations
  - HV Coupling
  - 15 Hz noise.
- Can make quantitative measurements of these in 8192 turns.
- 1113/5 artifacts are present in safe places.

# Backup Slides

# Further Details on TBT

- Documents earlier than 1565 discuss debugging the instrument.
- [Beams-doc-1565](#)
  - HEP Shot. One coalesced bunch.
  - Synchrotron, betatron motion.
- [Beams-doc-1566](#)
  - Tune up shot. Uncoalesced.
  - Synchrotron, betatron motion
  - Quadrupole oscillation of bunch in bucket.
  - Resolution.
- [Beams-doc-1571](#)
  - HV Coupling
- [Beams-doc-1577](#)
  - 15 Hz noise.
- Watch DocDb for latest developments.

# Fourier Transform

- $\tilde{F}(f)$ , defined by:

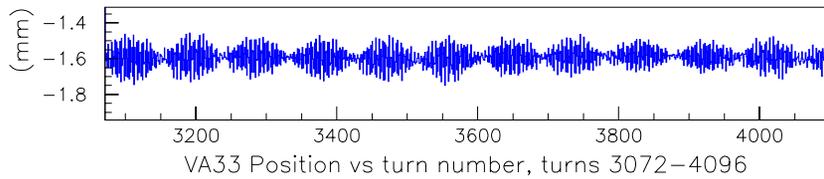
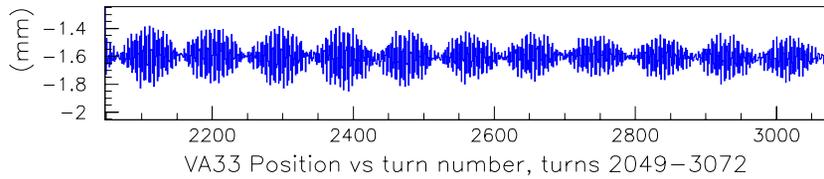
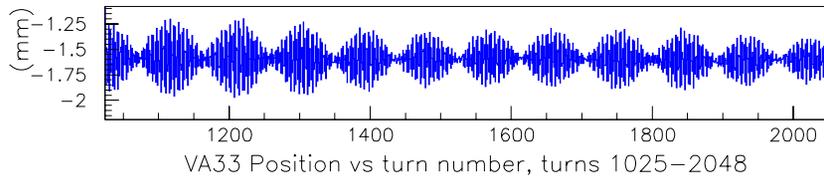
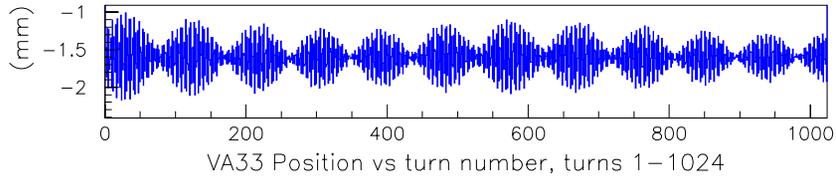
$$\tilde{F}(f) = C(f) \sum_{n=0}^{N-1} (P_n - \bar{P}) \exp(i2\pi f t_n)$$

- N is number of data points.
- $P_n, t_n$  are position and time on turn n.
- C(f) is a normalization factor.
- $\bar{P}$  is mean position of all data.
  - Subtracted to remove alias at 0 Hz.

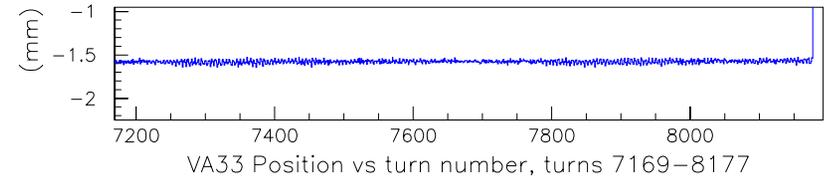
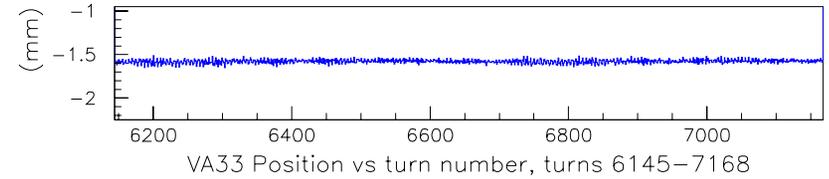
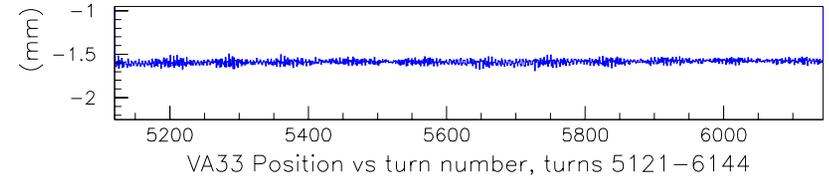
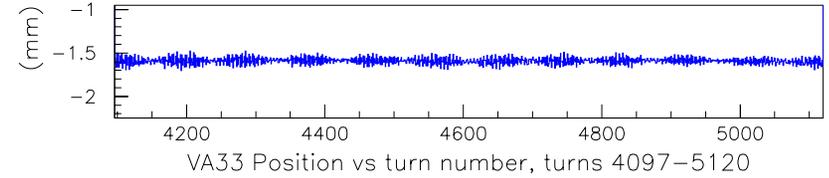
# 1113 / 5 Artifacts

- Digitizer is clocked at  $7/5 f_{RF}$ .
- After 7 cycles of this clock, and 5 cycles of RF, the  $7/5$  RF clock is back in sync with the RF.
- After one full turn of 1113 RF cycles, the  $7/5$  clock has not gone through a full cycle of 7 states.
- When first bunch of second turn arrives, the  $7/5$  clock has a different phase than it did when the first bunch of the first turn arrived.
- After 5 turns, the two clocks are back in sync.
- [Beams-doc-1066](#)

Position for VA33, Feb 7/05, Uncoalesced



Position for VA33, Feb 7/05, Uncoalesced



- All 8 plots on same scale.