



# mwave Schottky Pick-ups for LHC

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# Outline

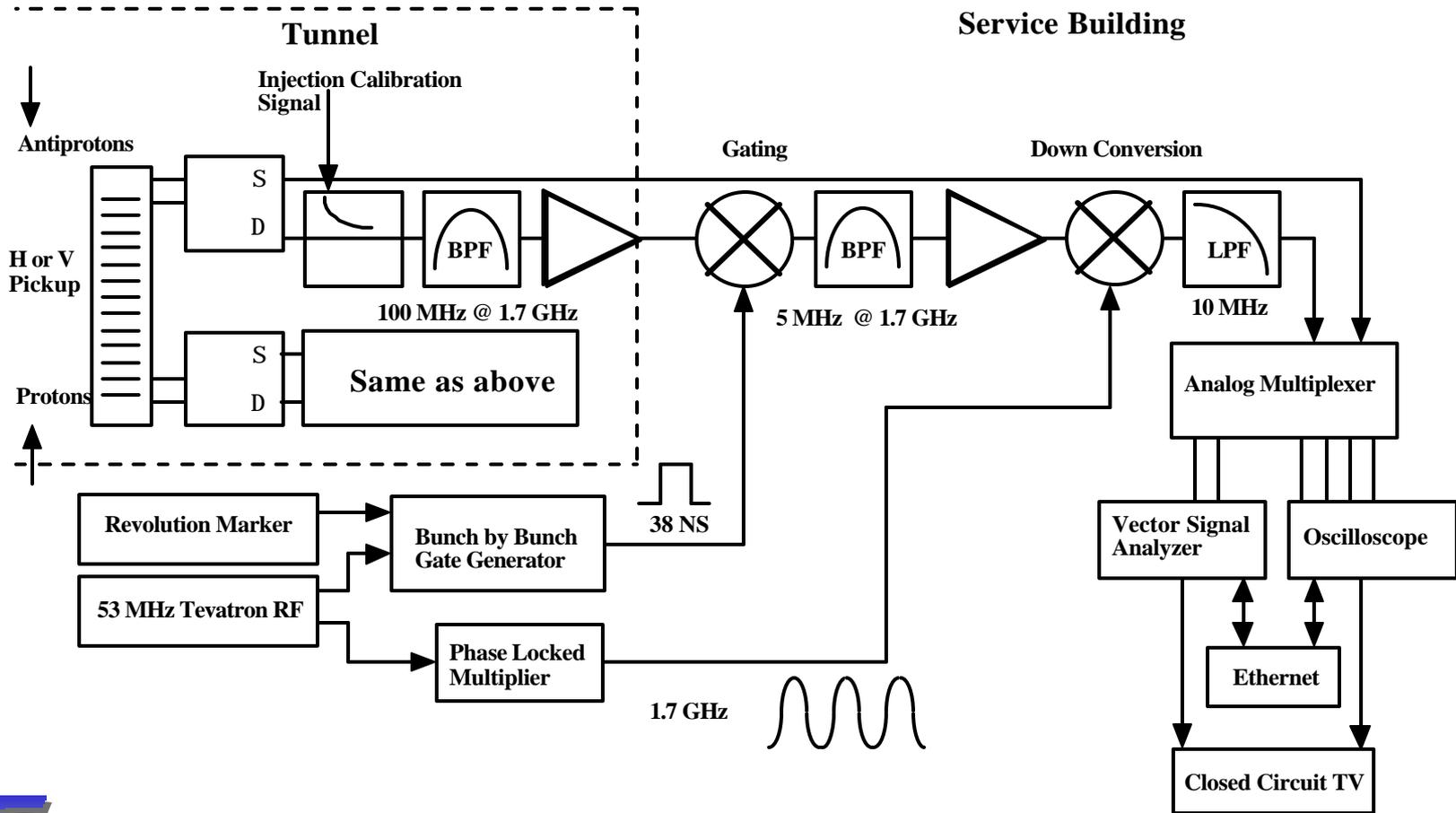
- Recent Tev Schottky results
  - Tune "tracking"
  - Chromaticity measurement
  - Momentum spread measurement
  - Emittance measurement
  - Effects of coupling
- LHC related studies
  - Single bunch resolution for low-intensity pbars
- Conclusions and outlook
- Sales pitch for LHC Schottky





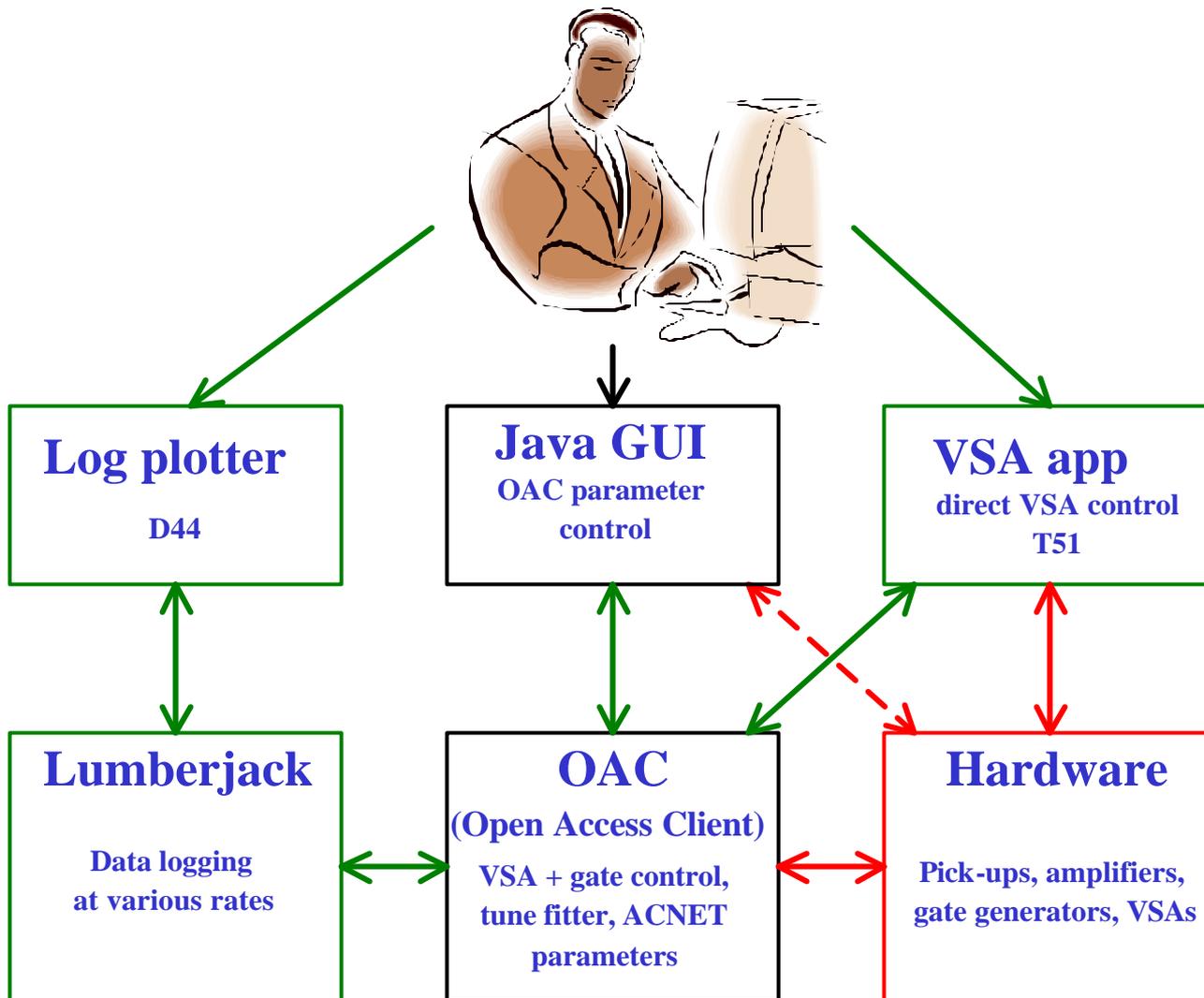
# Hardware overview

## Tevatron Schottky Signal Processing





# Software overview





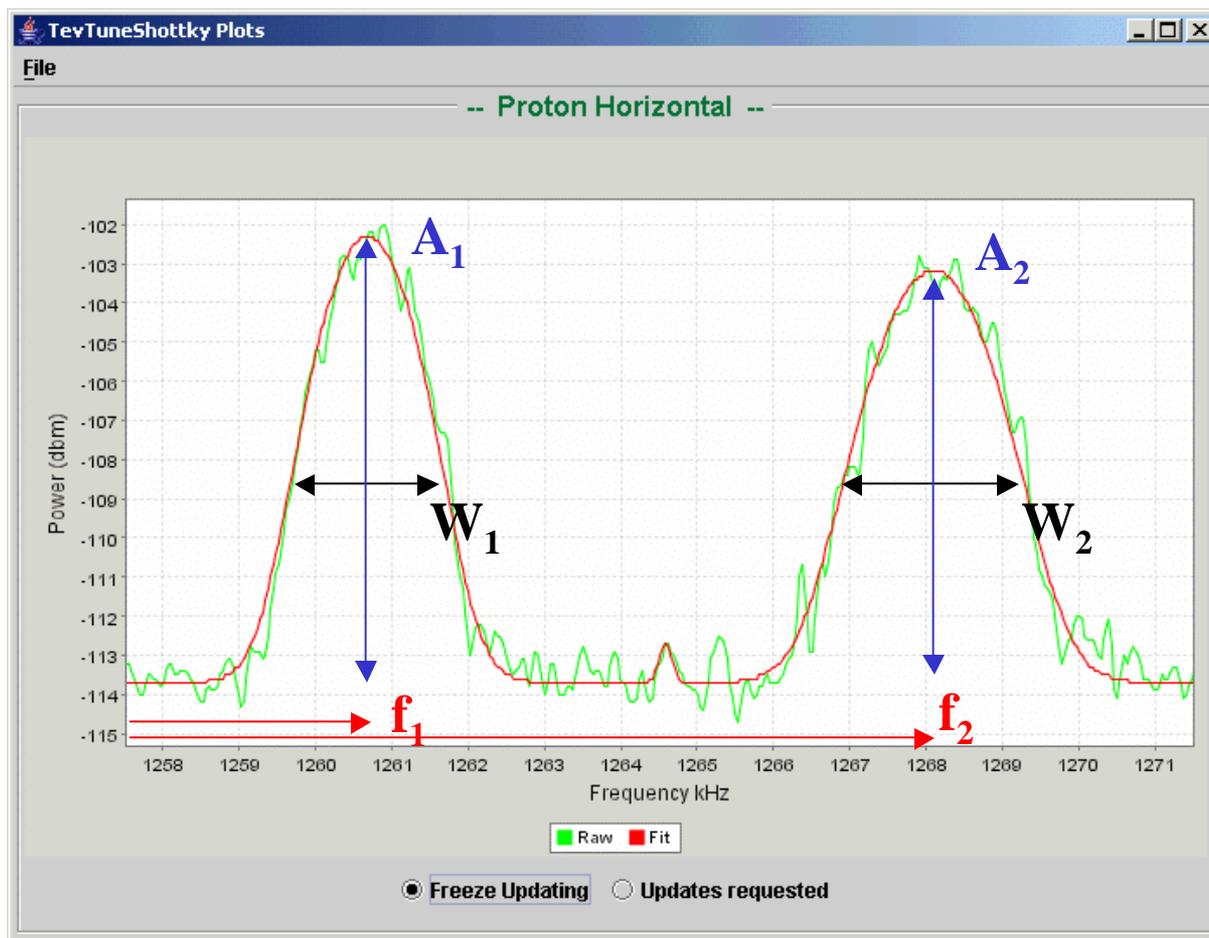
# Schottky spectra

$$q = \frac{1}{2} + \frac{(f_2 - f_1)}{2f_{\text{rev}}}$$

$$\frac{dp}{p} \propto W_1 + W_2$$

$$C \propto \frac{W_1 - W_2}{W_1 + W_2}$$

$$e \propto A_1 W_1 + A_2 W_2$$





# System hardware improvements

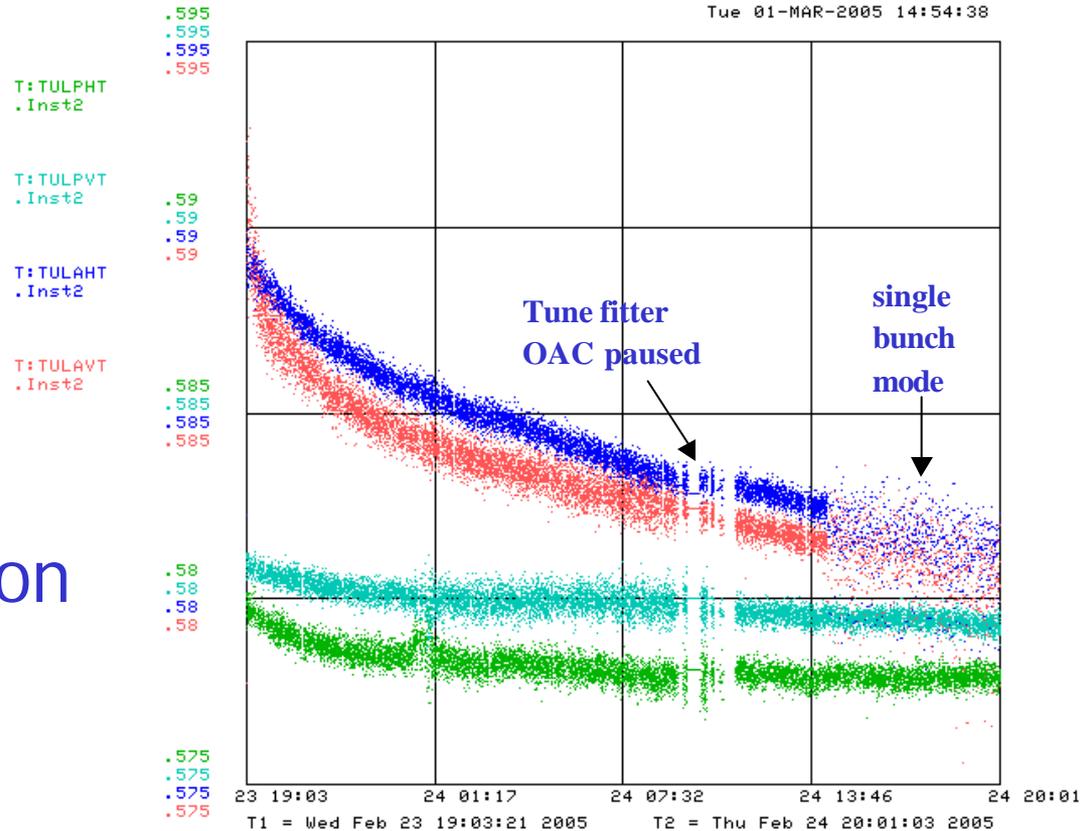
- Installed high-level FE amplifiers on all channels
- Bypassed noisy signal multiplexer
- Swapped out bad proton horizontal amplifier
- Installed test high-level mixer in proton vertical channel





# Tune during a store

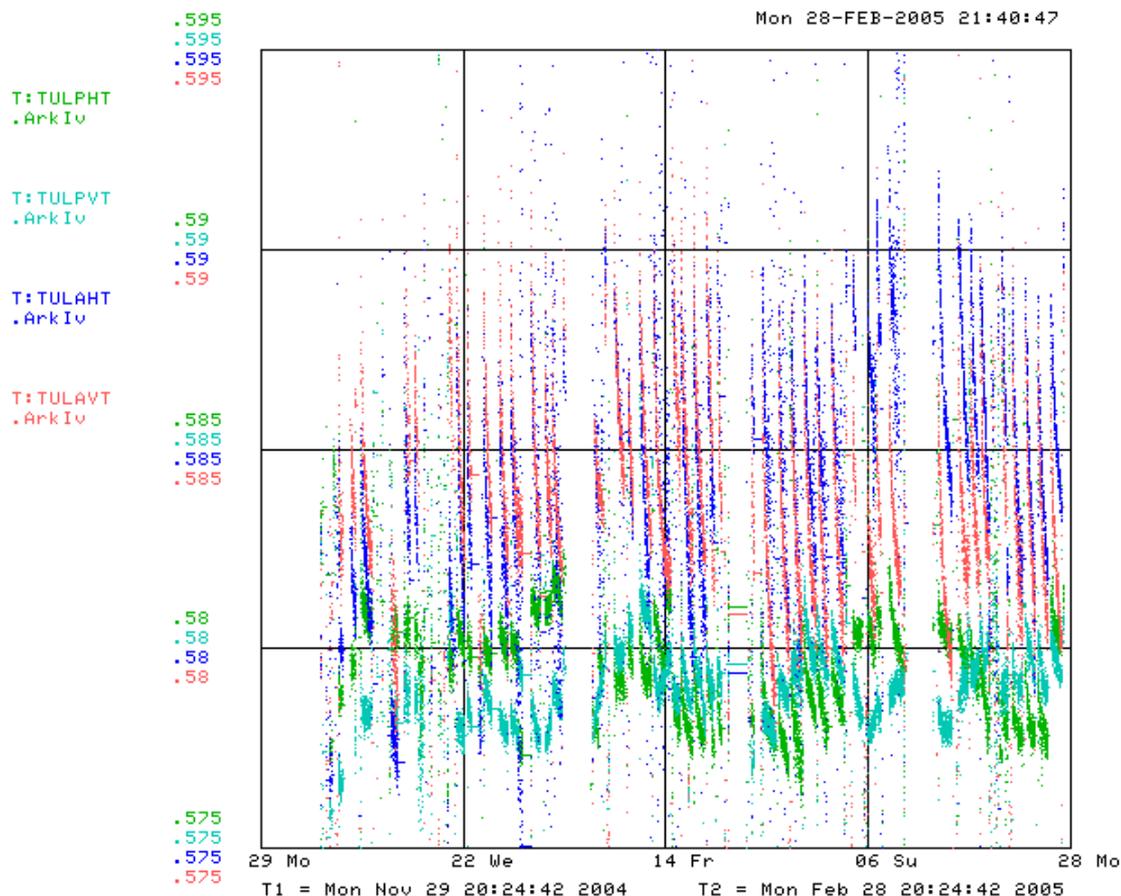
- Clearly see beam-beam effect (on both protons and pbars).
- Plan to implement slow feedback for pbar tunes based on these signals!





# Tev tune history

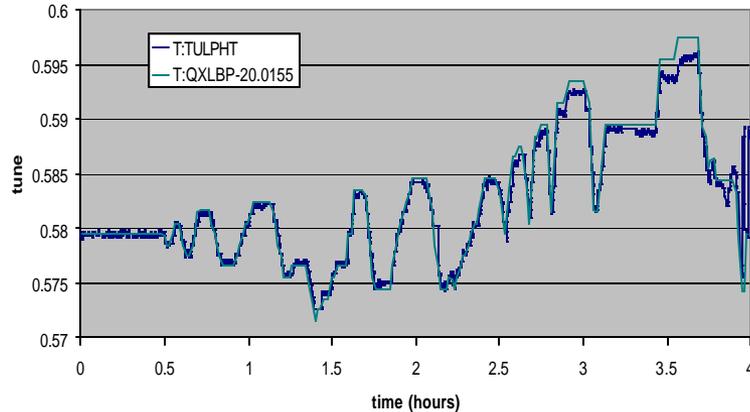
- Average tunes are logged continuously every store.
- Can use to correlate with efficiencies, lifetimes etc





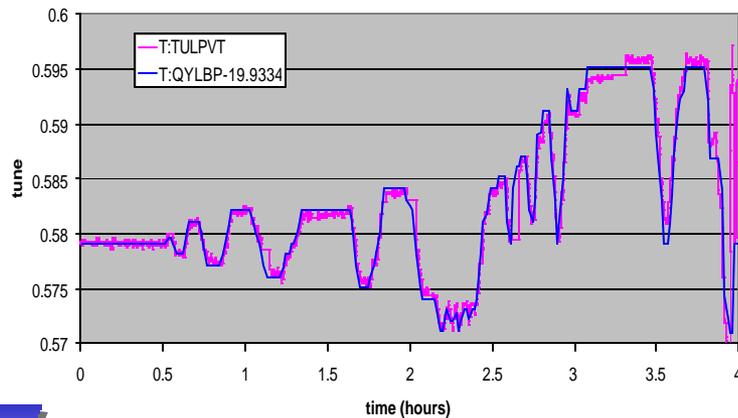
# Tune "tracking"

Horizontal proton tune

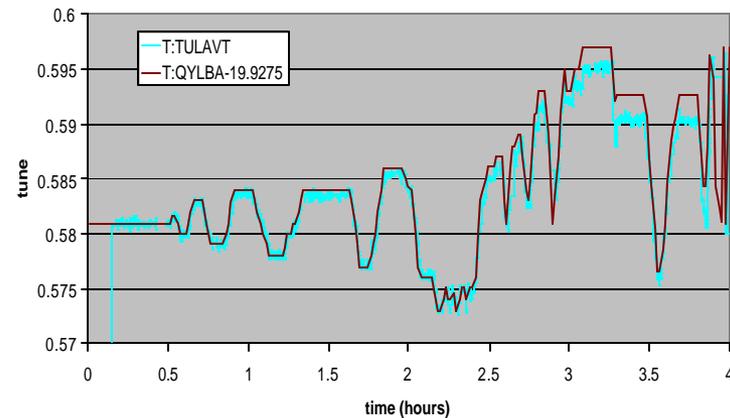


- Measured tune tracks changes in set tunes very well.

Vertical proton tune



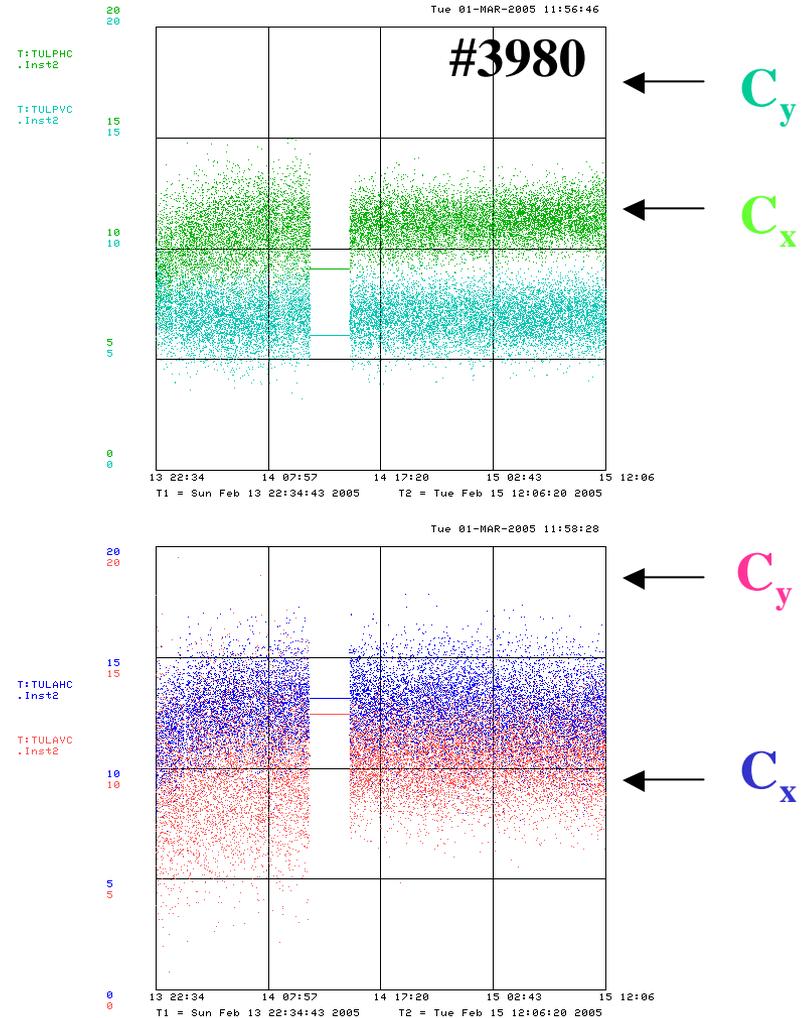
Vertical pbar tune





# Chromaticity

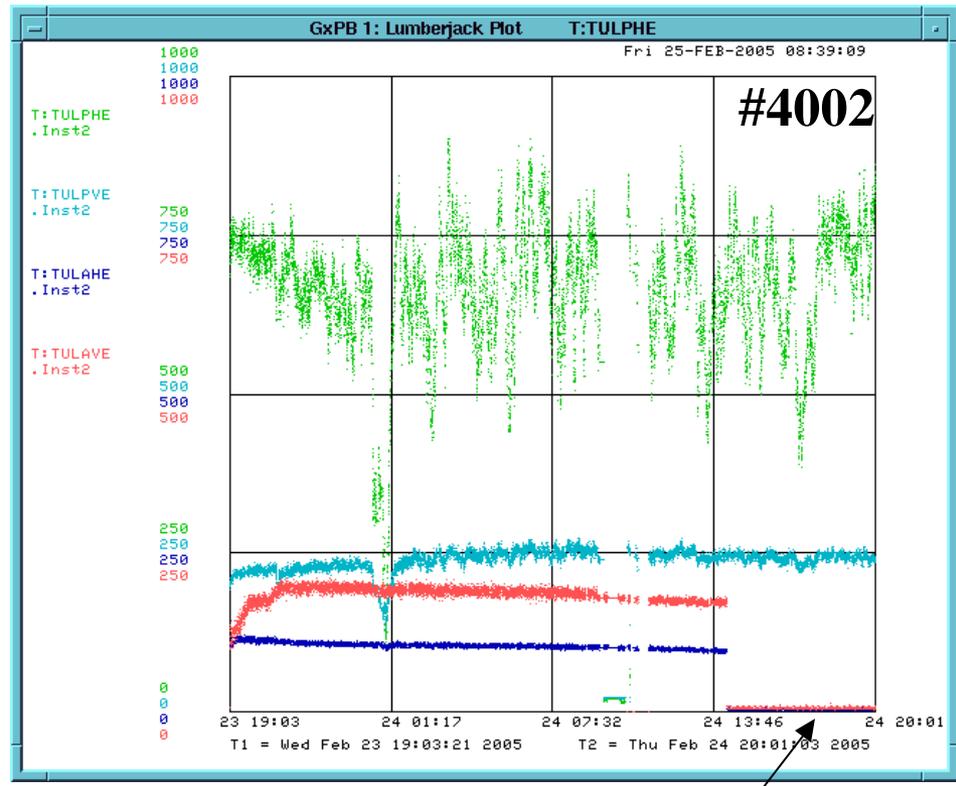
- Hard to make parasitic comparative measurements ? systematic study not done.
- Chromaticities measured at 980GeV during a store compared to traditional measurement (on next ramp).
- Appear to be missing factor  $\sim 2$  in vertical plane for both species.
- Not yet understood (could be real, could be a instrument problem).





# Emittance

- Horizontal proton emittance show large fluctuations...
- Still some issue with pbar emittance early in store...
- Tried high-level mixer. No improvement so far.



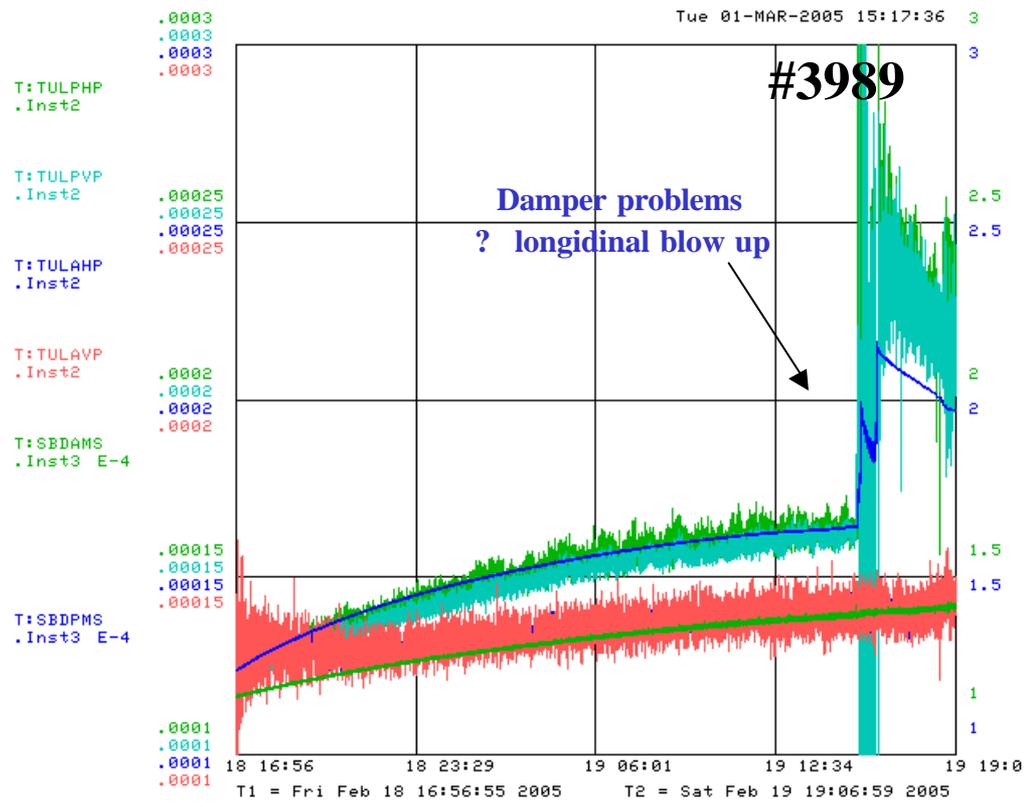
single bunch mode





# Momentum spread

- Measurement of momentum spread show good agreement
- Some issues early in store for pbars (S/N ?).



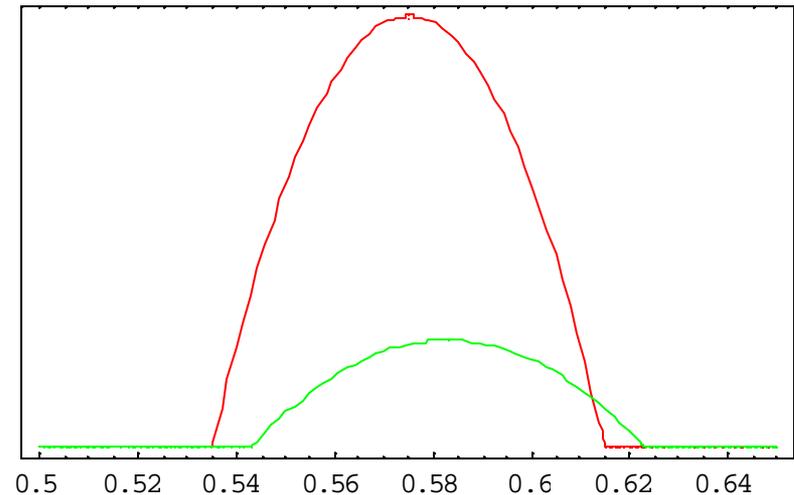
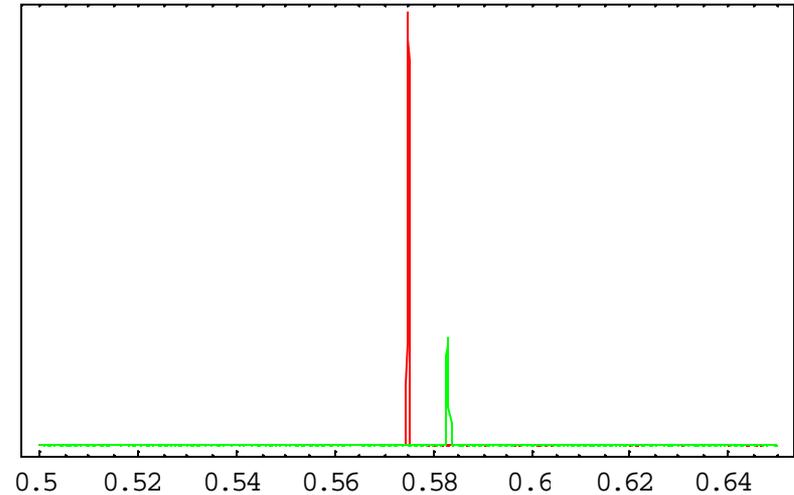
**NO fudge factors!!!**





# High frequency vs low frequency Schottky

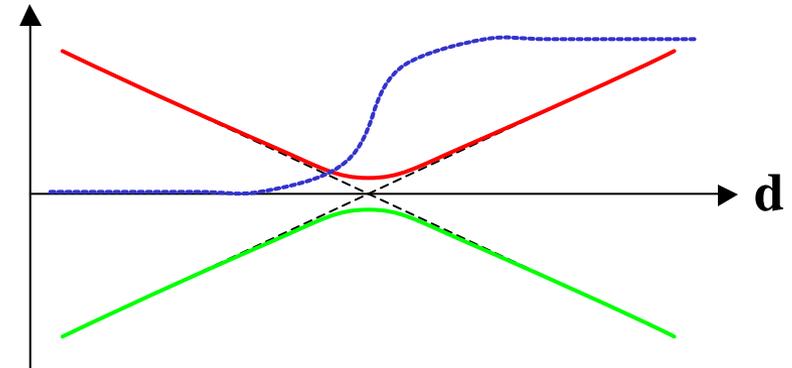
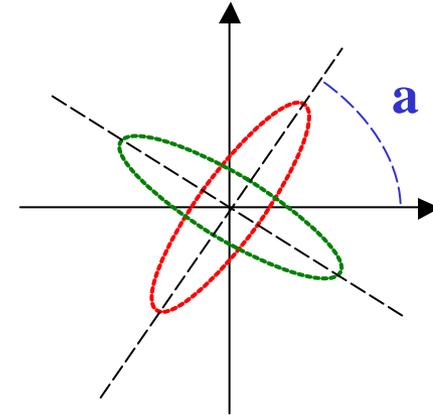
- In a low frequency Schottky spectra, can separate normal modes by frequency
- Microwave Schottky rely only on directional (hor/ver) sensitivity.





# Simple coupling theory

- Measured tune is a weighted average of the two modes.
- Weight is given by inclination angle  $a$ .
- Tends to bring measured tunes back together.
- Cancels coupling tune separation exactly in simple model.
- "We measure set tunes"

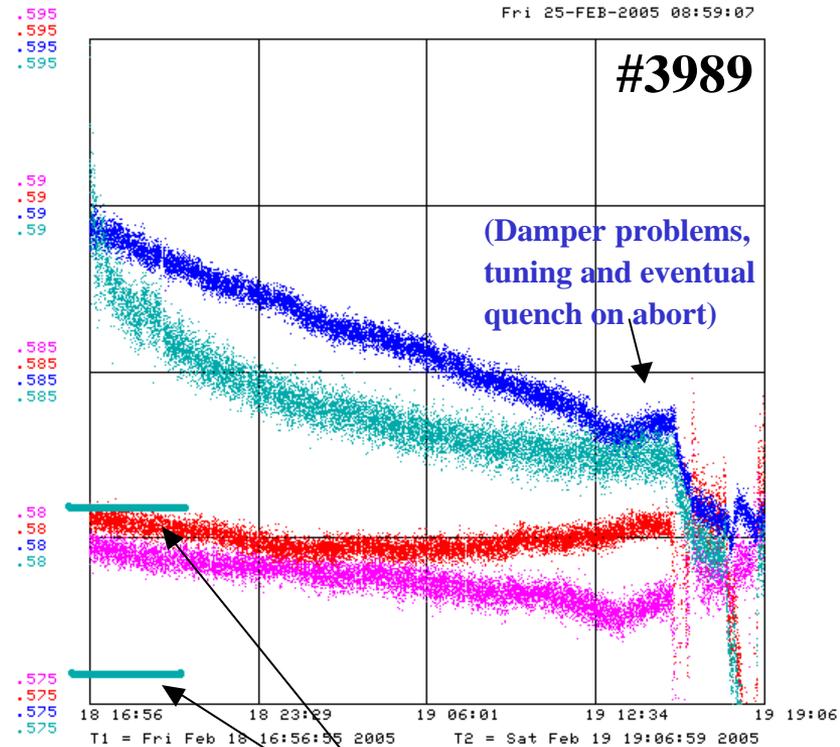




# Coupling observations

- Difference in measured tunes from 21MHz and 1.7 GHz Schottky show effect of coupling.
- More detailed analysis to follow, using e.g. measured coupled beta functions.

NB. Coupling affects emittance and chromaticity as well



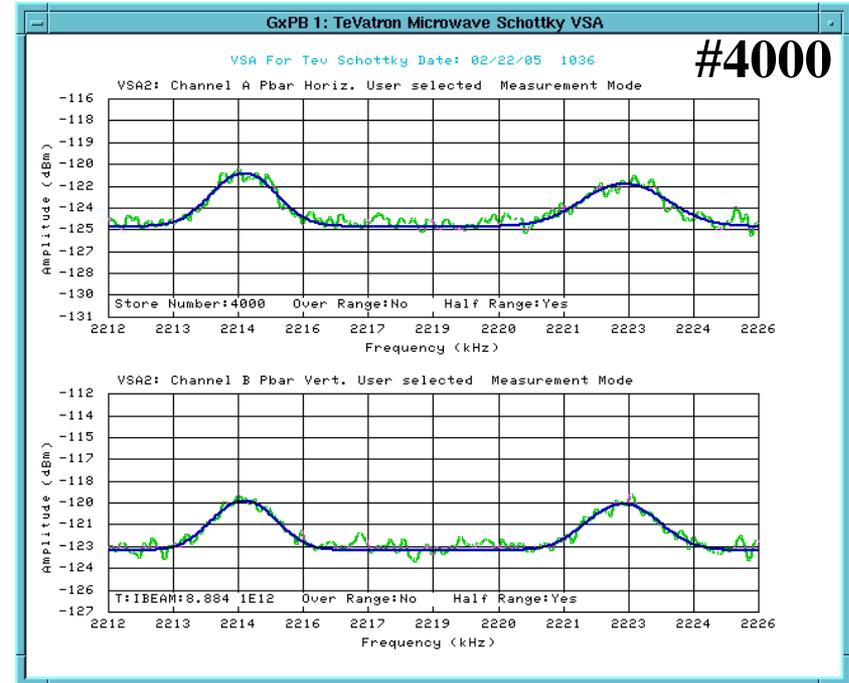
Initial tunes measured by 21 MHz Schottky





# Single pbar bunch measurements

- Found that OAC auto-ranging was not working in an optimal way.
- With manual tuning, got good signal from single pbar bunch at end of store.



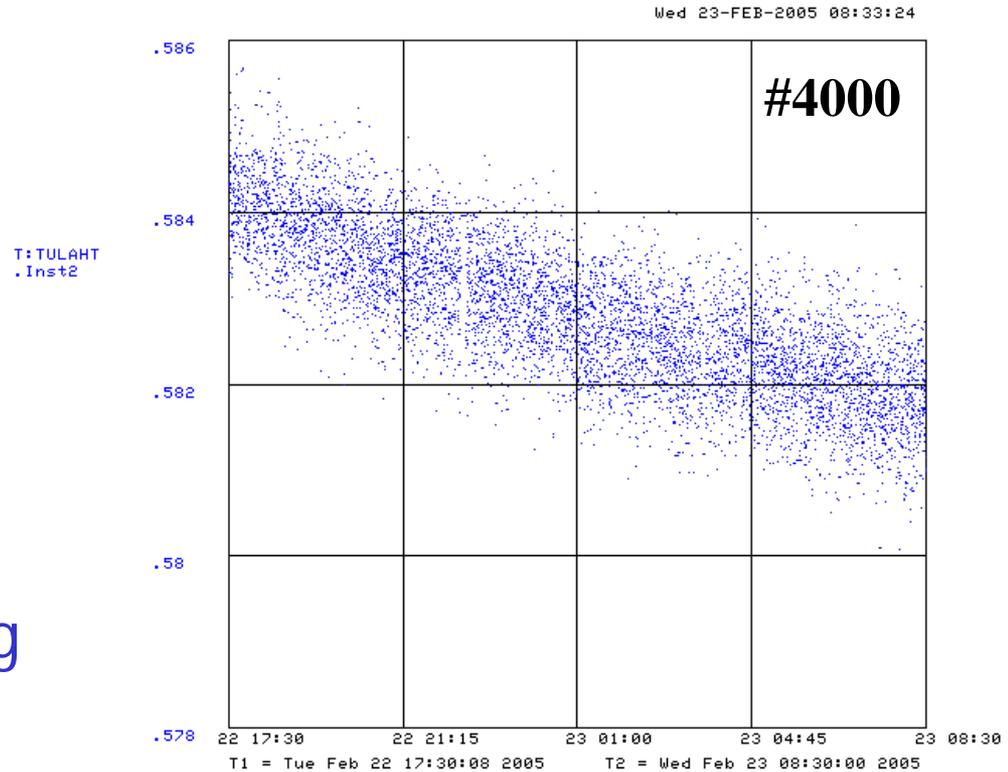
Pbar bunch #29  
Intensity:  $19 \cdot 10^9$   
Emittance:  $\sim 17$  p mm mrad





# Single pbar tune

- Ran tune fitter on single pbar bunch with manual input gain control.
- Observed tune sensitivity of  $5 \cdot 10^{-4}$ , and good momentum agreement.
- Implemented triggering of VSA internal auto-ranging every 20 mins.



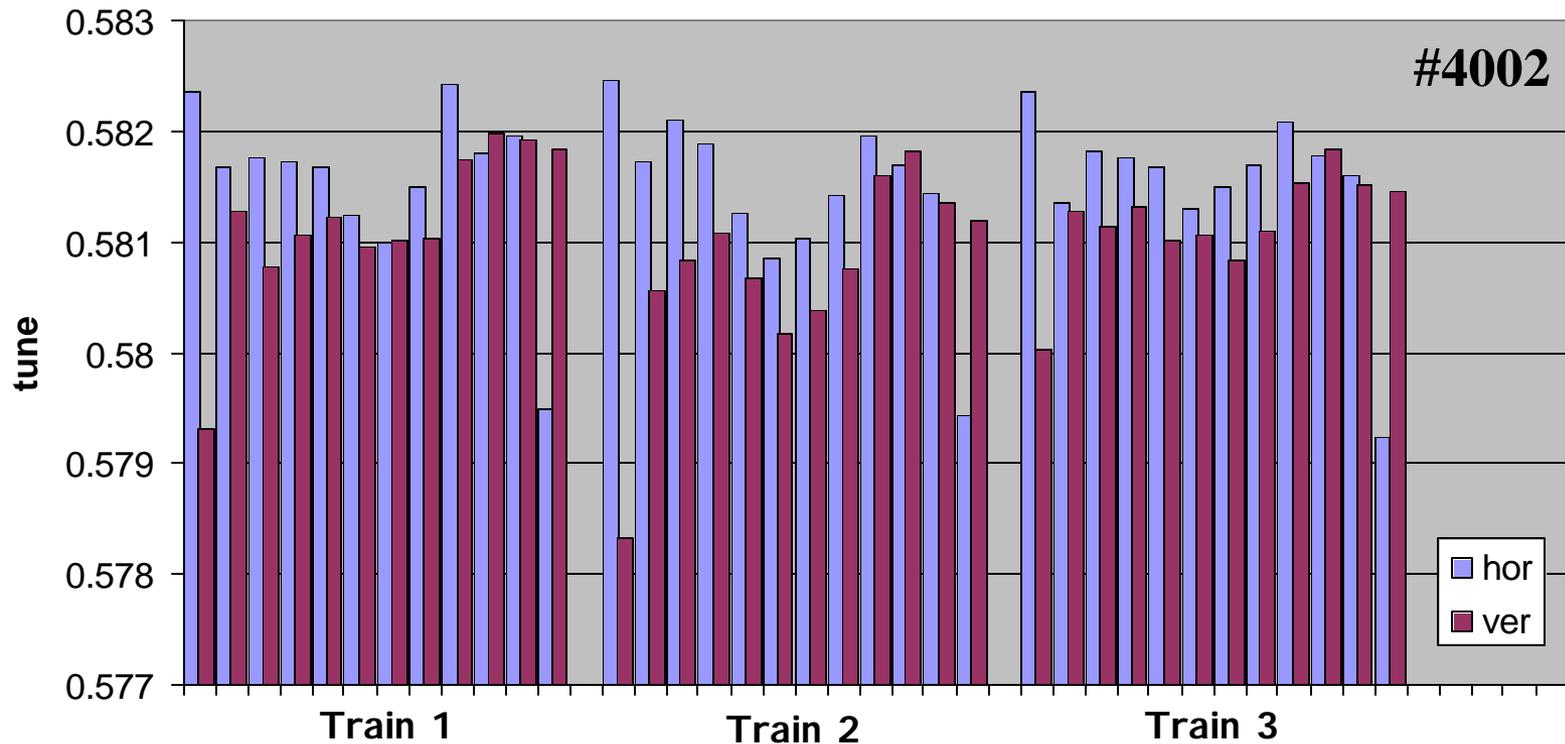
Bunch intensity:  $17 \cdot 10^9$   
Emittance:  $\sim 17$  p mm mrad





# Single bunch tunes

## bunch-by-bunch pbar tunes



Bunch intensities: 15-40  $10^9$  Emittances: 7-17 p mm mrad

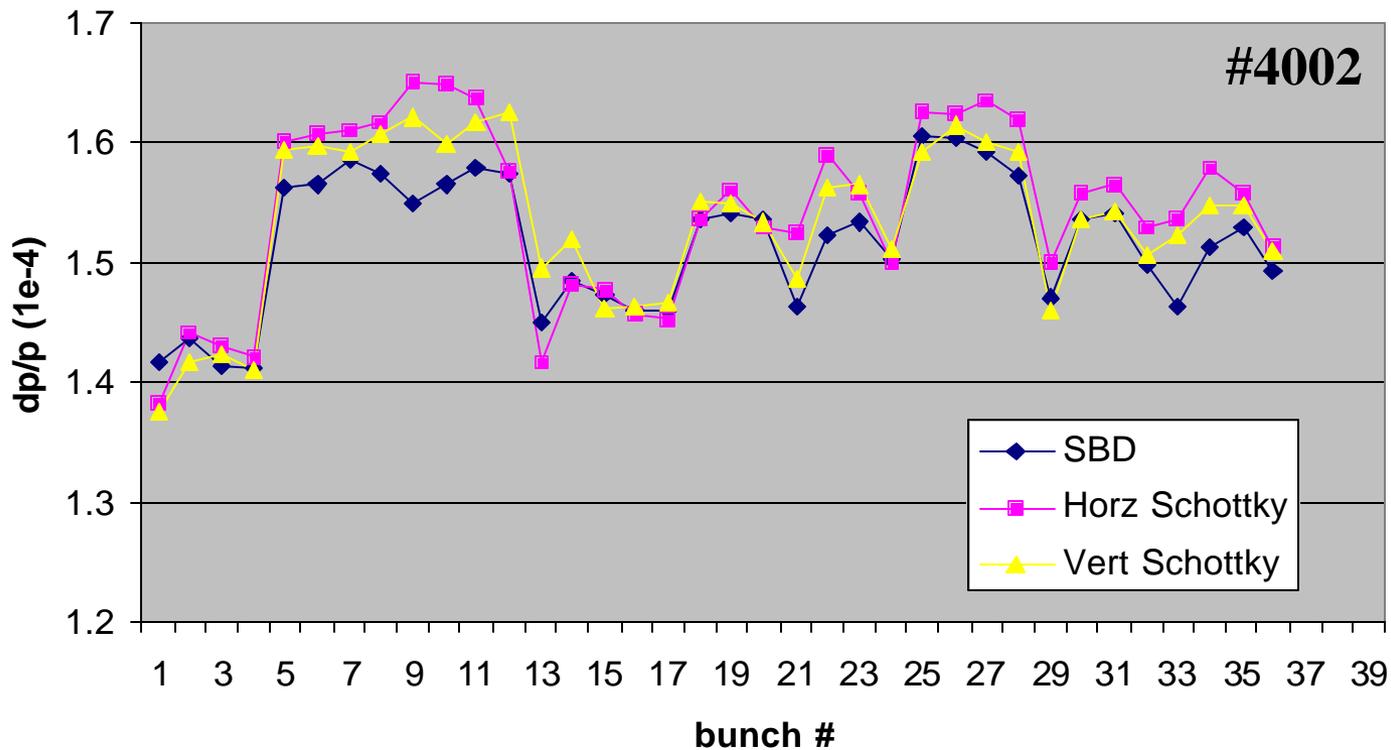
Note characteristic beam-beam signature on first and last bunches in each train!





# Single bunch momentum spreads

bunch-by-bunch momentum spread



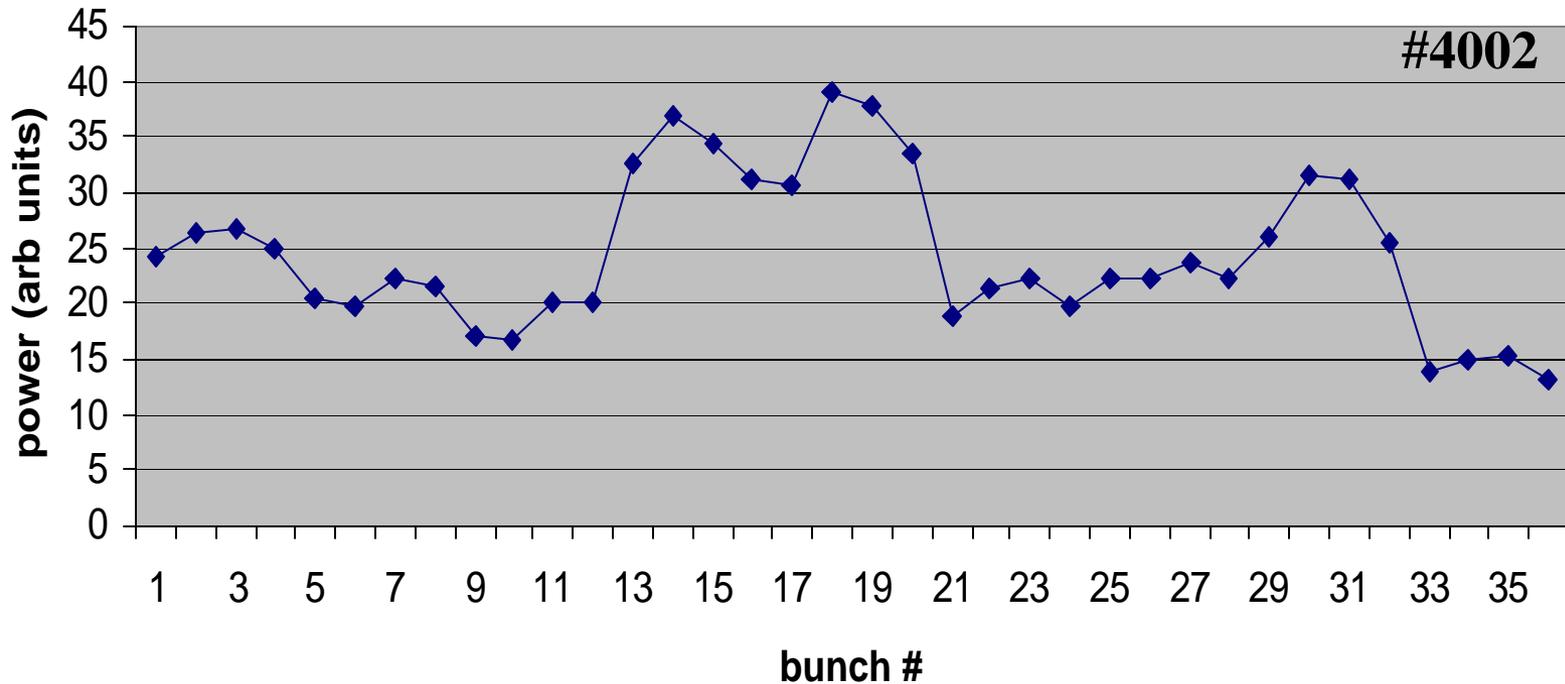
**NO fudge factors!!!**





# Single bunch emittance

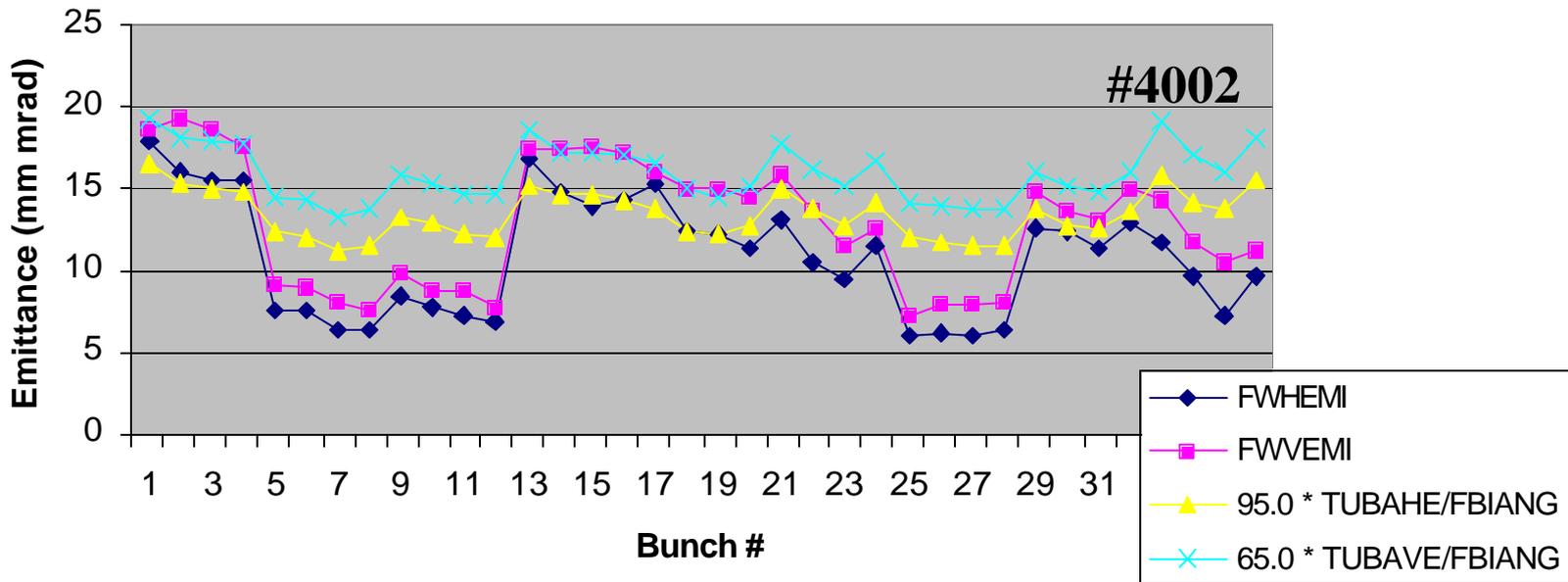
## bunch-by-bunch betatron band power





# Single bunch emittance

bunch-by-bunch emittance



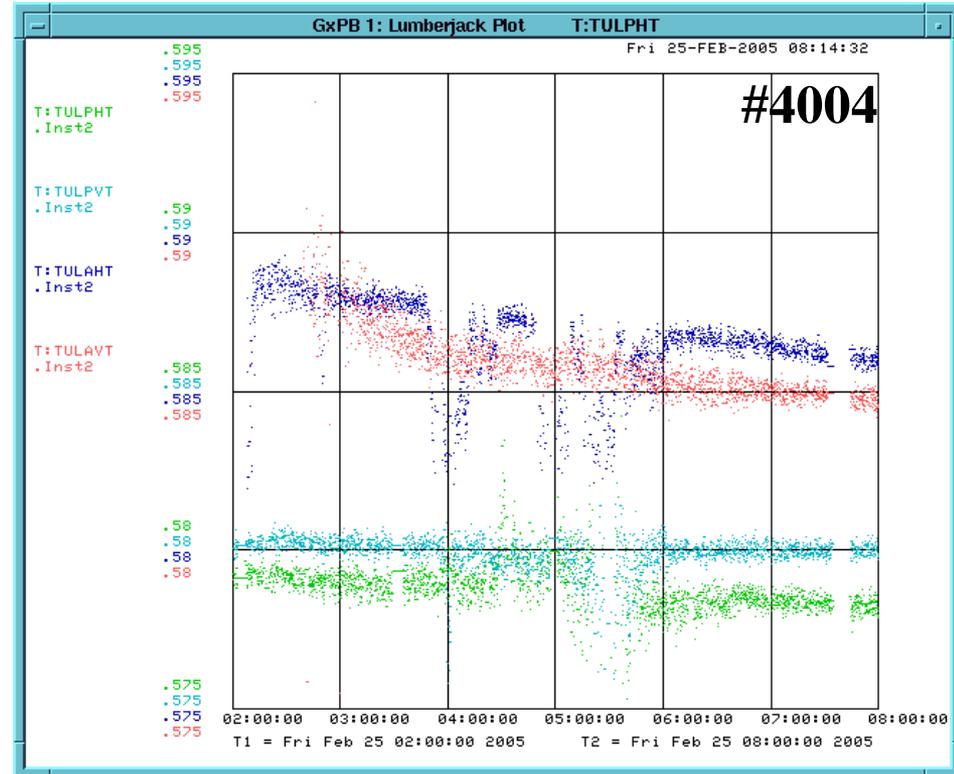
NB. Wire fly several hours before schottky measurement!  
Schottky emittance scale uncalibrated (arbitrary scaling).





# Implementing new auto-ranging

- Still some problems with auto-ranging.
- Found that one VSA channel was broken, will send for repair.
- Hopefully, 'proper' ranging will remove some of the strange effects (proton emittance, pbar noise floor...)





# Remaining issues

- Understand pbar noise floor early in store
- Understand cause for proton emittance fluctuations
- Understand ramp data...





# Conclusions

- Can measure tune of a single  $15 \cdot 10^9$  pbar bunch to  $5 \cdot 10^{-4}$ !!!
- Tune measurement is affected by coupling, in a "predictable" way.
- Very good momentum spread agreement.
- Qualitative emittance agreement for pbars, need to understand proton signals better.
- Chromaticity measurement need more work.
- Considering implementing slow tune feedback based on 1.7 GHz Schottky readings.





# LHC sales pitch

LHC Project Document No.

**LHC-B-ES-0009 rev 1.0**

## 5. EXPECTED TOLERANCES ON THE OBSERVABLES/PARAMETERS

The analysis of the expected tolerances of the beam dynamics to variations in the beam parameters is done to identify the requirements on accuracy for the instruments.

### 5.1 TUNE AND TUNE SPREAD

Tracking studies at injection (LHV v6.0, [15]) show that the LHC working point is located almost at the centre of a stability island with a width corresponding to  $\Delta Q = \pm 0.010$ . The tolerance on the tunes can be deduced from this observation, after subtracting tune spreads and modulations [12, section 2.3.2]:  $2 \cdot 10^{-3}$  for the amplitude detuning,  $2 \cdot 10^{-3}$  for the chromo-geometric detuning,  $2 \cdot 10^{-3}$  for the linear part of the chromatic tune modulation and  $1 \cdot 10^{-3}$  for the non-linear part. This leaves a tolerance  $\Delta Q = \pm 3 \cdot 10^{-3}$  for the adjustment of the central betatron tunes at injection.

In collision, the machine operates closer to the diagonal with a tune split of  $Q_y - Q_x = 0.01$ , which corresponds roughly to the tune spread induced by the beam-beam effects. A safe operation of the LHC in collision requests a control of the betatron tunes with an accuracy better than  $\Delta Q = 0.001$ , i.e. better than 10% of the tune separation.

Several mechanisms may induce a tune spread amongst the bunches:

- The electron cloud produces a tune shift which depends on the bunch position in a batch. A tune shift of the order 0.005-0.01 along a train has been observed at KEKB and in the SPS [16] and should be expected during the beam scrubbing.
- The Pacman effect induces a beam-beam linear tune shift which depends on the beam position. Its value is 0.001 for the nominal alternate crossing and might reach 0.003 if other crossing schemes remain possible [8].

## 12.6 BUNCH SELECTIVITY FOR THE MEASUREMENTS

In most cases, the beam average of the tunes, chromaticities,... are appropriate. This mode should be considered as the priority mode of operation for LHC in terms of availability and accuracy. The identification of the e-cloud effect would benefit from a bunch-by-bunch measurement of the tunes. When the machine performance reaches the nominal level, a bunch by bunch measurement of the tunes and possibly of chromaticity is likely to become necessary. The measurement of the amplitude detuning and of the beam-beam transfer function requires as well a bunch-by-bunch measurement. The bunch-by-bunch mode is thus demanded to be available from the beginning as a commissioning tool, whether or not the precision targets are initially reached

- Microwave TW Schottky provides passive bunch-by-bunch tune measurement (and more).
- CERN is requesting this!





# Final words of ancient wisdom

- The LHC will undoubtedly encounter numerous problems during commissioning and early running. Many are foreseen, some may well be surprises.
- Having proper instrumentation there from the start will certainly help diagnose these issues and reach higher luminosity, faster.





# LARP project criteria

- ☑ R&D – we are still trying to understand the signals in the Tevatron.
- ☑ Commissioning – would require people on location to commission devices.
- ☑ Luminosity – will help understand the machine, and hence increase luminosity.

