Coupling Measurement and Correction

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for the RHIC decoupling term, CA-D, BNL

1. Skew Quadrupole Modulation
   Coupling Measurement With Coupling Amplitude Mod.
   Coupling Correction With Coupling Angle Mod.
   PLL losing lock

2. Coupling Observables & Possible Decoupling Feedback

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Decoupling Methods

1. Our Goal: global decoupling ON THE RAMP

2. Decoupling modes
   Feedforth: first measurement, then correction
   Feedback: measurement and correction repeatitively

3. Global Decoupling Methods

   Skew quadrupole scan
   N-turn transfer map decoupling

Skew Quadrupole Modulation (1)

1. To fulfil decoupling on the ramp, a fast and robust decoupling method is needed.

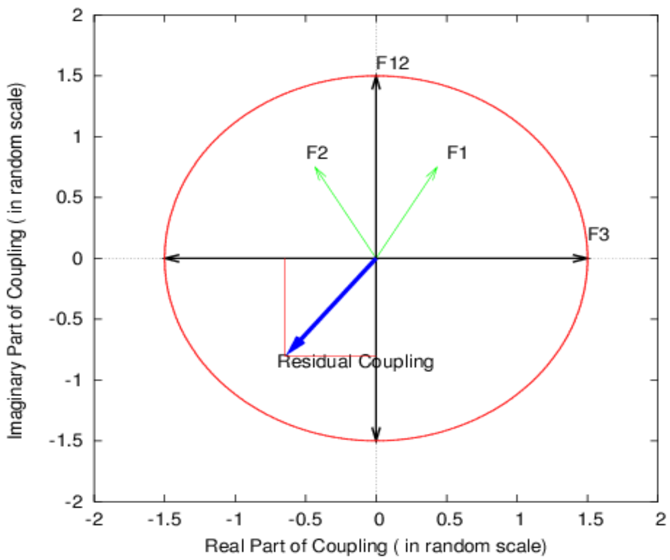
2. Skew quadrupole modulation was put forth for the ramp purpose. Theory worked out, beam experiment done.

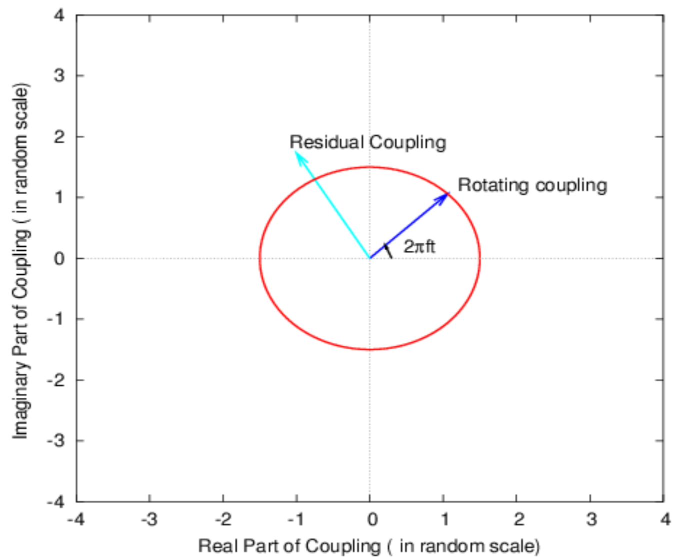
3. What's skew quadrupole modulation

   Modulating skew quadrupole's or skew quadrupole families' current to detect out the coupling or decoupling information.

Skew Quadrupole Modulation (2)

$$C^- = |C^-|e^{i\chi} = \frac{1}{2\pi}\int_0^L \sqrt{\beta_x\beta_y}k_s e^{i[\Psi_x - \Psi_y - 2\pi\Delta\cdot s/L]}dl.$$





used for coupling meas.

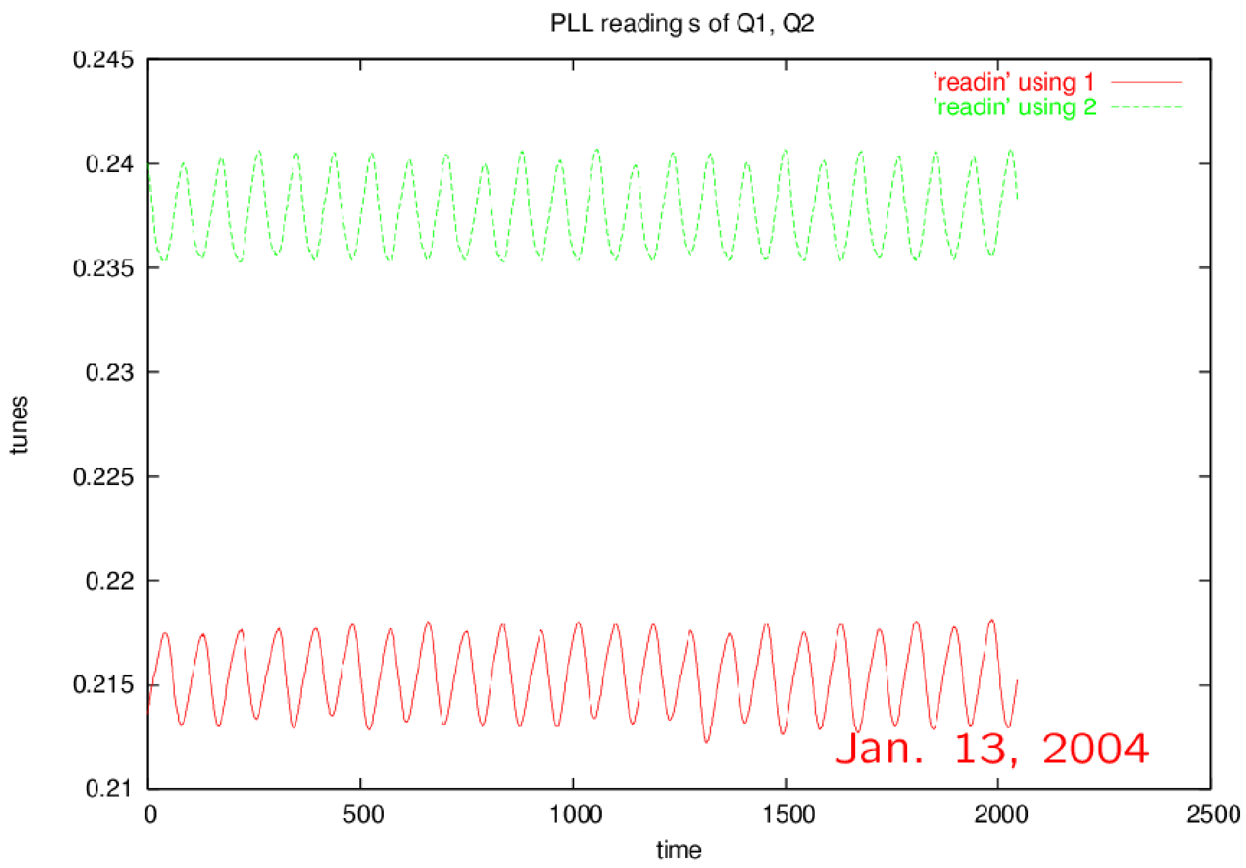
used for coupling corr.

Coupling amplitude modulation

Coupling phase modulation

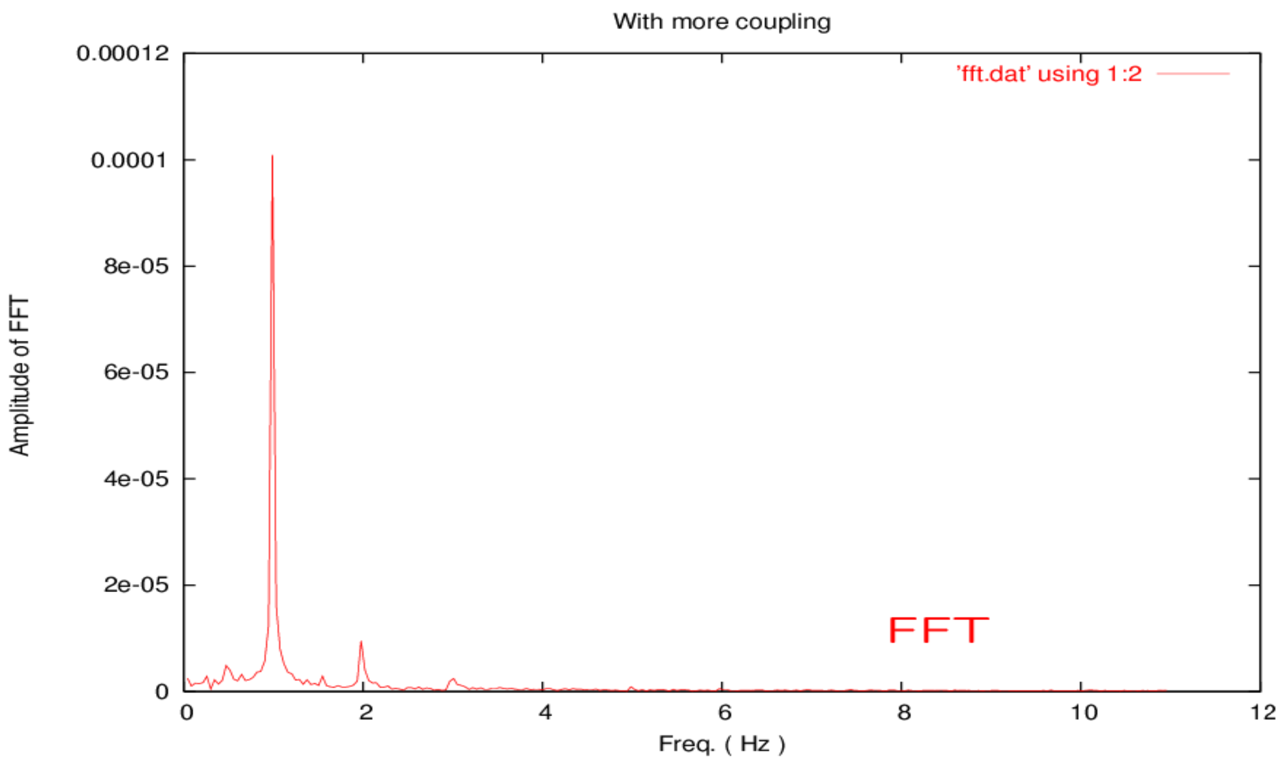
Coupling Amplitude Modulation (1)

At injection

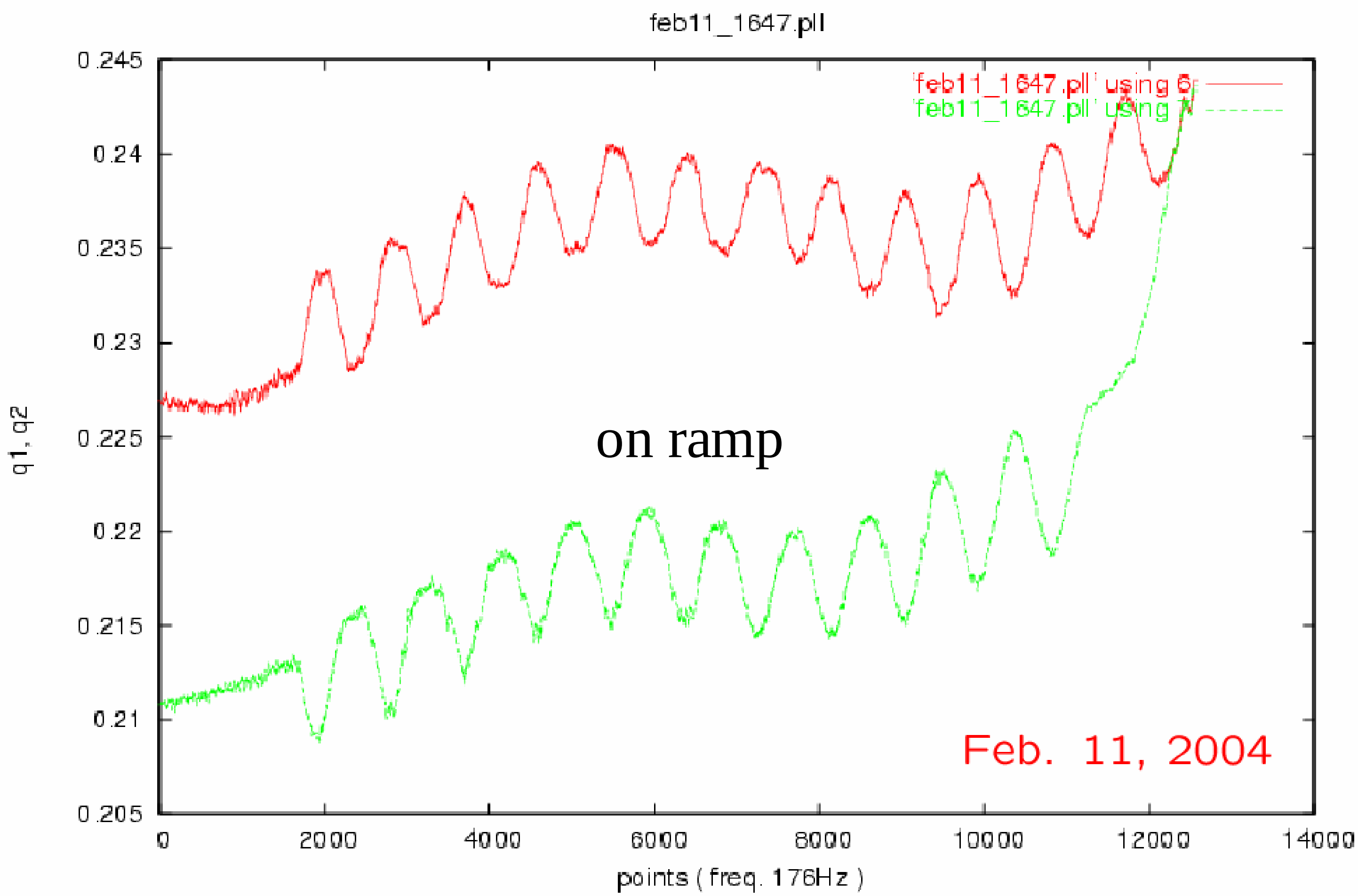


Coupling Amplitude Modulation (4)

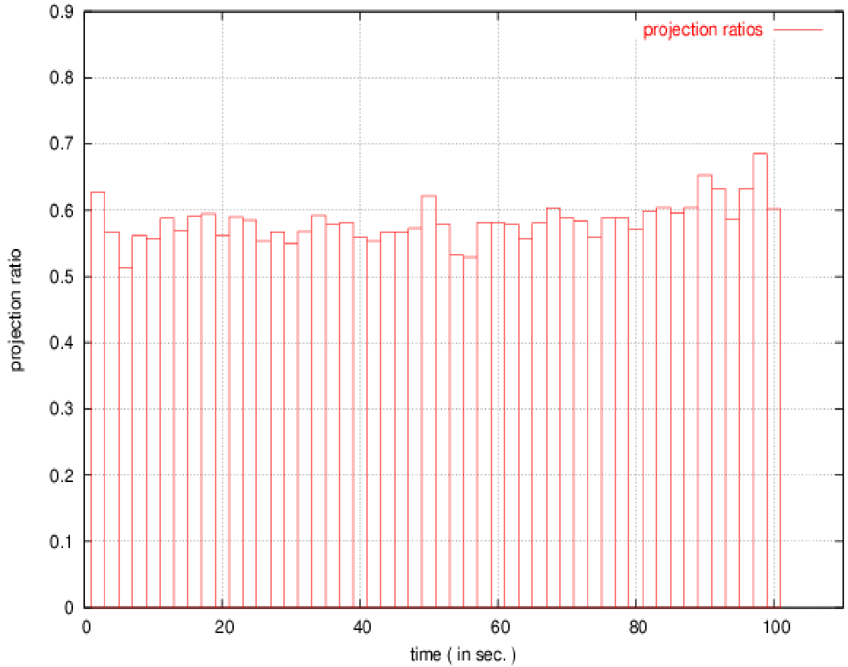
Data Analysis



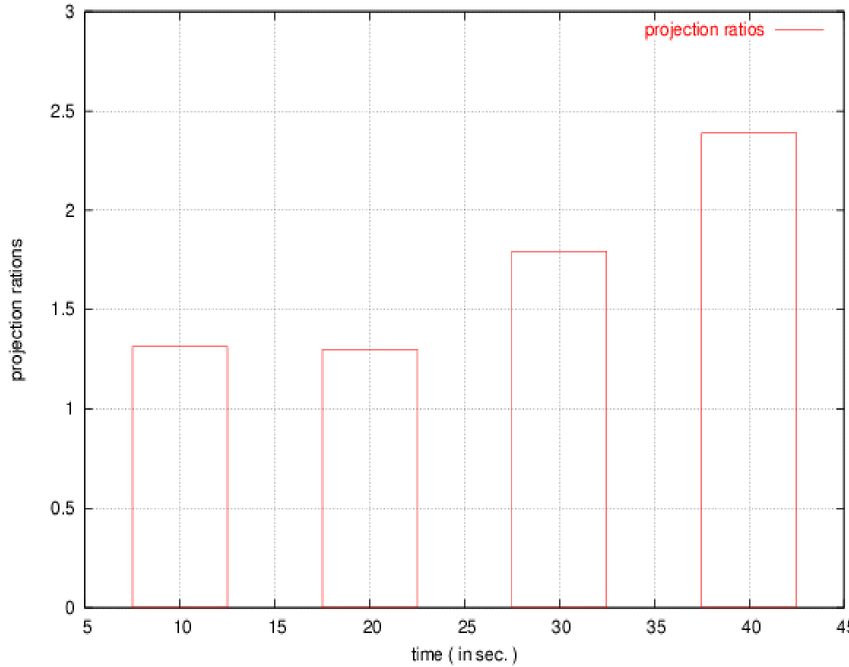
Coupling Amplitude Modulation (4)



Coupling Amplitude Modulation (5)



At injection



On the ramp

Coupling Angle Modulation (1)

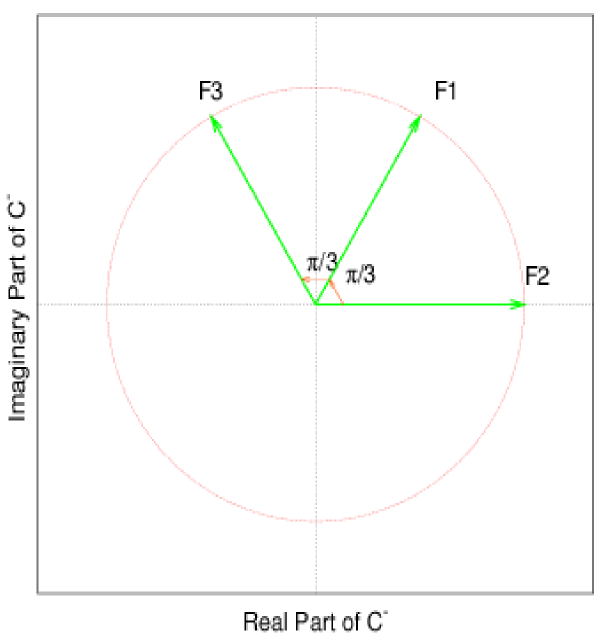


FIG. 2: Coupling contribution directions from the three skew quadrupole families.

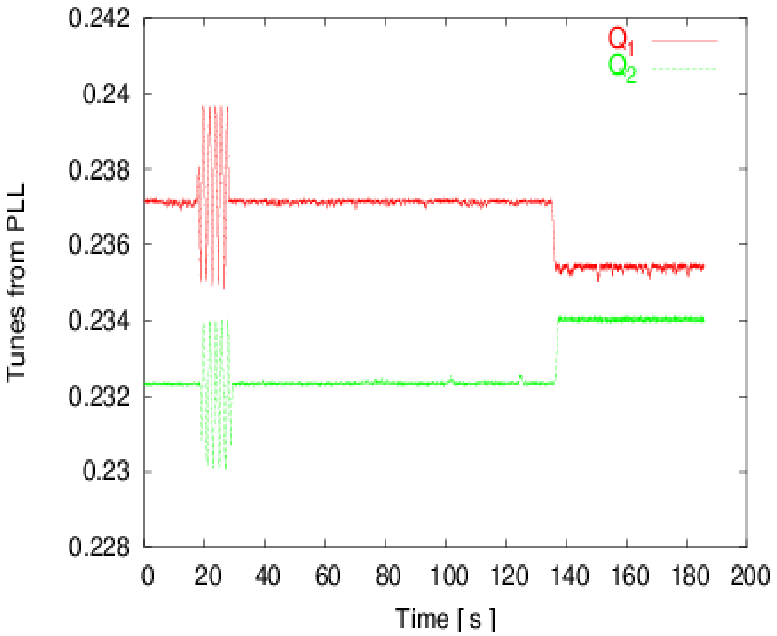


FIG. 3: The tunes during the coupling angle modulation at Blue store.

Coupling Angle Modulation (2)

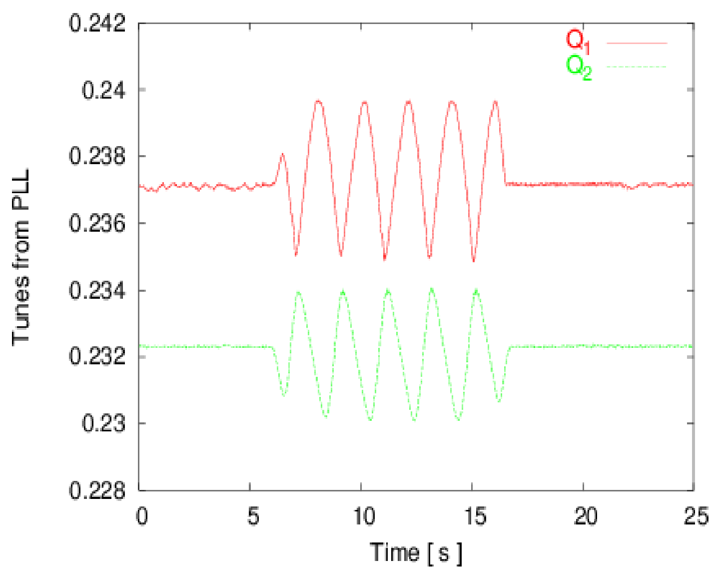


FIG. 4: Zooming-in of the above tunes during modulation.

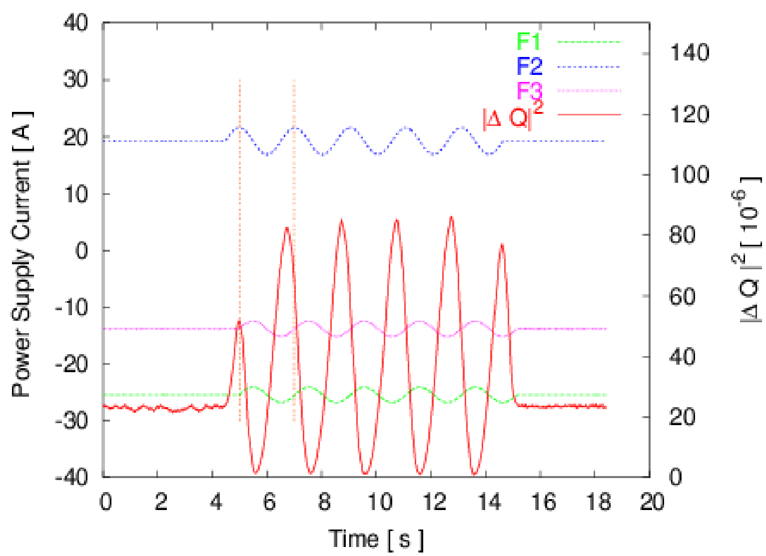
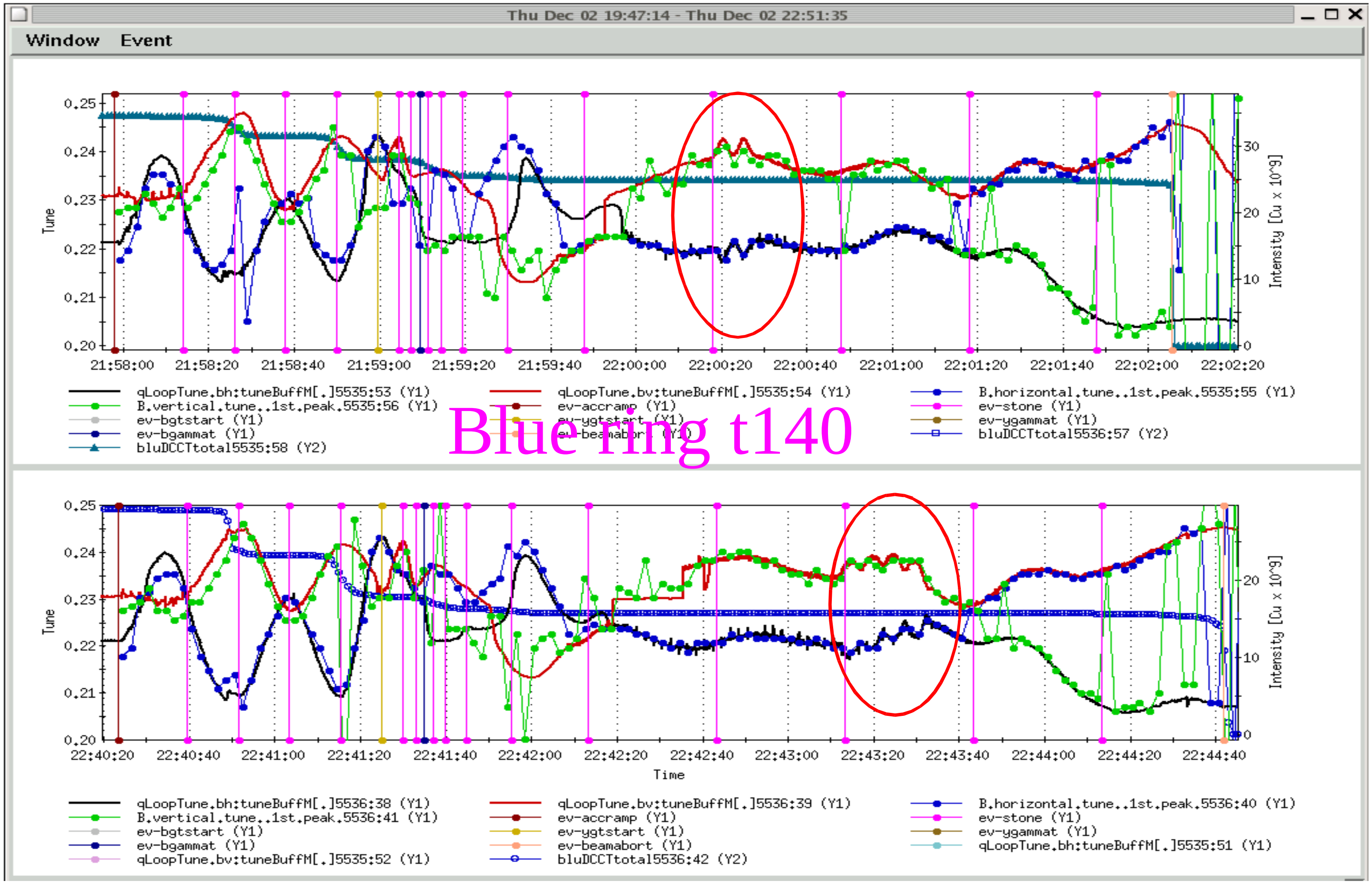


FIG. 5: The decoupling correction strength searching.

$$k = [4(\frac{\Delta Q^2_{max} - \Delta Q^2_0}{\Delta Q^2_{max} - \Delta Q^2_{min}} - \frac{1}{2})]^{-1}.$$

Coupling Angle Modulation (3)



Coupling Angle Modulation (4)

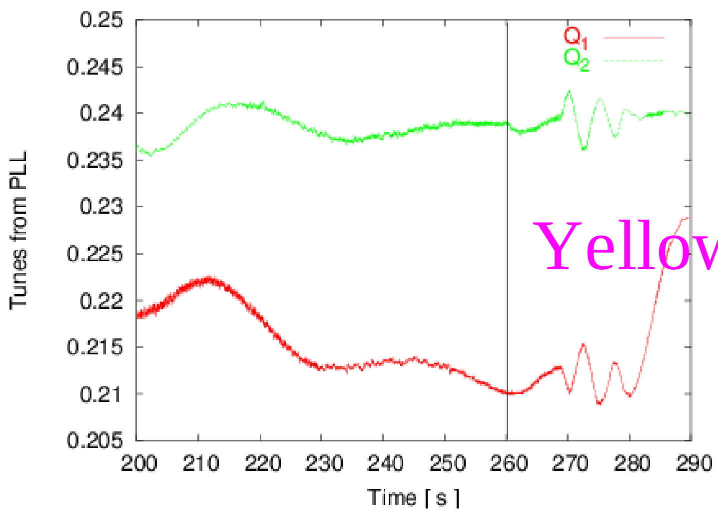


FIG. 6: The coupling angle modulation starting at t270 stone in the first ramp.

Yellow ring t260

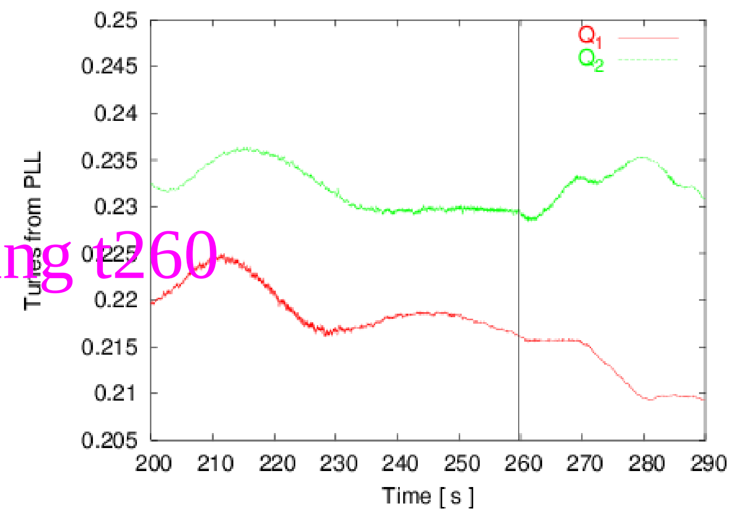


FIG. 7: The tune splits after coupling correction in the second ramp.

Challenge: PLL losing lock (1)

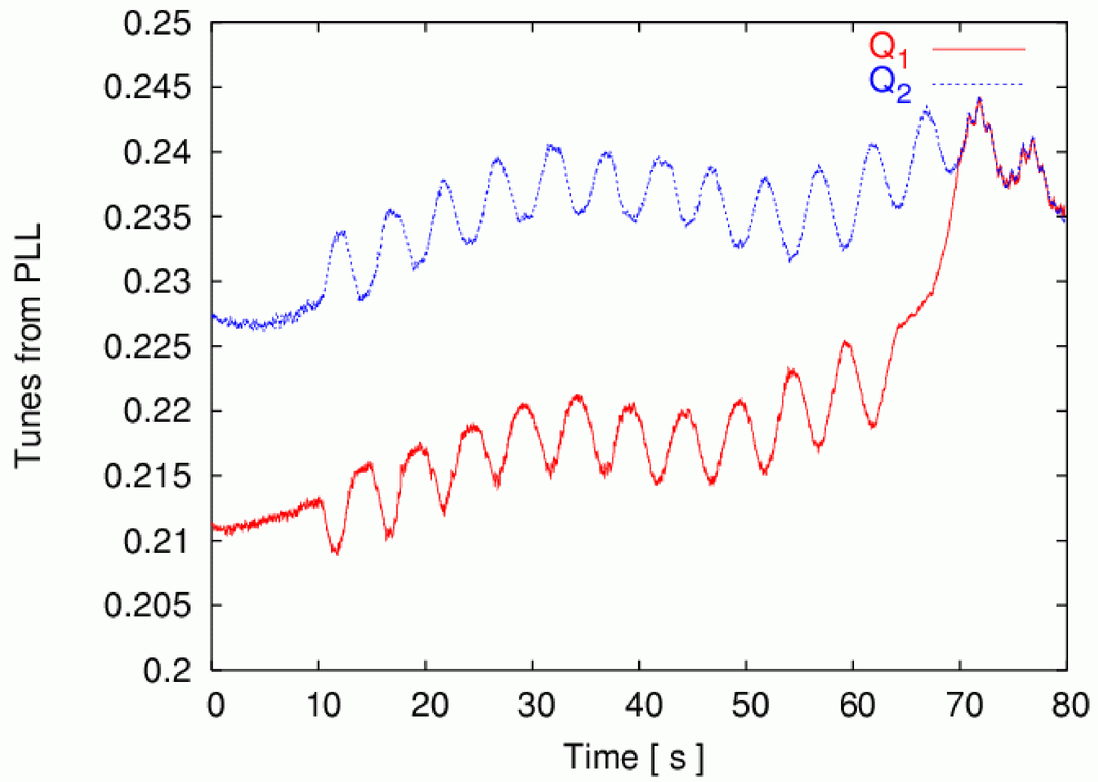
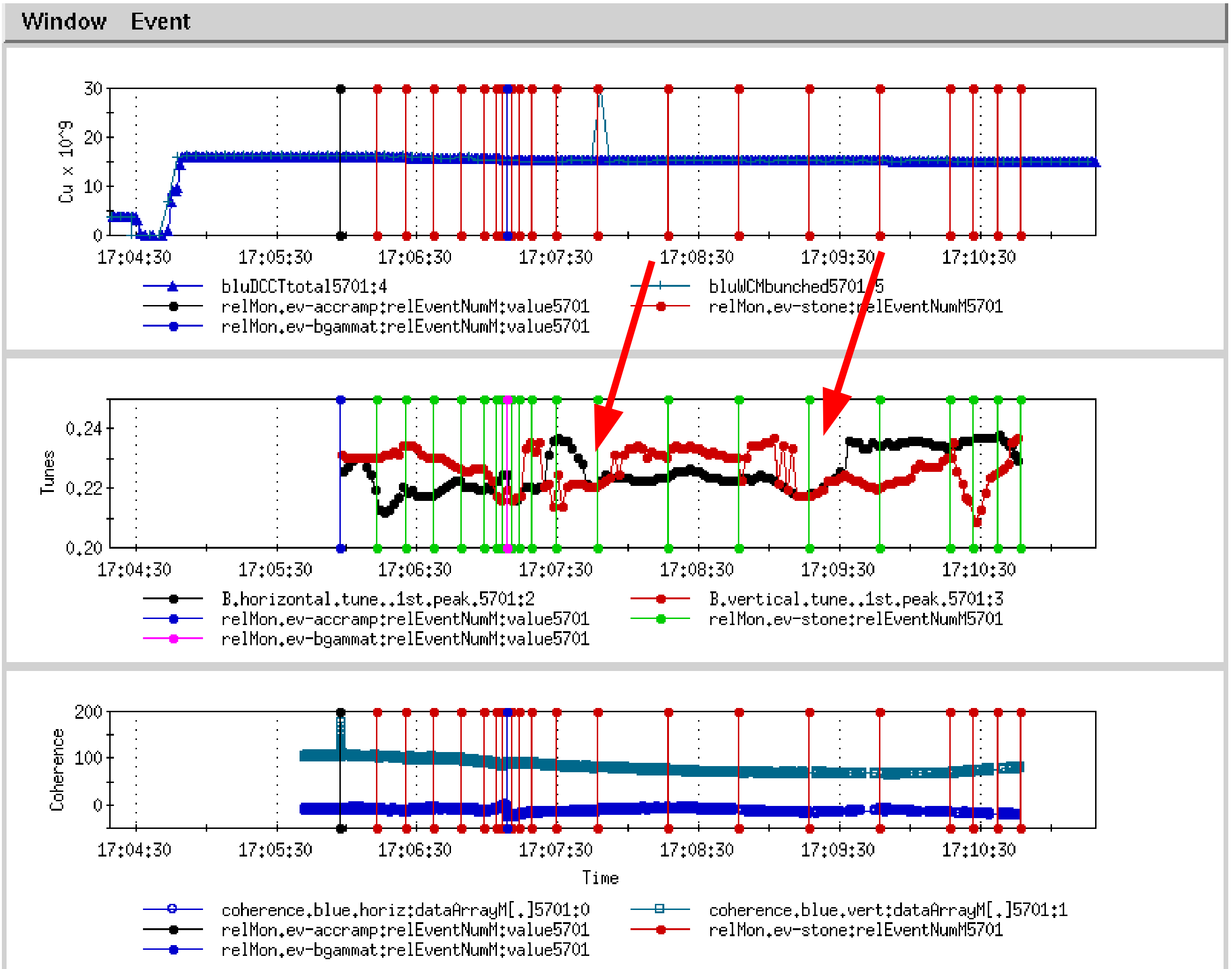


FIG. 6: An example of measurement on the ramp.

Challenge: PLL losing lock (2)



Coupling Observables (1)

In the view of instrumentation,

$$\begin{cases} x_n &= A_{1,x}\cos[2\pi Q_1(n-1)+\phi_{1,x}] + A_{2,x}\cos[2\pi Q_2(n-1)+\phi_{2,x}] \\ y_n &= A_{1,y}\cos[2\pi Q_1(n-1)+\phi_{1,y}] + A_{2,y}\cos[2\pi Q_2(n-1)+\phi_{2,y}] \end{cases}, \quad (10)$$

Besides the two eigentunes Q_1 and Q_2, we define another 2 amplitude ratios

$$\begin{cases} r_1 &= |A_{1,y}|/|A_{1,x}| \\ r_2 &= |A_{2,x}|/|A_{2,y}| \end{cases}. \quad (11)$$

and two phase difference

$$\begin{cases} \Delta\phi_1 &= \phi_{1,y} - \phi_{1,x} \\ \Delta\phi_2 &= \phi_{2,x} - \phi_{2,y} \end{cases}. \quad (12)$$

They are measurable from turn-by-turn digital BPMs and PLL pickups.

Coupling Observables (2)

2-D scan simulation

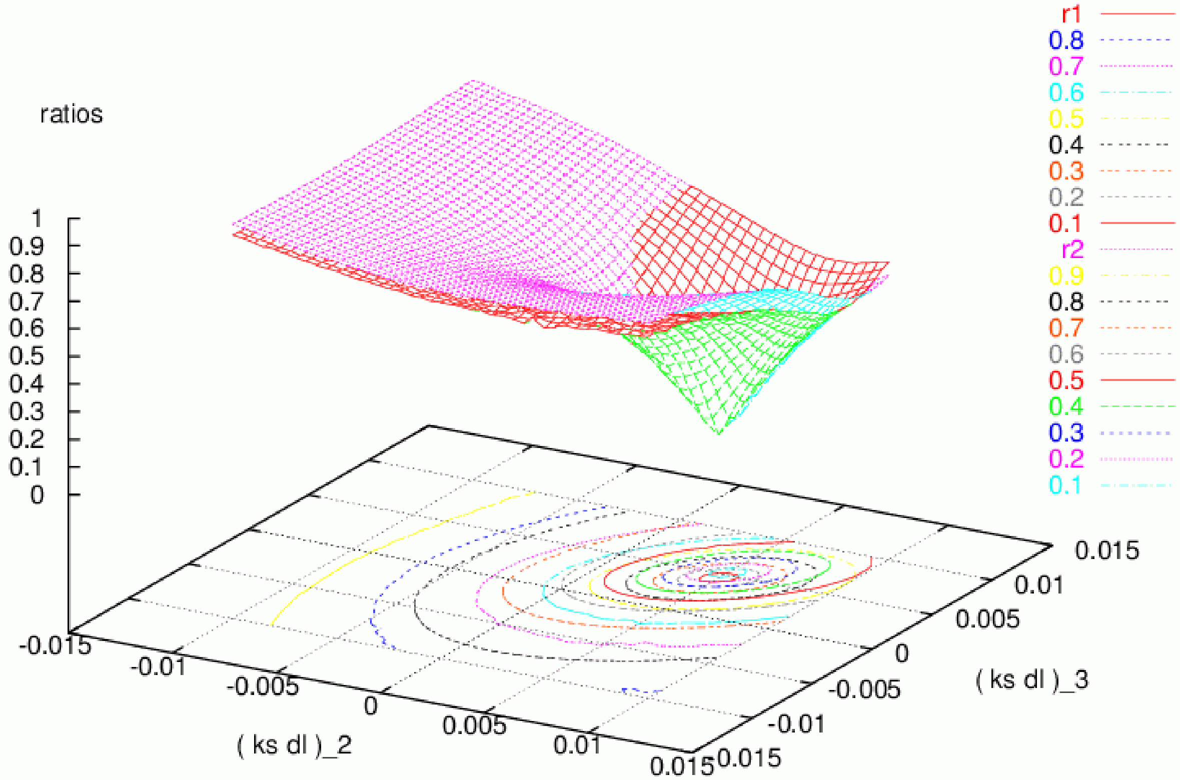


Figure 6: The amplitude ratios $r_{1,2}$ in the 2-D decoupling scan.

Coupling Observables (3)

2-D scan simulation

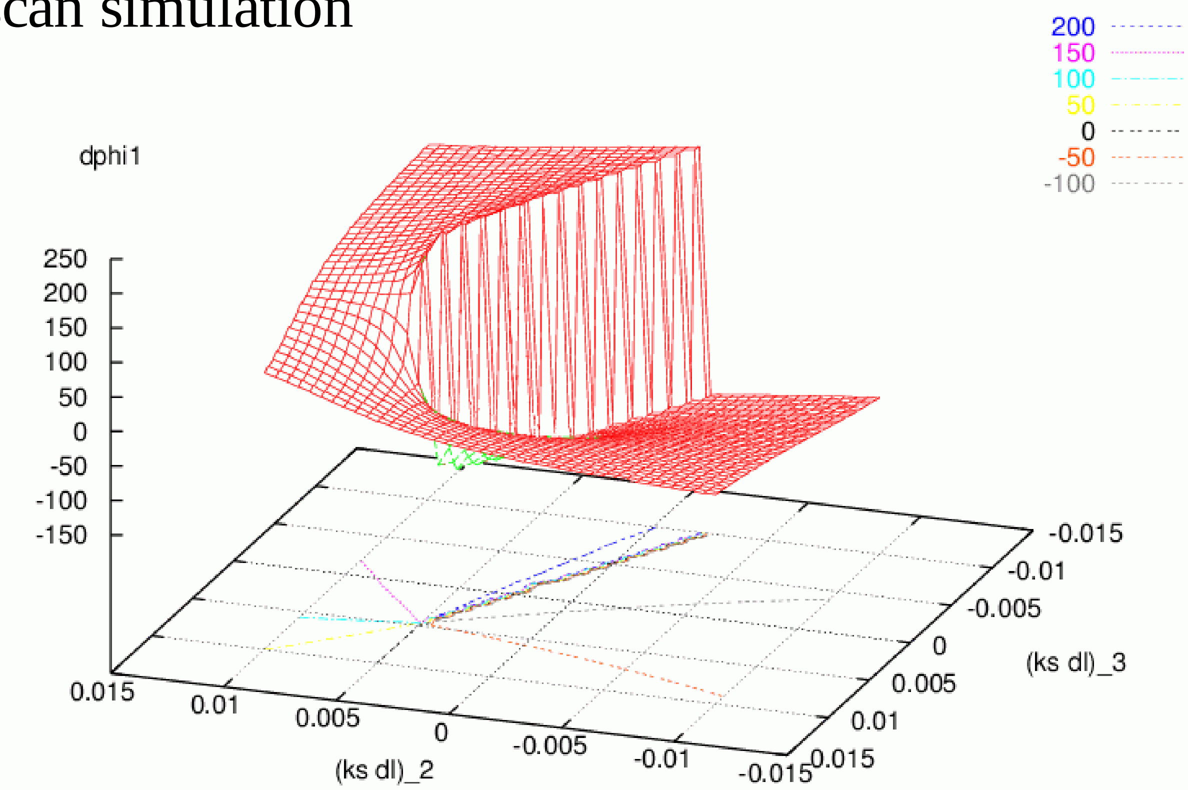


Figure 7: The phase differences $\Delta\phi_1$ in the 2-D decoupling scan.

Coupling Observables (4)

Coupling Hamiltonian theory

$$C^- = |C^-|e^{i\chi} = \frac{1}{2\pi}\int_0^L \sqrt{\beta_x\beta_y}k_s e^{i[\Psi_x-\Psi_y-2\pi\Delta\cdot s/L]}dl.$$

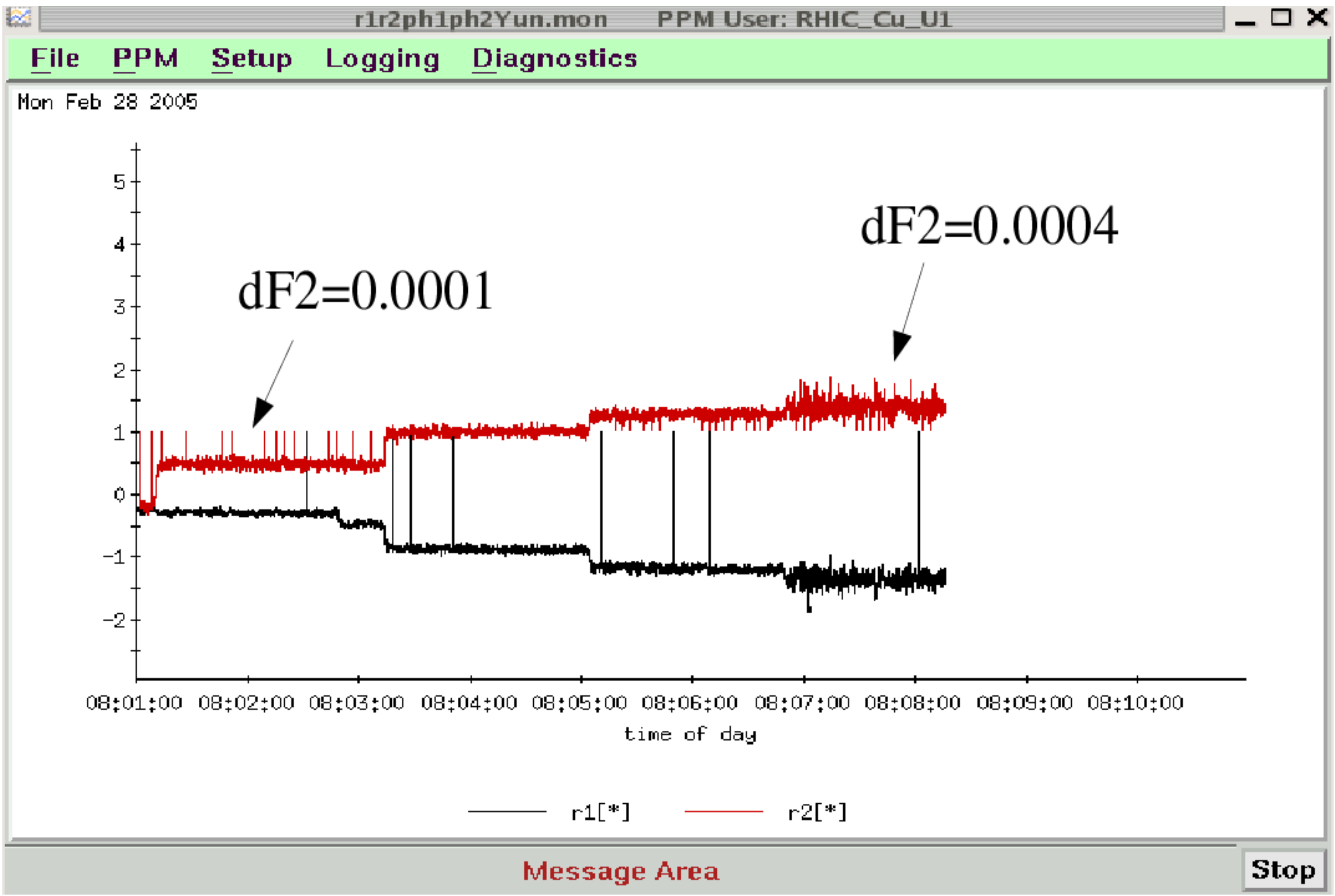
$$\begin{cases} Q_1 &= Q_{x,0} - \frac{1}{2}\Delta + \frac{1}{2}\sqrt{\Delta^2 + |C^-|^2} \\ Q_2 &= Q_{y,0} + \frac{1}{2}\Delta - \frac{1}{2}\sqrt{\Delta^2 + |C^-|^2} \end{cases} .$$

$$\begin{cases} r_1 &= \sqrt{\frac{\beta_y}{\beta_x}} \cdot \frac{|C^-|}{2\nu+\Delta} \\ r_2 &= \sqrt{\frac{\beta_x}{\beta_y}} \cdot \frac{|C^-|}{2\nu+\Delta} \end{cases} ,$$

$$\begin{cases} \Delta\phi_1 &= \chi \\ \Delta\phi_2 &= \pm\pi - \chi \end{cases} .$$

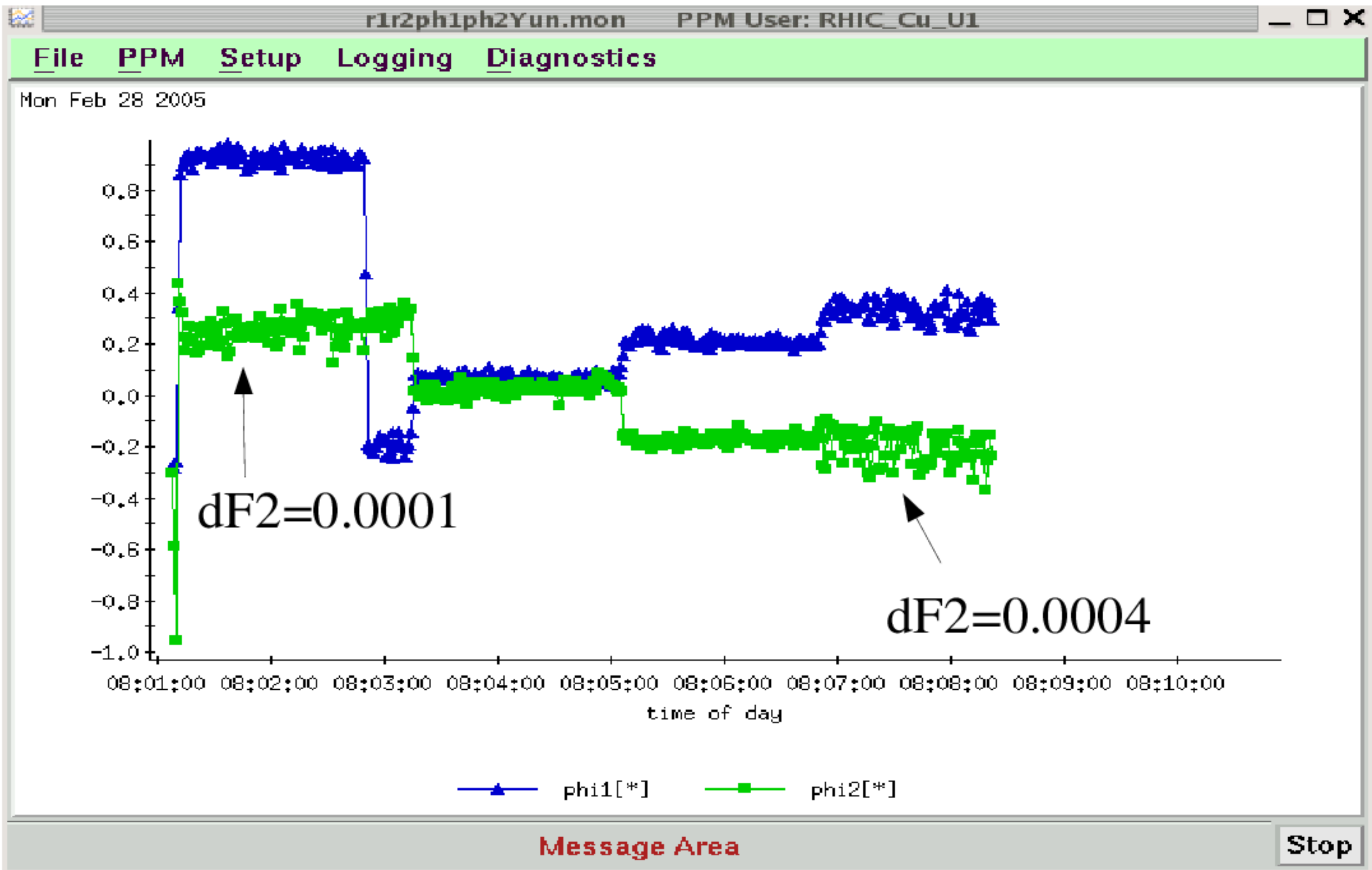
Coupling Observables (6)

1-D scan at injection



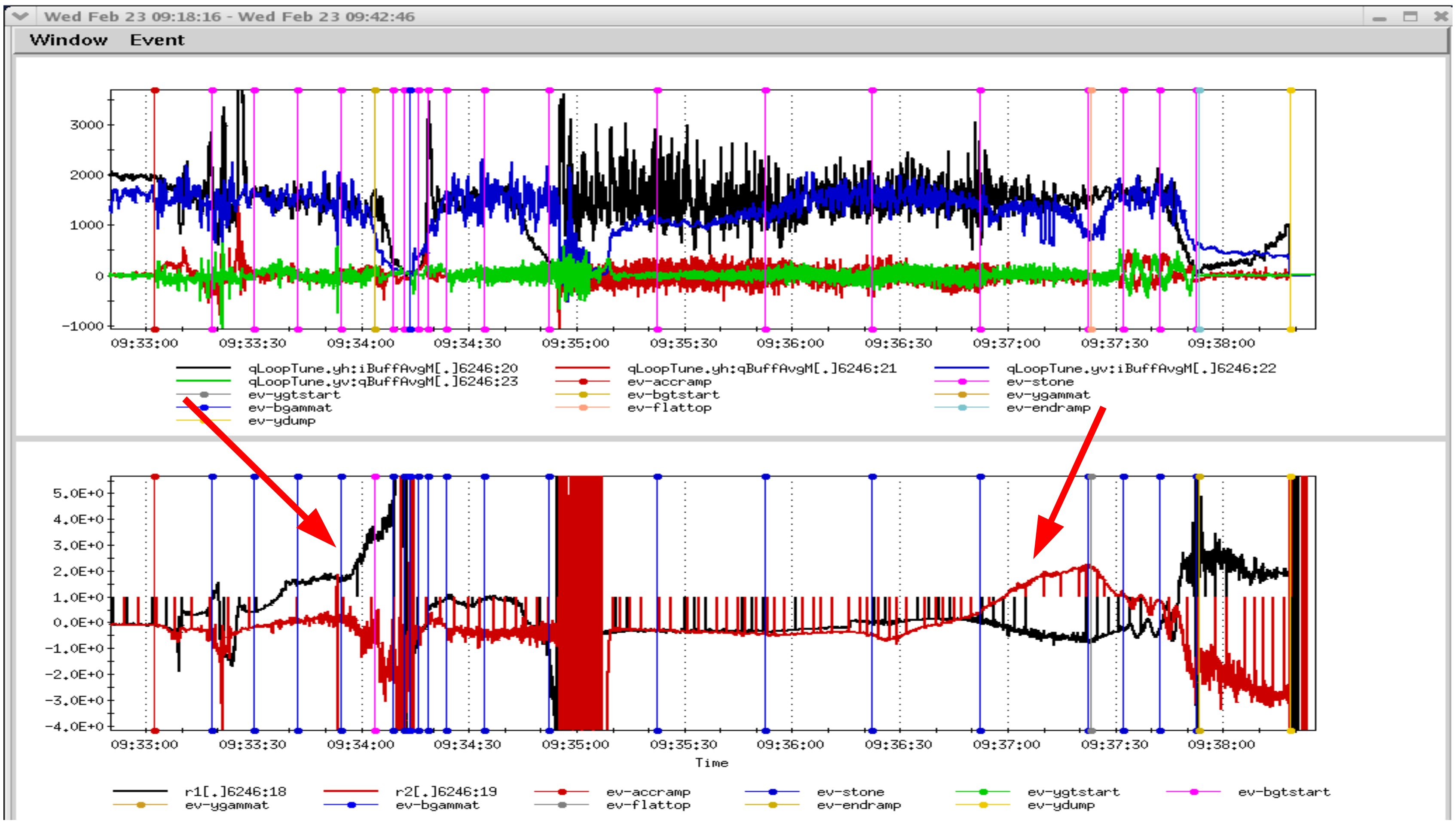
Coupling Observables (7)

1-D scan at injection

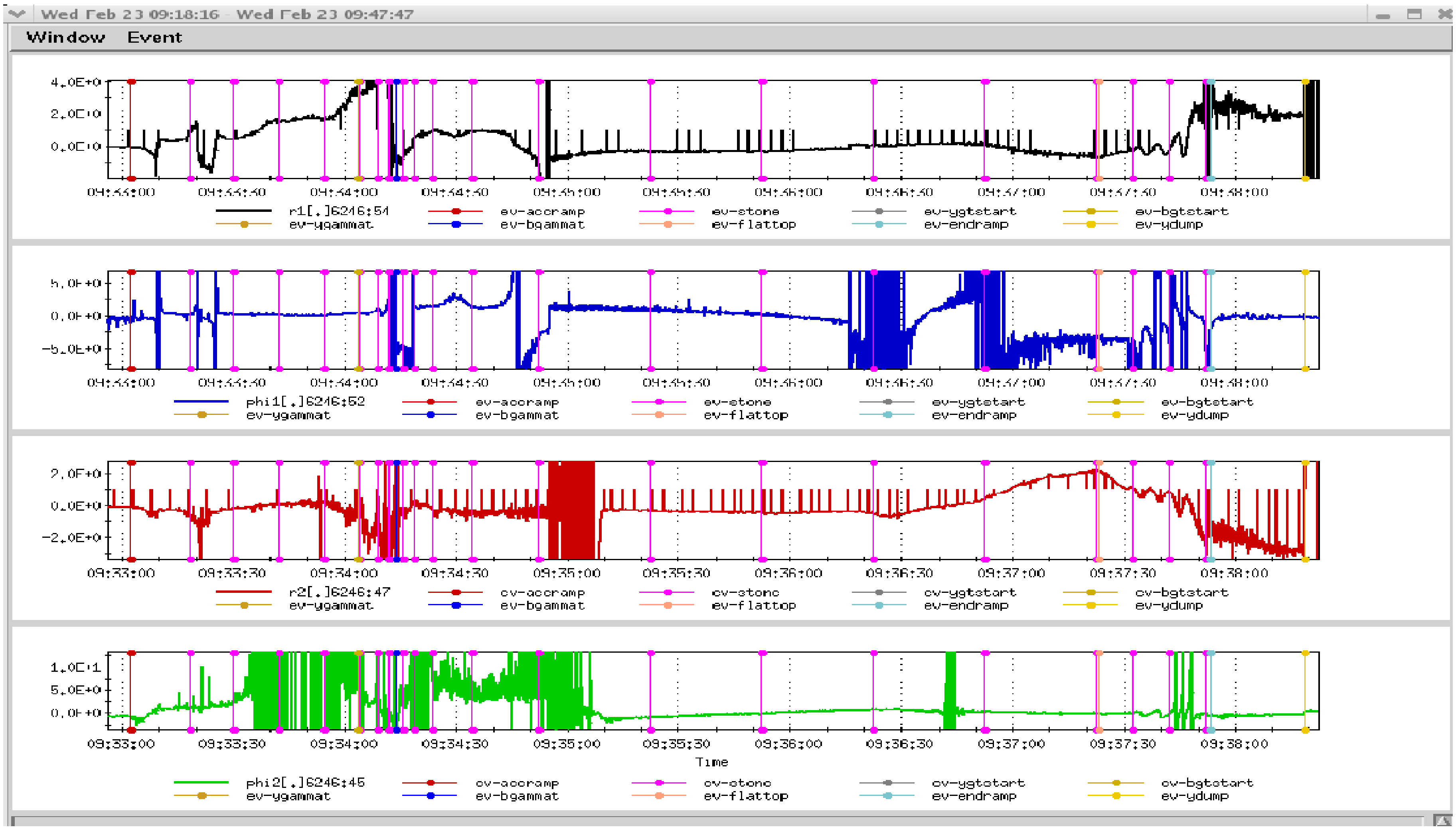


Coupling Observables (8)

On the ramp



Coupling Observable (9)



Decoupling Feedback ? (10)

1. Stability of the PLL data is the starting point.

2. Phase calibration is the key to decoupling feedback.

Knowing the phase difference exact value, the right combination of decoupling skew quadrupole families can be determined from the optics model.

How Far Decoupling Feedback Is?