LIGO

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Update on Bicoherence Monitors

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Statistics (1)

- "1D" Statistics: (2nd Order Cumulants, 1st Order Spectra)
  - » Correlation: $C_{xy}(t) = \int_{-\infty}^{\infty} x(\tau)\, y(t+\tau)\, d\tau \quad \Leftrightarrow \quad X(f)\, Y^{*}(f) = S_{xy}(f)$
  - » Power Spectral Density: $C_{2x}(t) \quad \Leftrightarrow \quad X(f)\, X^{*}(f) = S_{2x}(f)$
  - » Coherence: $\mathsf{C}_{xy}(f) = \dfrac{S_{xy}(f)}{\sqrt{S_{2x}(f)\, S_{2y}(f)}}$
    - – Tells us power and phase coherence at a given frequency

Statistics (2)

- "2D" Statistics: (3rd Order Cumulants, 2nd Order Spectra)
  - » Bicumulant:

$$C_{xyz}(t,t') = \int_{-\infty}^{\infty} x(\tau)\, y(t+\tau)\, z(t'+\tau)\, d\tau \quad \Leftrightarrow \quad X(f_1)\, Y(f_2)\, Z^*(f_1+f_2) = S_{xyz}(f_1,f_2)$$

  - » Bispectral Density: $C_{3x}(t) \quad \Leftrightarrow \quad X(f_1)\, X(f_2)\, X^*(f_1+f_2) = S_{3x}(f_1,f_2)$

  - » Bicoherence:

$$\mathbf{C}_{xyz}(f) = \frac{S_{xyz}(f_1,f_2)}{\sqrt{S_{xx}(f_1)}\sqrt{S_{yy}(f_2)}\sqrt{S_{zz}(f_1+f_2)}}$$

$$\mathbf{C}_{xyz}(f) = \frac{S_{xyz}(f_1,f_2)}{\sqrt{S_{xx}(f_1)\, S_{yy}(f_2)}\sqrt{S_{zz}(f_1+f_2)}}$$

    - Tells us power and phase coherence at a coupled frequency

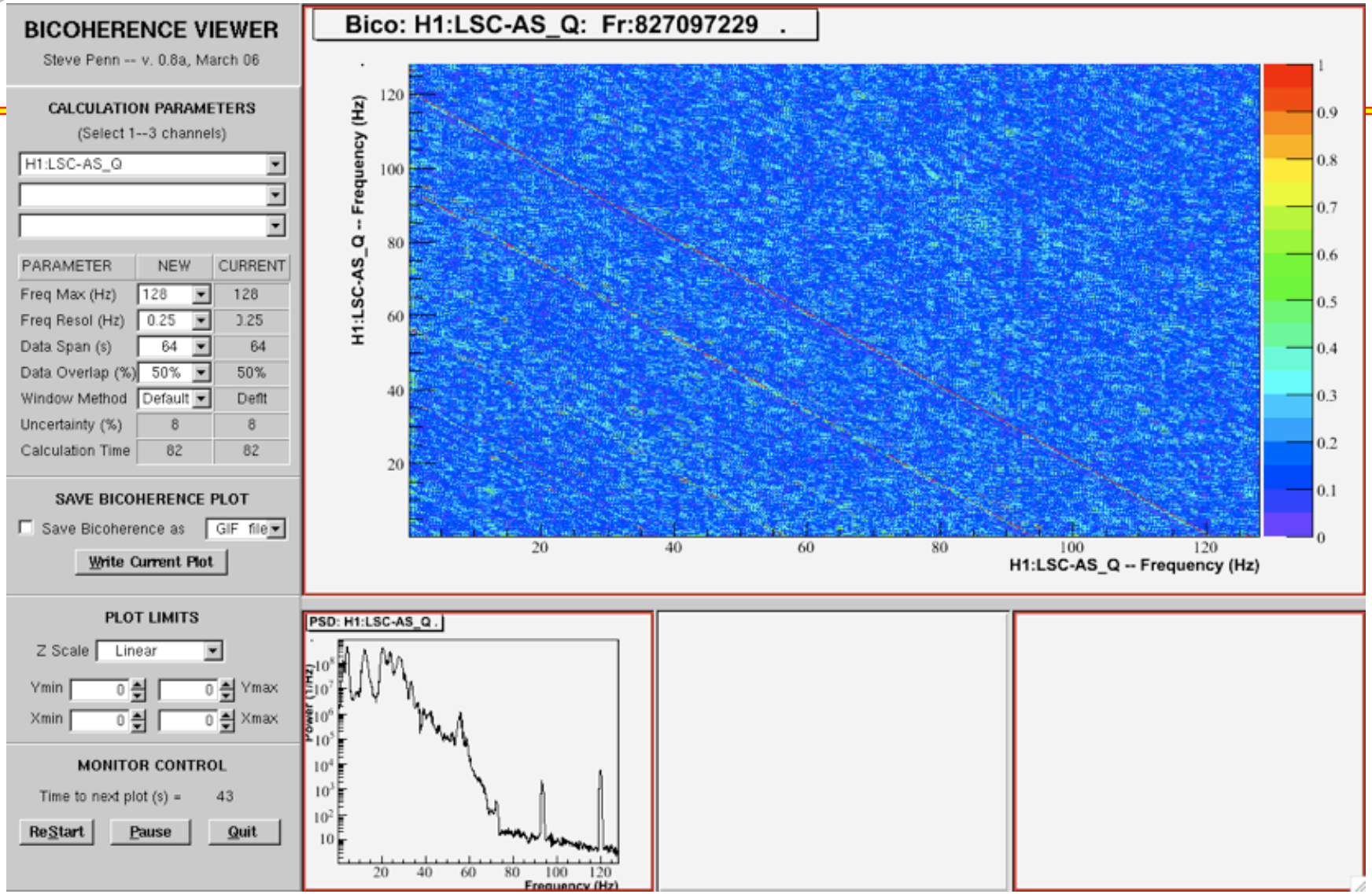
Why Higher Order Statistics?

- For a Gaussian process: $C_{nx}(t) = 0, \text{ for } n > 2$
- For independent processes:

$$z(t) = x(t) + y(t), \quad C_{nz}(t) = C_{nx}(t) + C_{ny}(t) \xrightarrow{n>2} C_{ny}(t)$$

- Allows for isolation of nonGaussian processes
  - » Visual check of frequency coupling and phase noise
  - » Statistical test for the probability of gaussianity and linearity
  - » Iterative process to reconstruct nongaussian signal from the higher order cumulants

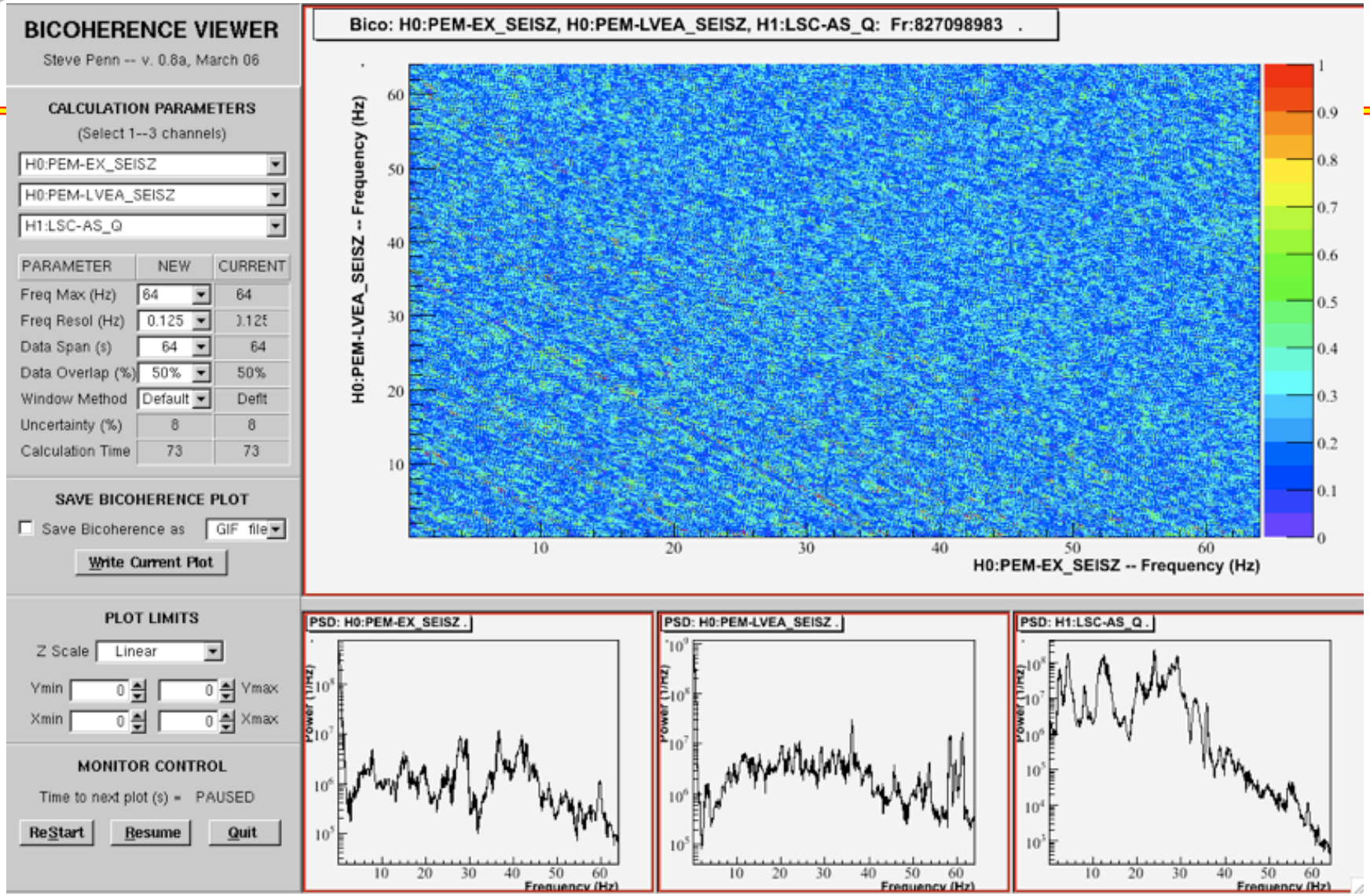
Current Version



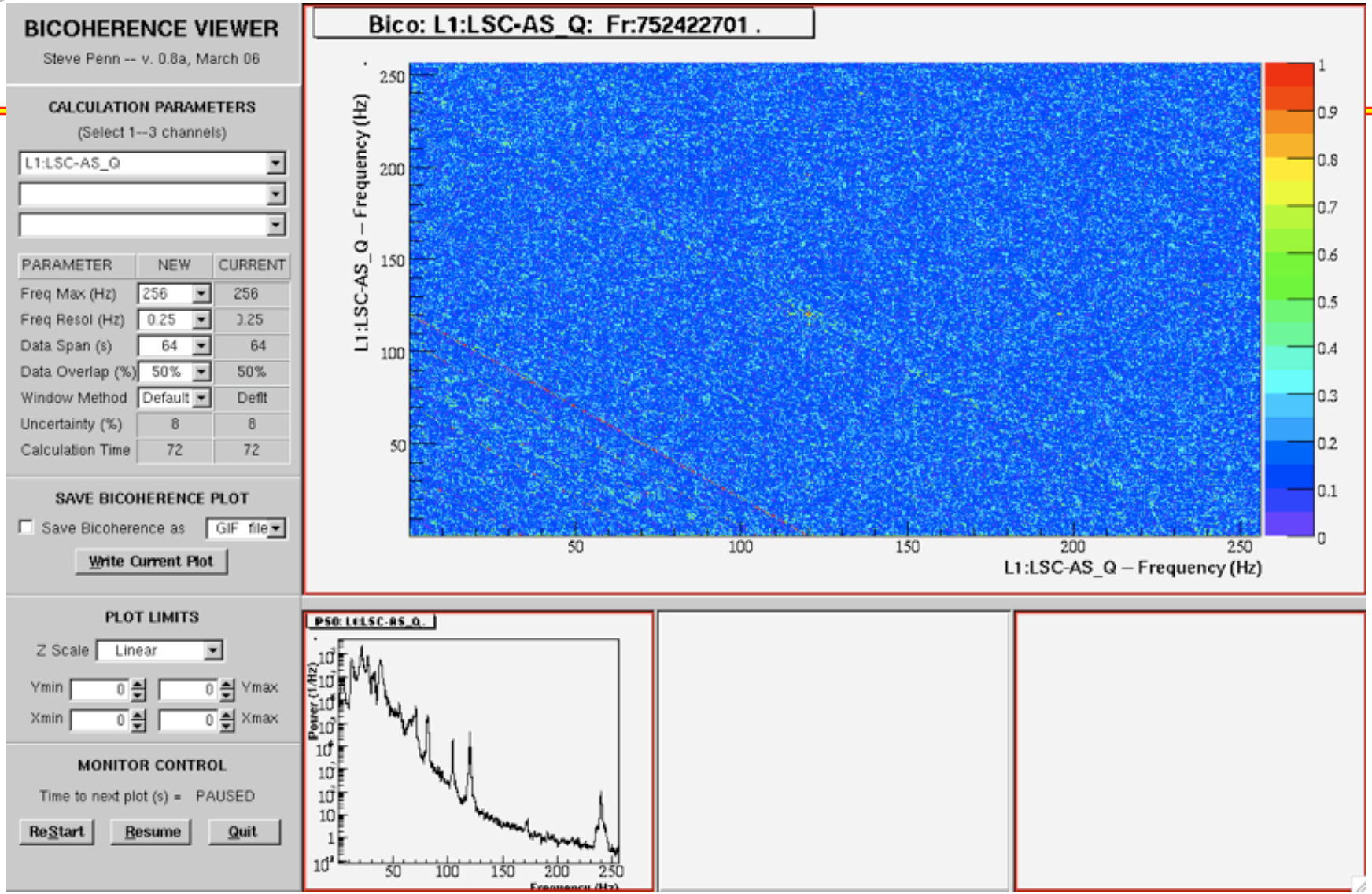
Monitor Versions: BicoViewer (Foreground Monitor)

- Plots Bicoherence (auto- or cross-) & PSD's of input channels
- Proper decimation, Optimized windowing, Vectorized FFT
- User selects: (Channels, Frequency Range, Frequency resolution, Data Span, Overlap)
- Outputs GIF files.
- Table of Current and New Parameters with Accuracy & Time Estimates
- Plot Countdown clock
- Better Smoothing Routine
- Heterodyning
- GUI panel for Input file or frame retrieval
- Strip Chart for Monitoring Bicoherence of certain ROI

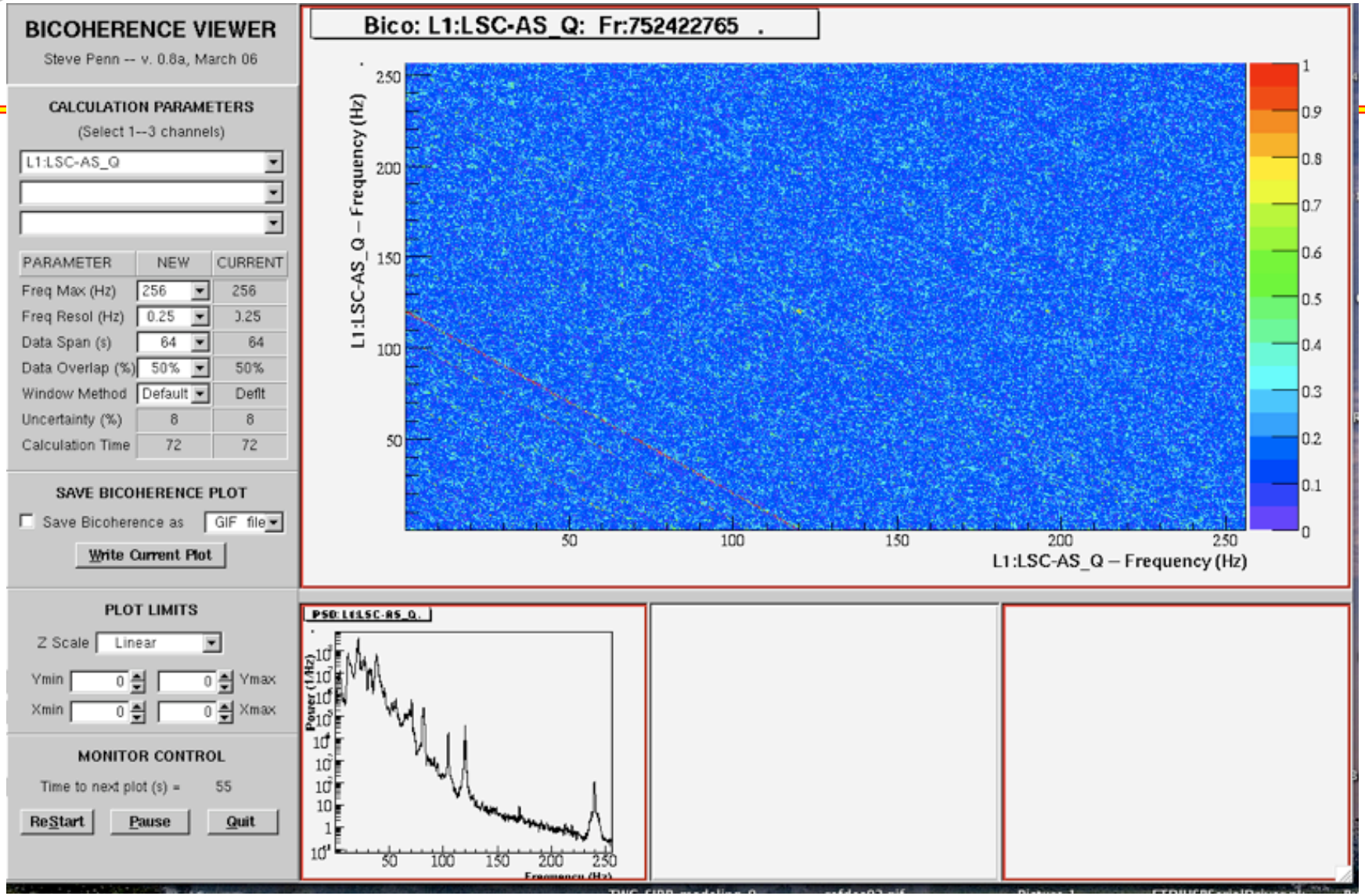
Current Version (2)



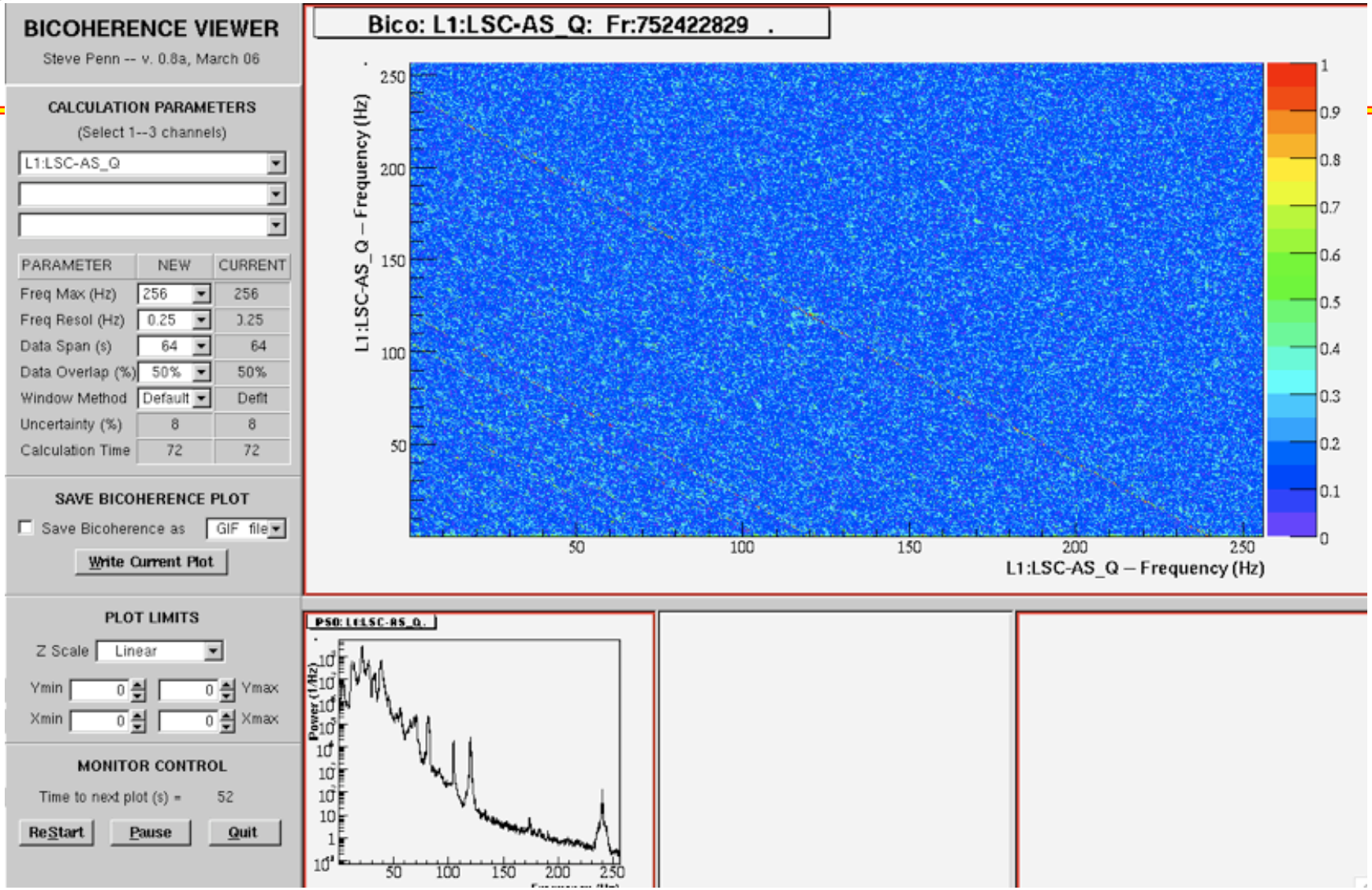
Current Version (3)



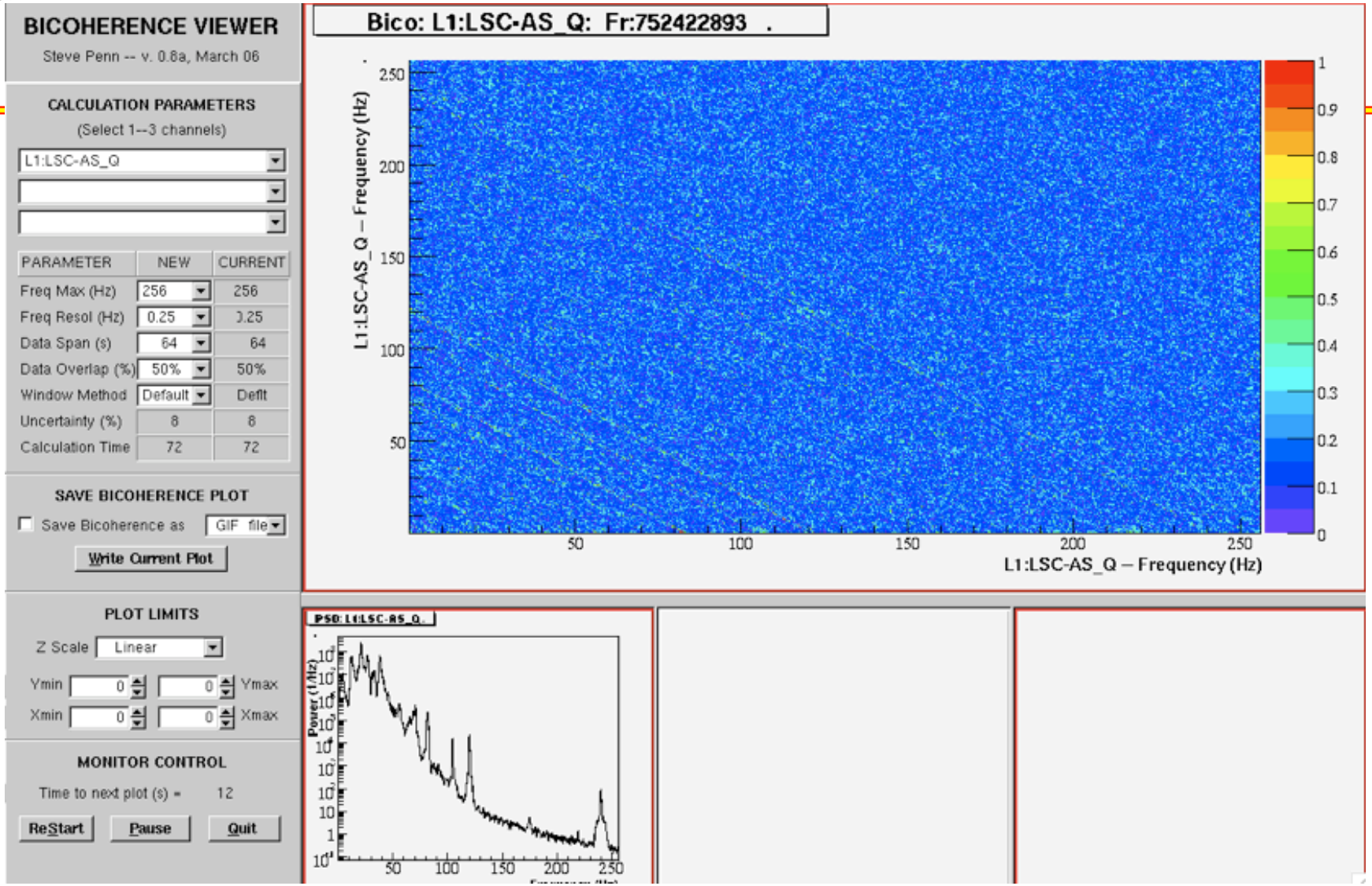
Current Version (4)



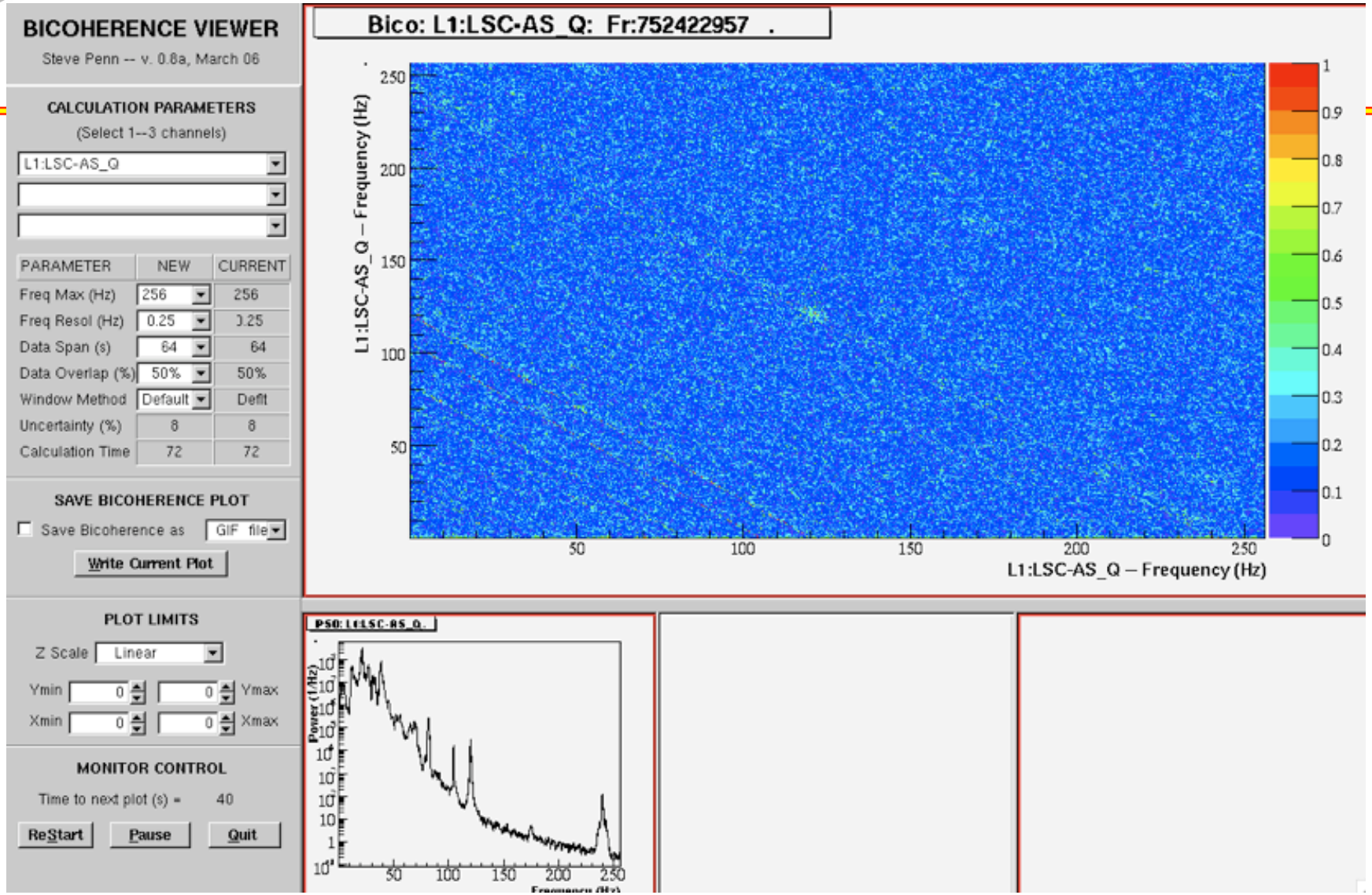
Current Version (5)



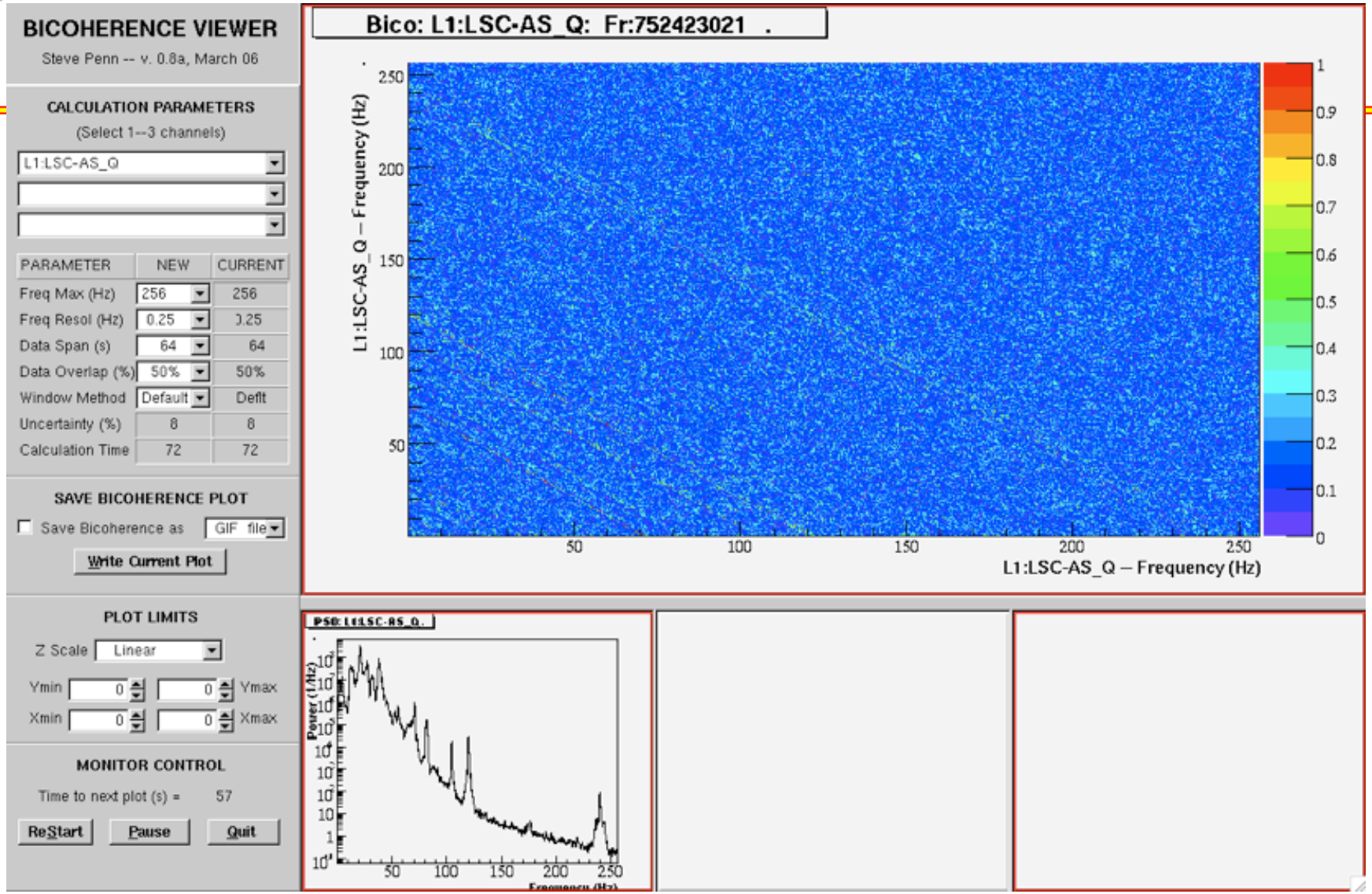
Current Version (6)



Current Version (7)



Current Version (8)



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Online Demo

BicoMon: Current Version

- Multiple configurations: Bicoherence calculated for each configuration
- Multiple measurements: Integrates bicoherence over specified ROI's
- Measurements trended and sent to DMTviewer & to trend dataframes.
- Fixed problem with decimation that was causing crash when there was input data discontinuity.

LIGO

Configuration File

Calculation Parameters

Measurement Parameters

```
3  30

C 2   H1:LSC-AS_Q                          16384
      H1:SUS-ITMX_OPLEV_PERROR  2048
      256      1.0            0.5          64

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M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_60_2_2      60  2 2
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_60_10_2     60 10 2
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_60_38_2     60 38 2
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_60_50_2     60 50 2
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_120_2_2    120  2 2
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_120_10_2   120 10 2
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_120_38_2   120 38 2
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M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_180_10_2   180 10 2
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_180_38_2   180 38 2
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_180_50_2   180 50 2

C 2   H1:LSC-AS_Q                          16384
      H1:SUS-ITMY_OPLEV_PERROR  2048
      256      1.0            0.5          64

M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_ALL          0  0 0
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M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_60_10_2     60 10 2
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_60_38_2     60 38 2
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_60_50_2     60 50 2
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M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_120_10_2   120 10 2
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_120_38_2   120 38 2
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_120_50_2   120 50 2
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_180_2_2    180  2 2
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_180_10_2   180 10 2
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_180_38_2   180 38 2
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_180_50_2   180 50 2

C 1   H1:LSC-AS_Q                          16384
      256      1.0            0.5          64

M  Bico:H1:AS_Q_ALL            0   0 0
M  Bico:H1:AS_Q_120_2_2      120   2 2
M  Bico:H1:AS_Q_120_10_2     120  10 2
M  Bico:H1:AS_Q_120_38_2     120  38 2
```

Conclusions

- Bicoherence monitors could be a useful tool for analyzing data for glitches, gaussianity, upconversion, and chirps.
- LIGO is currently sensitive to upconversion noise.
- BicoMon operational, needs some
- BicoViewer works (beta) (Developer-Users Needed).