Visualising gravitational-wave event candidates with the

Coherent Event Display

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Overview

- Justification
- Coherent Analysis
- Gravitational-wave Sources
- Structure
- Conclusions

Justification

- World-wide network of gravitational-wave detectors now online: LIGO (H1, H2 & L1), GEO, VIRGO
- Visualise event candidates from search pipelines running on data from these detector networks
- Follow up tool for coherent analysis

Coherent Analysis

- Combine the detector responses into a single coherent statistic and generate a list of burst event candidates
- Simultaneously analyse data from all the detectors within the network
- Only events coincident in all detectors make it through the pipeline
- Coherent Event Display is implemented using the Coherent WaveBurst algorithms (I. Yakushin R12.4)

GW Sources

- Coherent Event Display is targeted at burst gravitational-wave sources
- Transient gravitational-wave signals, no accurate knowledge of the waveforms
- Supernovae, GRBs, BH Mergers...

Structure

- Web Page
- Job Parameters
- Event Parameters
- Time-Frequency Maps
- Likelihood Time-Frequency Maps
- Reconstructed Detector Responses
- Skymaps

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Example: Sine Gaussian Injection

Coherent WaveBurst Event Summary Page

- Job Parameter Table
- Event Parameter Table
- Network Data Matrix
- Time-Frequency Maps
- Reconstructed Detector Responses
- Skymaps
- Likelihood Time-Frequency Map
- Event Parameters (XML File)
- Configuration File
- Documentation

Job Parameter Table

GPS Segment Time (s)	816258792
UTC Segment Time	Nov 17 2005 10:32:59 UTC

Top

Event Parameter Table

IFO	L1	H1	H2
Time Lag (s)	0.000	0.000	0.000
GPS Start Time (s)	816258866.406	816258866.406	816258866.406
GPS Stop Time (s)	816258866.461	816258866.461	816258866.461
GPS Central Time (s)	816258866.436	816258866.429	816258866.429
Central Time (s)	74.436	74.429	74.429
hrss	5.33e-22	8.59e-22	8.59e-22
SNR	1.06e+02	5.03e+02	6.88e+01
Null	1.14e+01	6.15e+00	3.35e+00
Rank SNR	6.76e+01	6.07e+01	5.05e+01
Rank Significance	3.15e+01	2.78e+01	2.19e+01
Gaussian Significance	4.72e+01	2.37e+02	2.77e+01
Noise	5.28e-23	3.92e-23	9.61e-23
Likelihood			3.28e+02
Phi (degrees)			194.50
Theta (degrees)			46.50
Correlation			9.29e-01
Size			6
flow (Hz)			64.00
fhigh (Hz)			128.00
Central Frequency (Hz)			101.70
Bandwidth (Hz)			64.00
Resolution (Hz)			128
Geometric Significance			[illegible]

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Simulated GW Injection, LIGO Network

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fhigh (Hz)			128.00
Central Frequency (Hz)			101.70
Bandwidth (Hz)			64.00
Resolution (Hz)			128
Geometric Significance			3.29e+00
Event Duration (s)			0.054688
F+	-3.91e-01	6.39e-01	6.39e-01
Fx	-3.50e-01	5.54e-01	5.54e-01

← Injected at 1e-21 (hrss)

← Injected at 100 Hz (Central Frequency)

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Time-Frequency Maps

- Coherent WaveBurst algorithms use wavelet transformations to produce data in the time-frequency domain (time-frequency maps)
- Shows the wavelet coefficients normalised by the noise RMS as a function of time and frequency
- Time-Frequency maps then used to produce the coherent statistic

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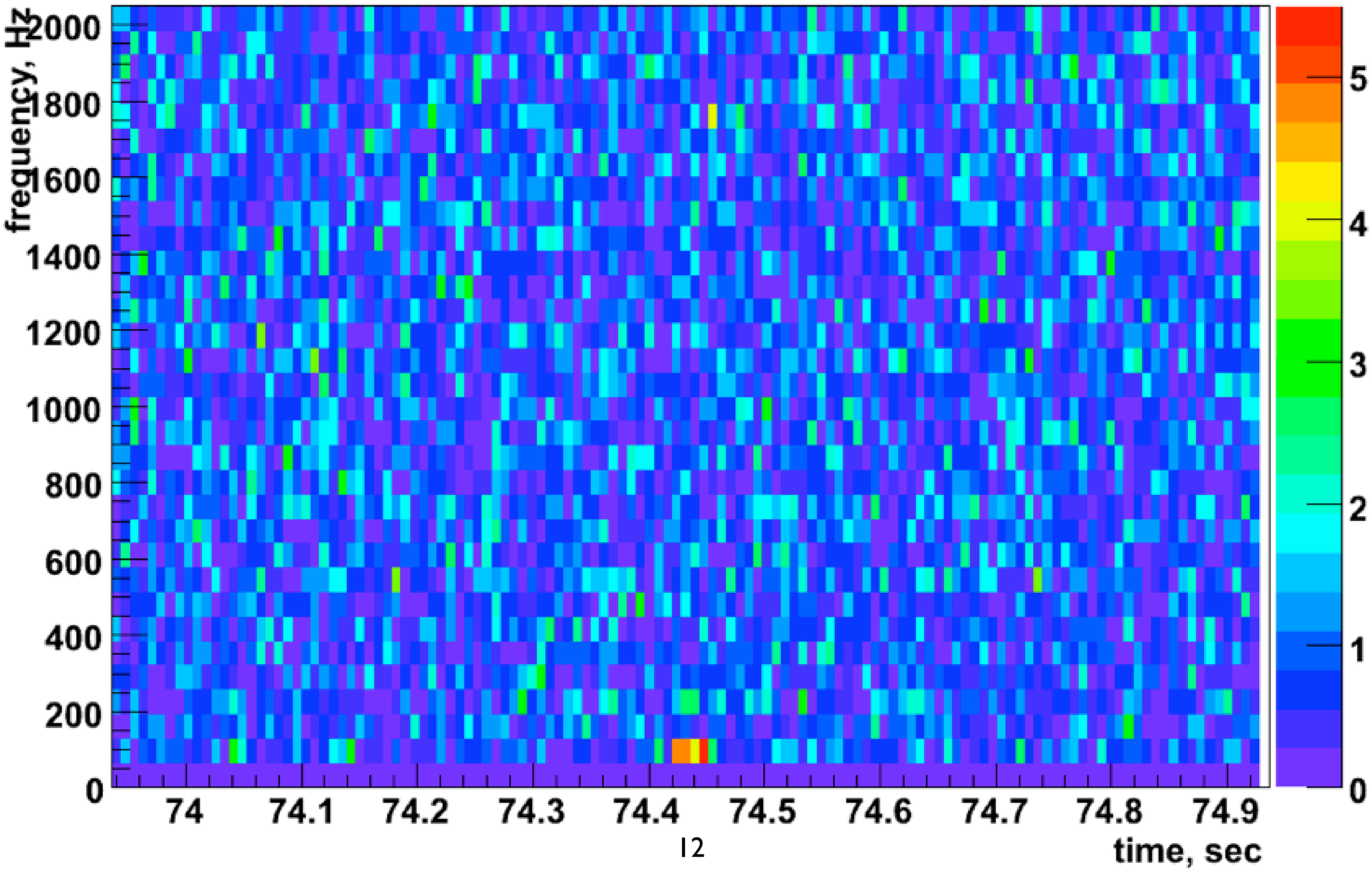
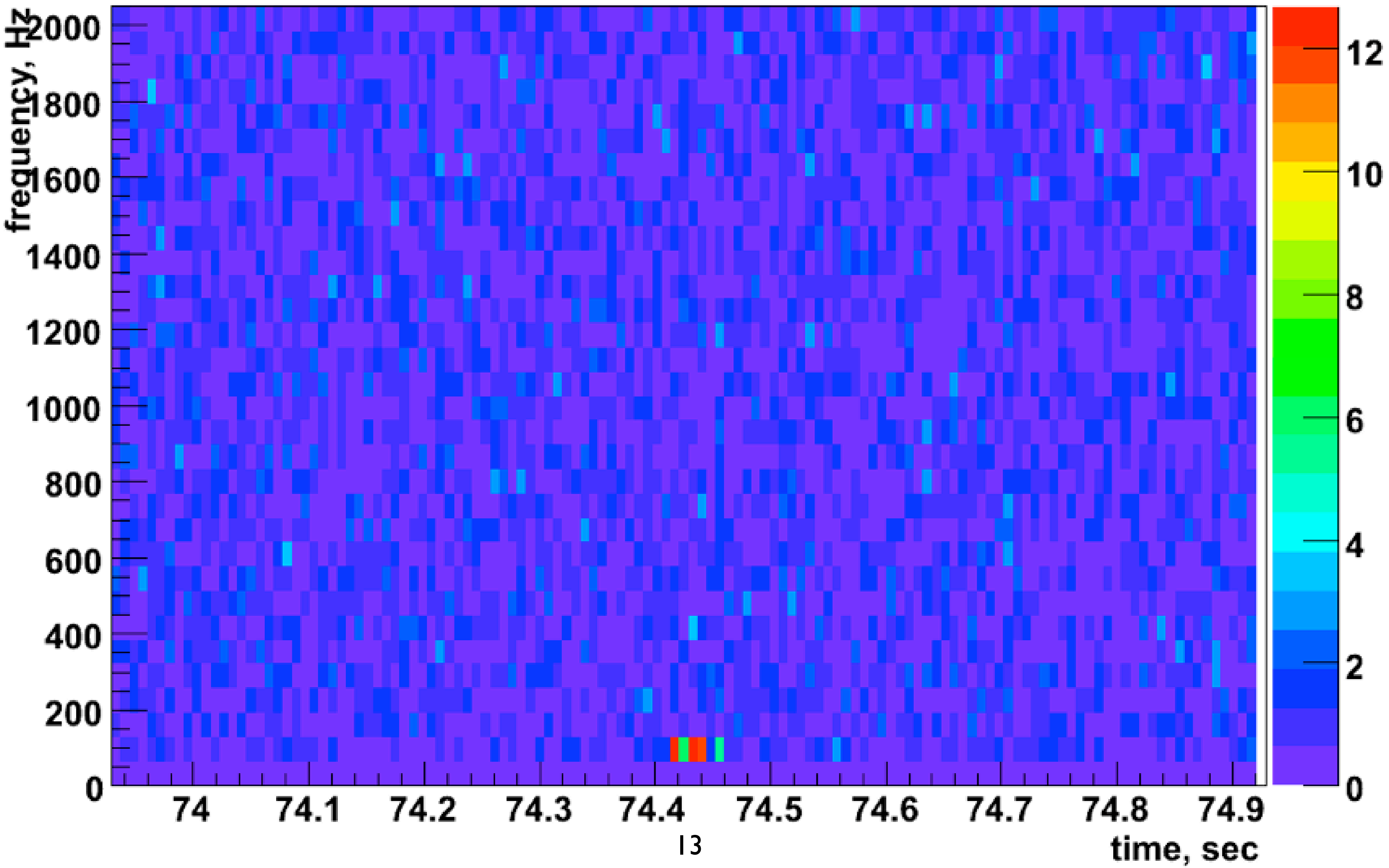
L1

Simulated GW Injection
LIGO Network



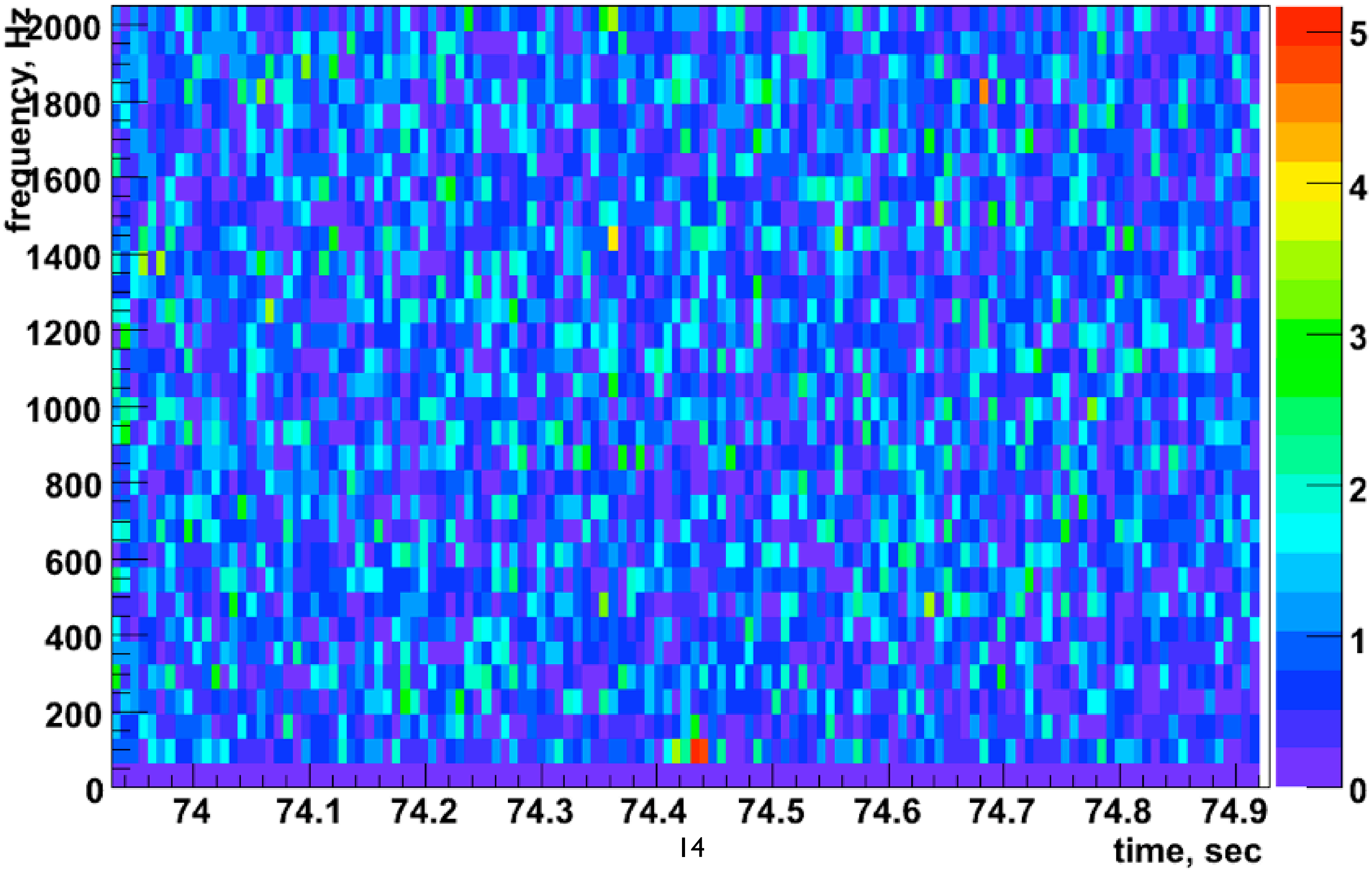
H1

Simulated GW Injection
LIGO Network



H2

Simulated GW Injection
LIGO Network



Structure

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Likelihood

- Likelihood for Gaussian noise

$$\mathcal{L} = \sum_{i=1}^{N} \sum_{k=1}^{K} \frac{1}{2\sigma_k^2} \left[x_k^2[i] - \left(x_k[i] - \xi_k[i] \right)^2 \right]$$

- Detector response

$$\xi_k[i] = F_{+k} h_+[i] + F_{\times k} h_\times[i]$$

- Energy split between signal and noise

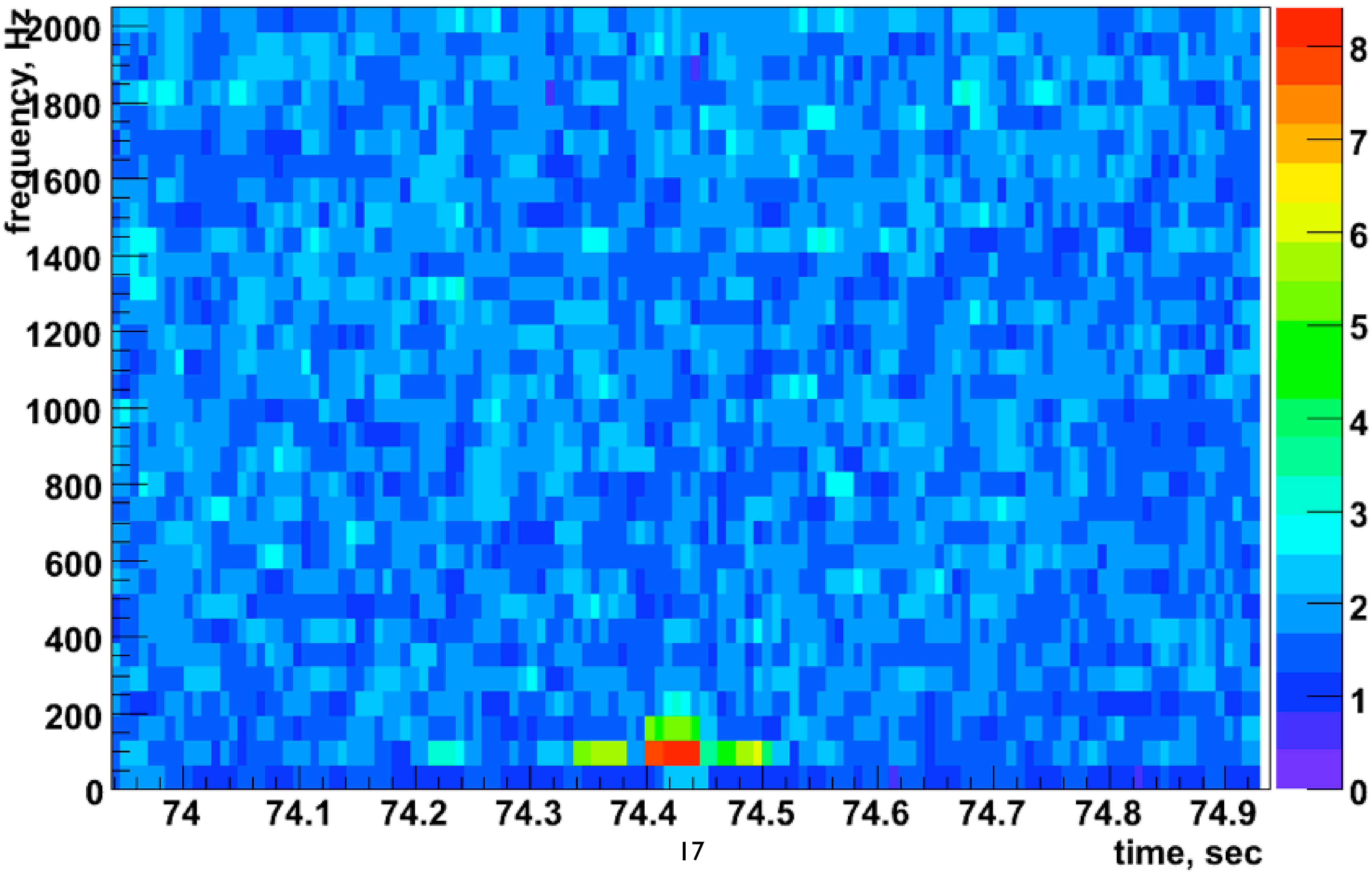
$$2\mathcal{L} = E - \mathrm{Null}$$

detected (signal) energy

total energy

noise (null) energy

Likelihood Time-Frequency Map



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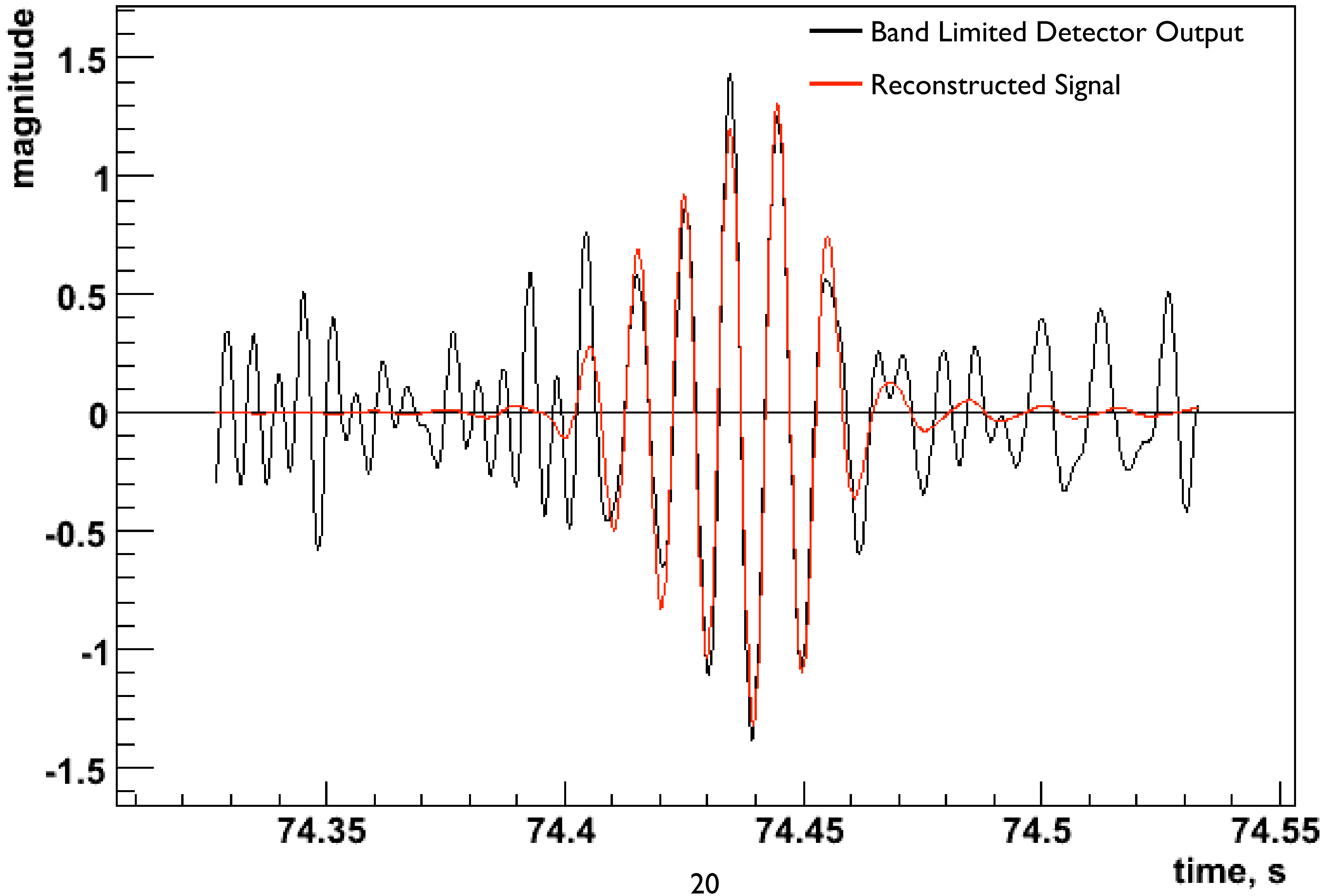
Reconstructed Detector Responses

- Reconstructed detector responses and gravitational-wave waveforms are given by variations of the likelihood functional
- Potentially reconstructed waveforms and detector responses can be compared to source models for extraction of source parameters, if such models are available

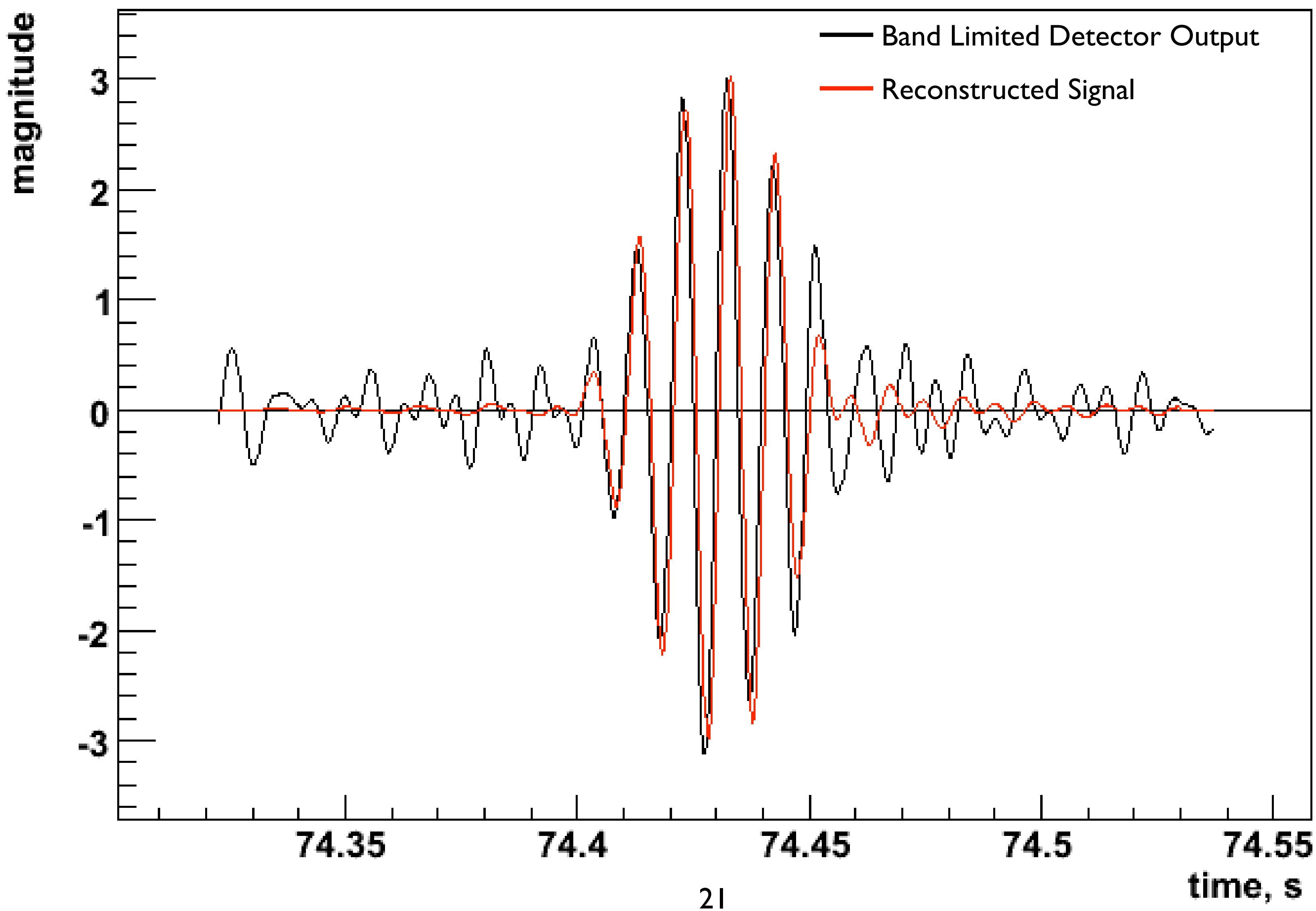
LI

Simulated GW Injection
LIGO Network



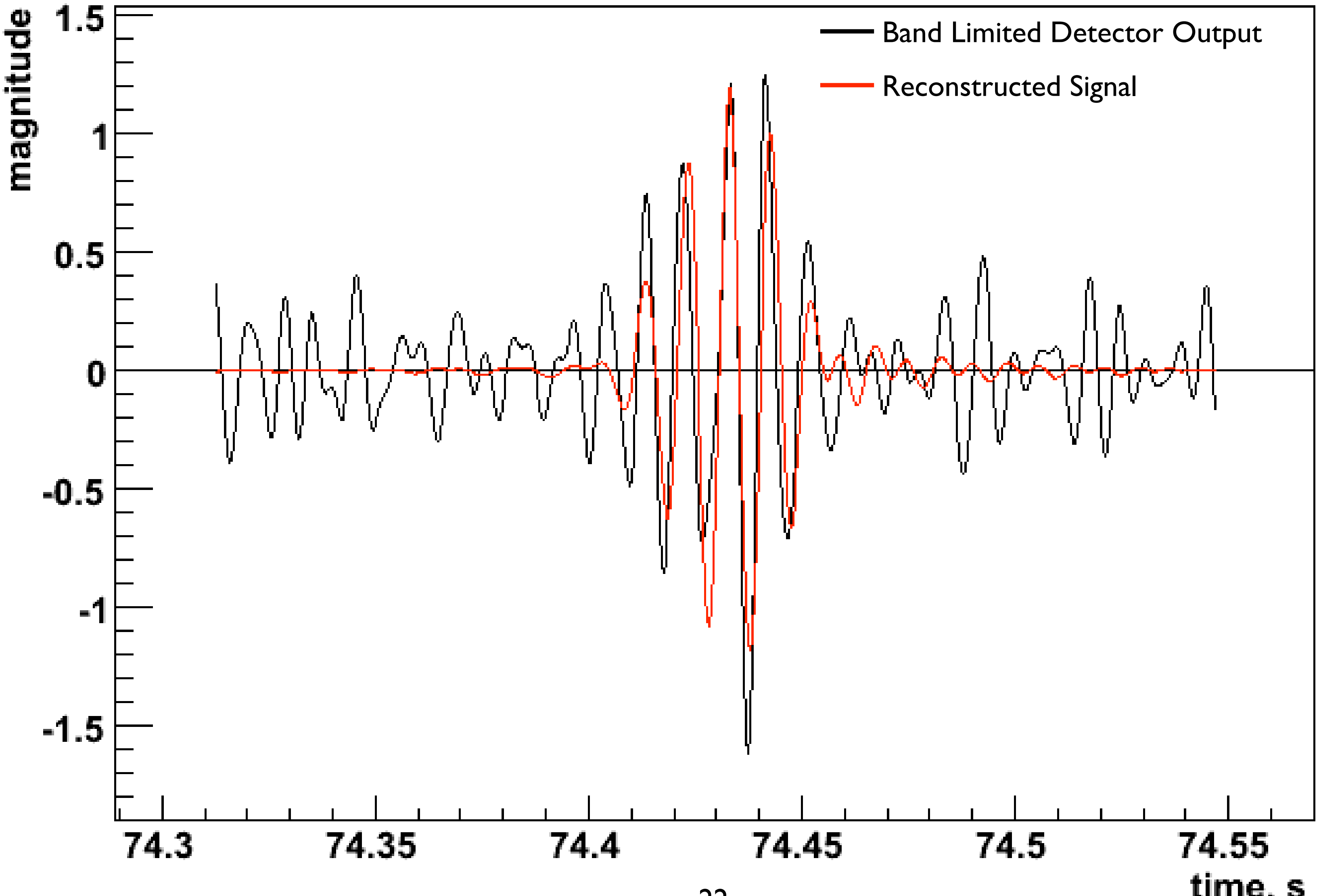
H1

Simulated GW Injection
LIGO Network



H2

Simulated GW Injection
LIGO Network



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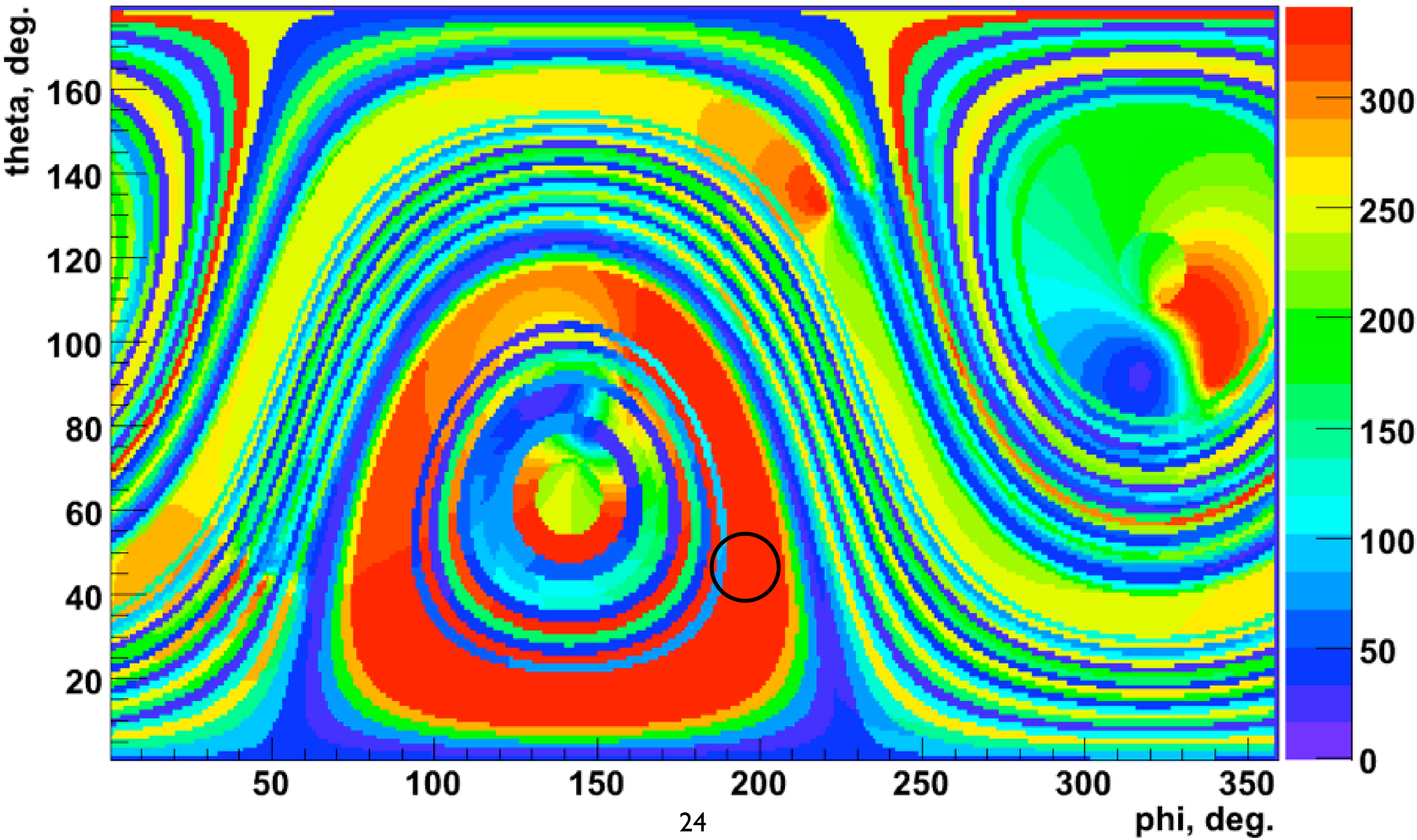
Likelihood

Simulated GW Injection
LIGO Network



Correlation

- Detected energy

incoherent — coherent

$$2\mathcal{L} = \sum_{mn} C_{mn} \langle x_m x_n \rangle = E_{m=n} + E_{m \neq n}$$

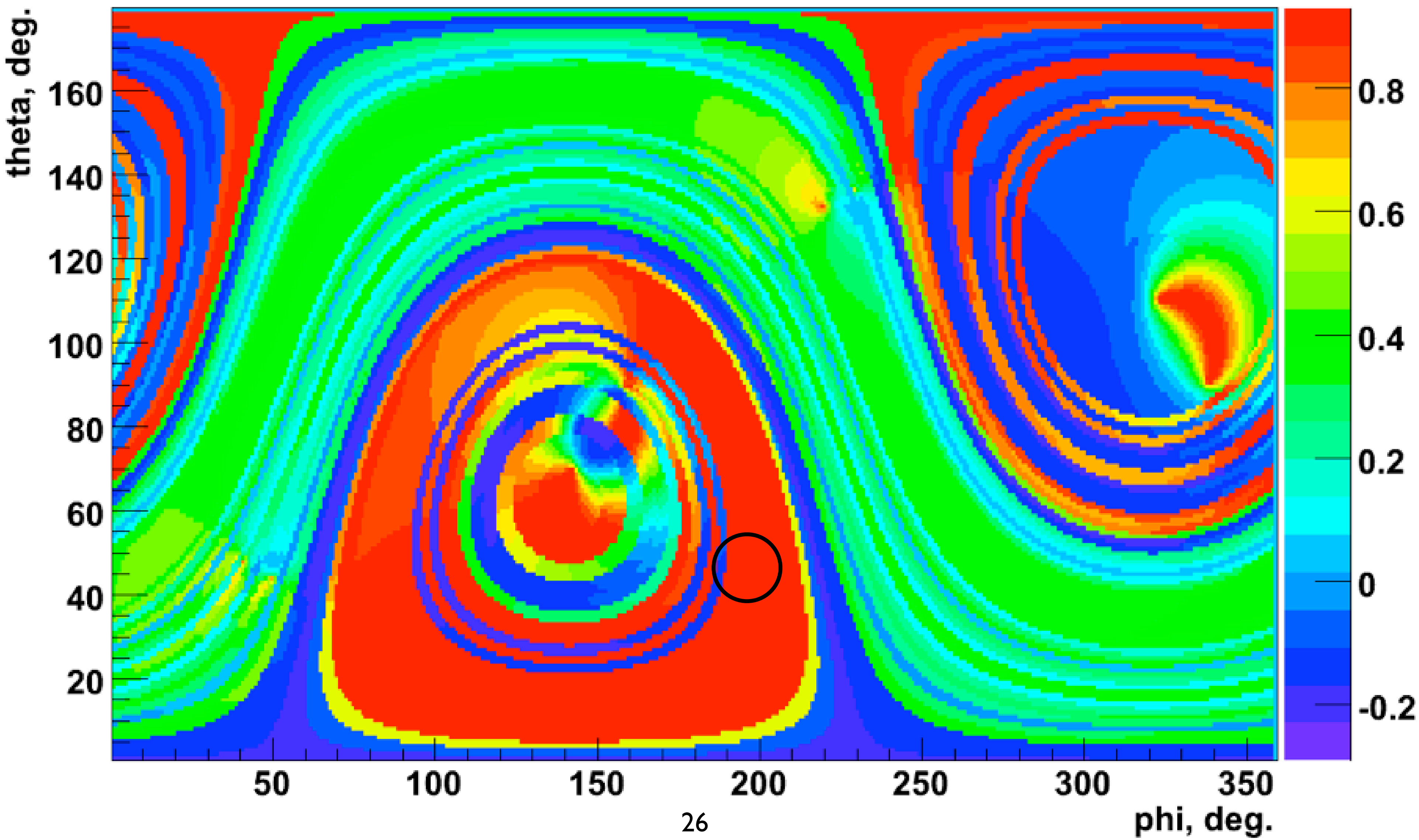
- Network correlation

$$C_{\text{net}} = \frac{E_{m \neq n}}{\text{Null} + E_{m \neq n}}$$

- Used for post-production selection of triggers

Correlation

Simulated GW Injection
LIGO Network



Alignment & Sensitivity

- Two important network parameters that measure the alignment and sensitivity of the network to the two components of the incident gravitational-wave

$$\mathrm{SNR}_{\mathrm{total}} = 2g\left(\left\langle h_1^2\right\rangle + \epsilon\left\langle h_2^2\right\rangle\right)$$

network sensitivity (→ g) network alignment (→ ϵ)

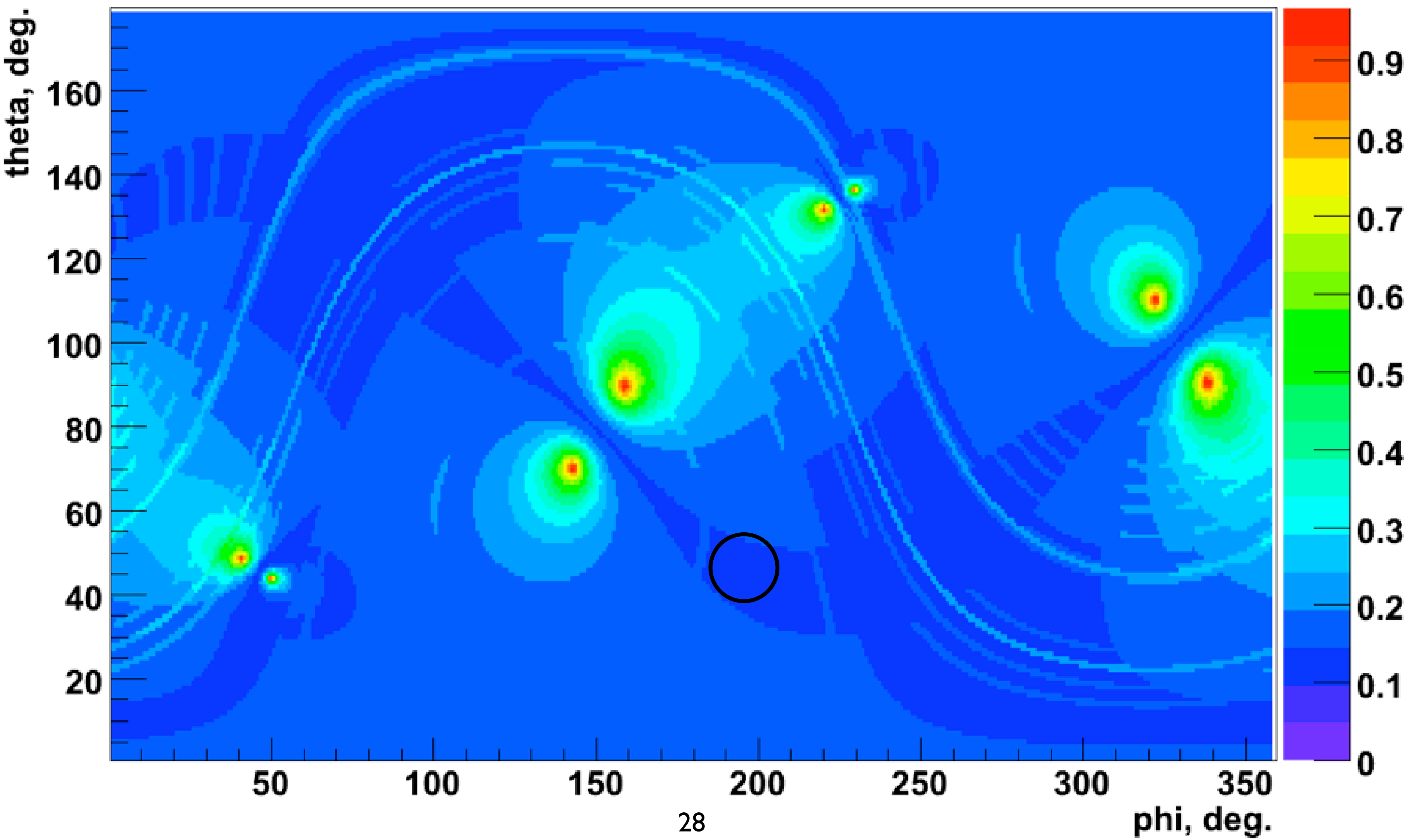
$$g = g_r + |g_c| \qquad \epsilon = \frac{g_r - |g_c|}{g_r + |g_c|}$$

- Network antenna patterns

$$g_r = \sum_{k=1}^{K} \frac{F_{+k}^2 + F_{\times k}^2}{4\sigma_k^2} \qquad g_c = \sum_{k=1}^{K} \frac{\left[F_{+k} + iF_{\times k}\right]^2}{4\sigma_k^2}$$

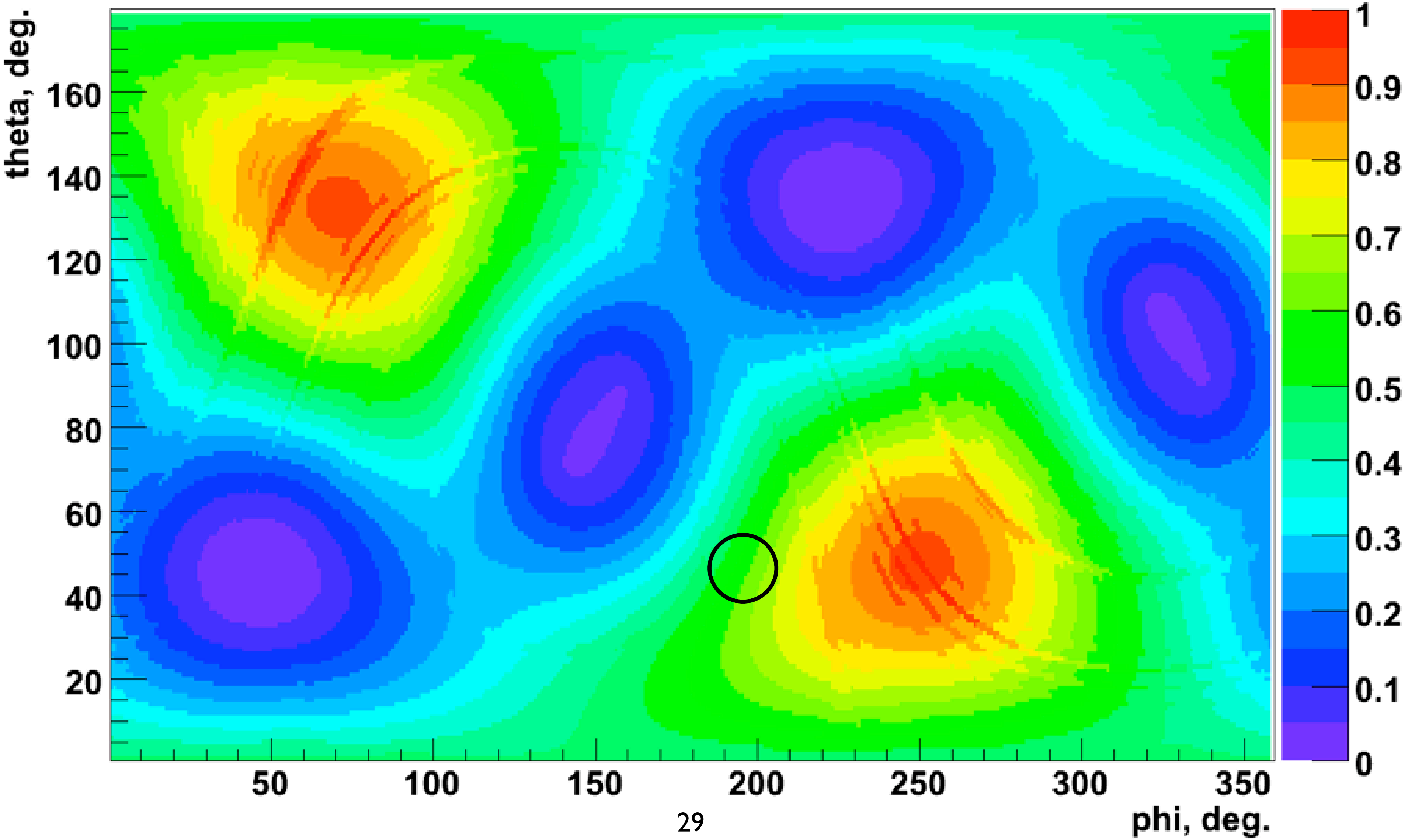
Alignment

Simulated GW Injection
LIGO Network



Sensitivity

Simulated GW Injection
LIGO Network



Conclusions

- Coherent tool for event candidate visualisation
- Coherent follow up analysis
- Based upon the Coherent WaveBurst algorithms
- Currently supports LIGO and LIGO/GEO detector networks
- Extendible to other networks

Extra Slides

Time Lags

- Introduce time lags to obtain an estimate of the false alarm rate due to random coincident noise in the detectors
- Shift data from one detector relative to the other detectors in the network
- Apply a time shift τ to first detector
- $S_1(t + \tau)$, $S_2(t)$ and $S_3(t)$ treated as being coincident