LIGO

LIGO Burst Search Analysis

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Burst Search Goals

- **Search for gravitational wave bursts of unknown origin**
  - » The waveform and/or spectrum are a-priori unknown
  - » Short duration (typically < 0.2 s)
  - » *Level 1 goal:* upper limit expressed as a bound on rate of detected bursts from fixed-strength sources on a fixed-distance sphere centered around Earth
    - – Result expressed as excluded region in a rate vs strength diagram
  - » *Level 2 goal:* upper limit expressed as a bound on rate of cosmic gravitational wave bursts (vs strength)
    - – Nominal signal model:fixed strength 1 ms width Gaussian pulse distributed according to galactic model

- **Search for gravitational wave bursts associated with gamma ray bursts**
  - » Unknown waveform, spectrum (Finn et al. Phys.Rev. D60 (1999) 12110)
  - » Bound gravitational wave burst strengths coincident with gamma-ray bursts
    - – No signal model: focus on inter-detector cross-correlation immediately preceding GRB

Untriggered Burst Search

Classical problem of extraction of <u>signal</u> in presence of <u>noise</u>

   Complication: <u>unknown signal morphology</u>

Apply filters to the strain time series
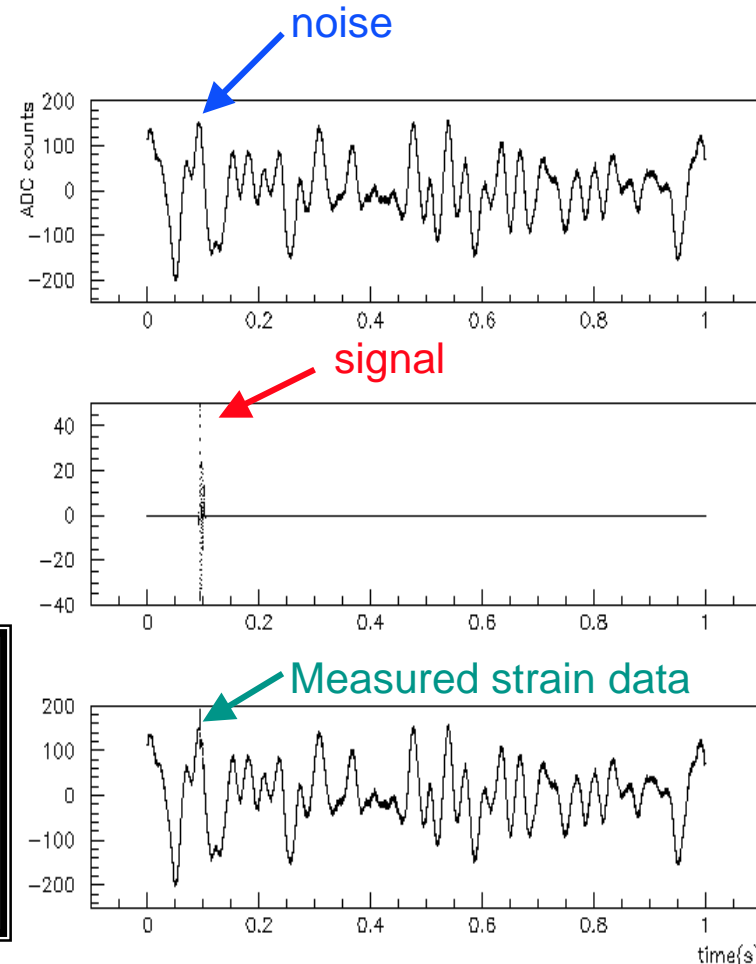
Generate a list of *candidate event triggers*

   Event trigger: indicator for gravitational wave events, characterized by:
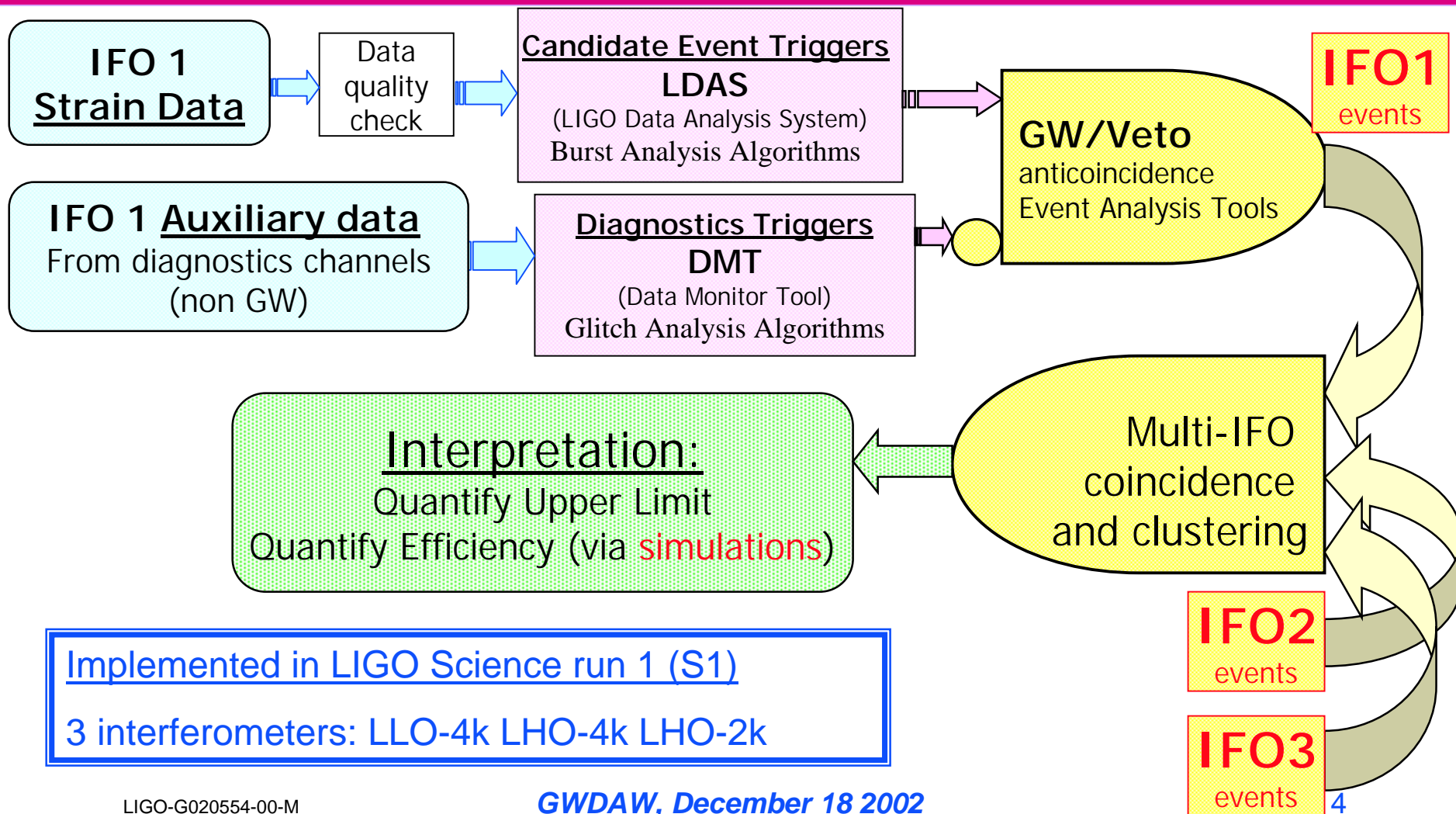
   T, ΔT, SNR, (frequency, bandwidth)

Method:

Tune thresholds, veto settings, simulation, learn and test analysis methods in a playground data set (~10% of total).

After all parameters are set, analyze the remaining 90%

noise

signal

Measured strain data

Burst Analysis Pipeline

LIGO

IFO 1 Strain Data

Data quality check

Candidate Event Triggers
LDAS
(LIGO Data Analysis System)
Burst Analysis Algorithms

IFO 1 Auxiliary data
From diagnostics channels
(non GW)

Diagnostics Triggers
DMT
(Data Monitor Tool)
Glitch Analysis Algorithms

GW/Veto anticoincidence
Event Analysis Tools

IFO1 events

Multi-IFO coincidence and clustering

Interpretation:
Quantify Upper Limit
Quantify Efficiency (via simulations)

IFO2 events

IFO3 events

Implemented in LIGO Science run 1 (S1)

3 interferometers: LLO-4k LHO-4k LHO-2k

Data quality issues:
Non-Stationarity and Epoch Veto

Noise Power at H1 (360 sec segments) vs UTC time
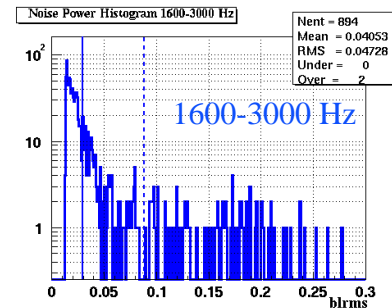
Legend:
- 320-400Hz
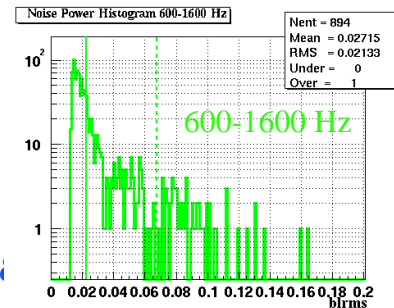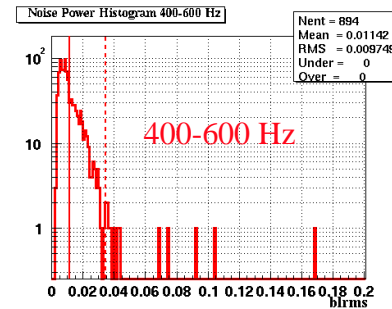- 400-600Hz
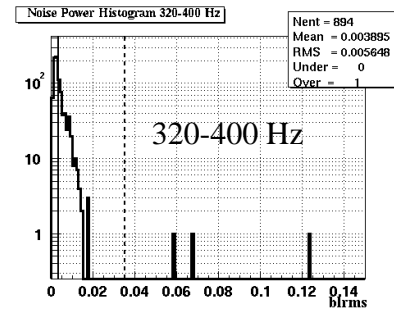- 600-1600Hz
- 1600-3000Hz
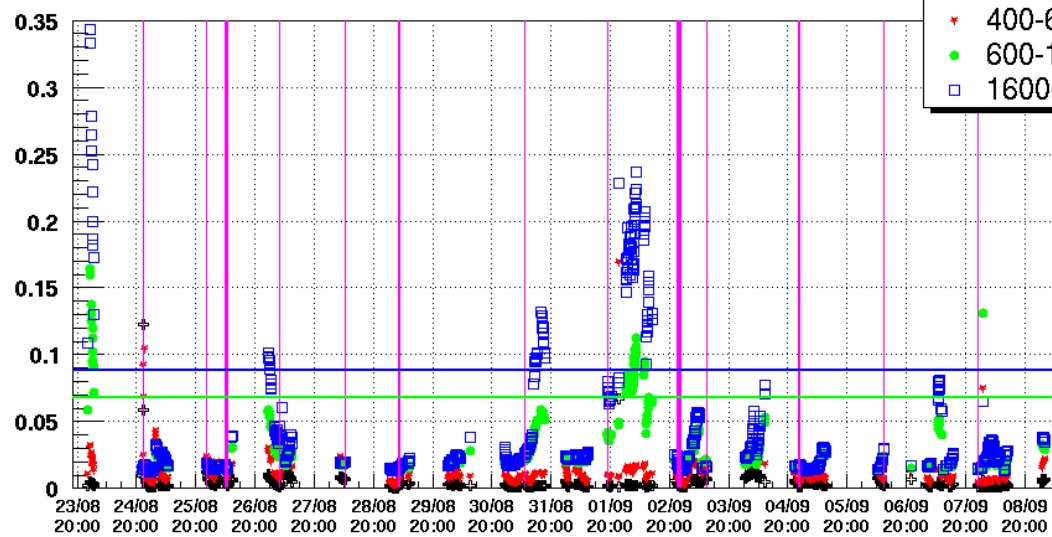
Band-Limited RMS (BLRMS)
(6 min segments)
Non-stationary noise
*Here shown for S1:
Hanford-4km (H1)*

Strategy in the S1 analysis:
Veto certain epochs based on excessive BLRMS noise in some Bands (3σ cut, σ=68-percentile)

Event Trigger Generators

Several methods, sensitive to different morphologies? Combine them?

- **"Slope"**
  - » *Time domain* search: evaluate "best line" through interval (~1 ms) of data. When the slope exceeds threshold, generate a trigger. (Pradier et al. Phys.Rev. D63 (2001) 04200)
- **"TFCluster"**
  - » Search the *time-frequency plane* for clusters of pixels with excess power (Sylvestre, accepted Phys. Rev. D)

- **"Power"**
  - » Tiles with excess power in the *time-frequency plane* (Anderson et al., Phys.Rev. D63 (2001) 042003)
- **"BlockNormal"**
  - » *Change-point analysis*: look for changes in time of mean, variance of data as signal of GW burst onset (Finn & Stuver, in progress)
- **"WaveBurst"**
  - » Time-frequency analysis in *wavelet domain* (Klimenko & Yakushin, in progress)

Diagnostics triggers and Veto

glitch finders: absGlitch/GlitchMon
on auxiliary channels
absolute threshold in time domain

Definitions:

Veto efficiency $\varepsilon_V = N_{vetoed}/N_{detected}$
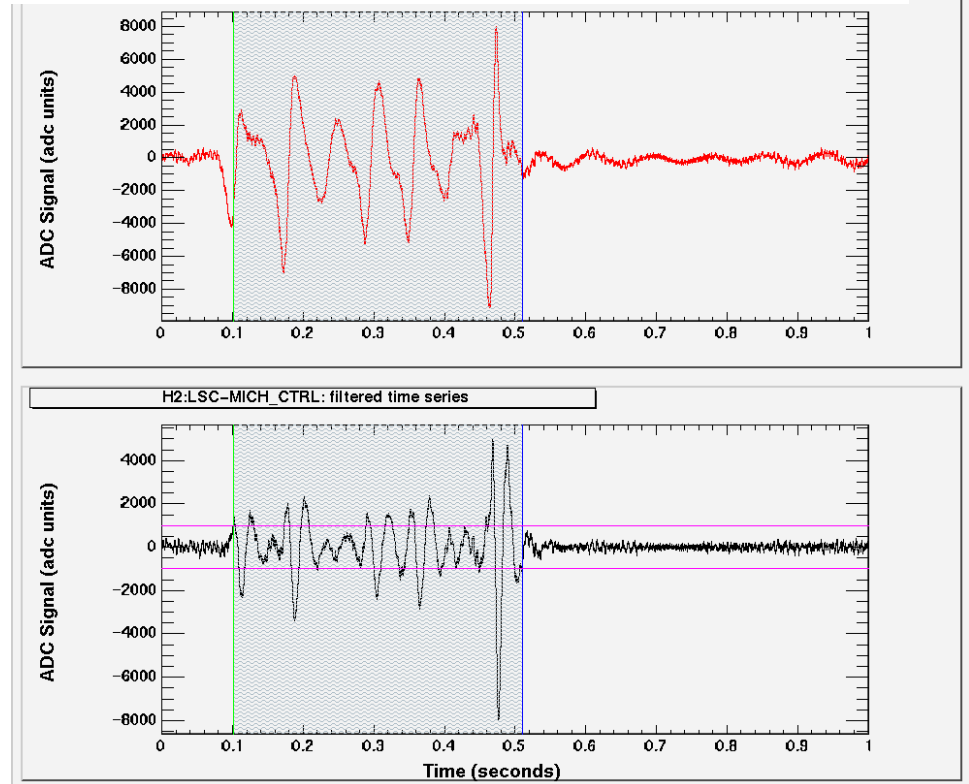
Deadtime fraction $\tau = T_D/T$

T = measurement time

$T_D = \Sigma t_i$ = dead time, sum of individual
diagnostics trigger durations (t_i)

Strategy:
look for statistical correlation
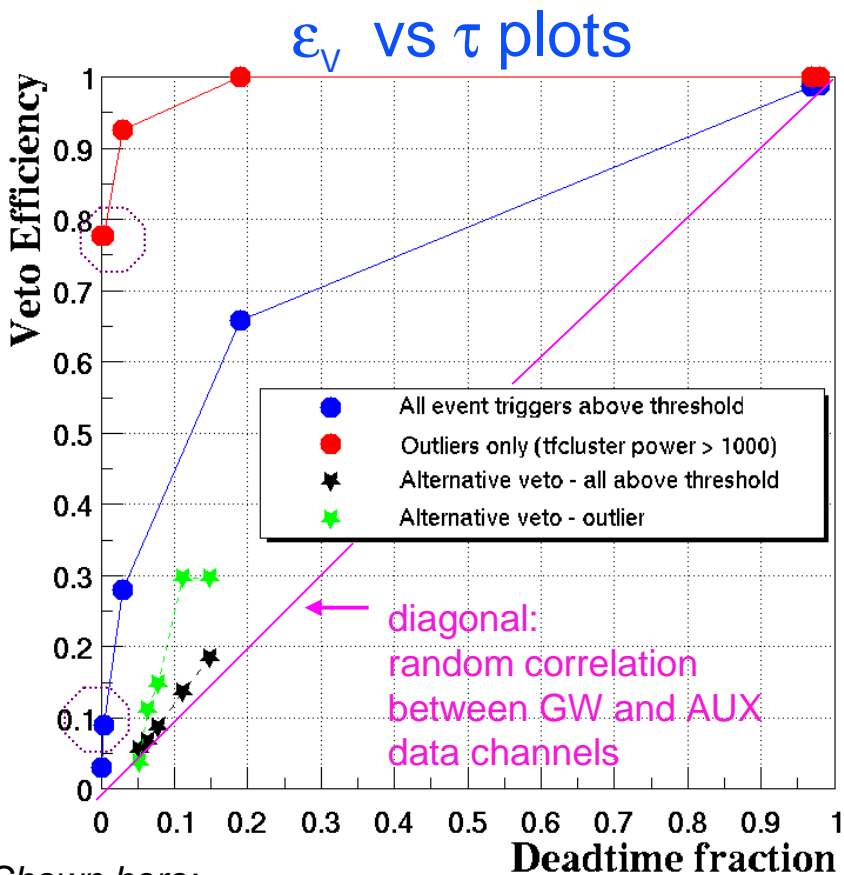between candidate events and diagnostics triggers

Example from the E7 engineering run - H2:LSC-MICH_CTRL

H2:LSC-MICH_CTRL: filtered time series

Threshold tuning for the diagnostics veto example: LHO-4k during S1

ε_V vs τ plots

All event triggers above threshold
Outliers only (tfcluster power > 1000)
Alternative veto - all above threshold
Alternative veto - outlier

diagonal:
random correlation
between GW and AUX
data channels

Shown here:
Veto channel: H1:LSC-REFL_I
Alternative:H1:LSC-REFL_Q
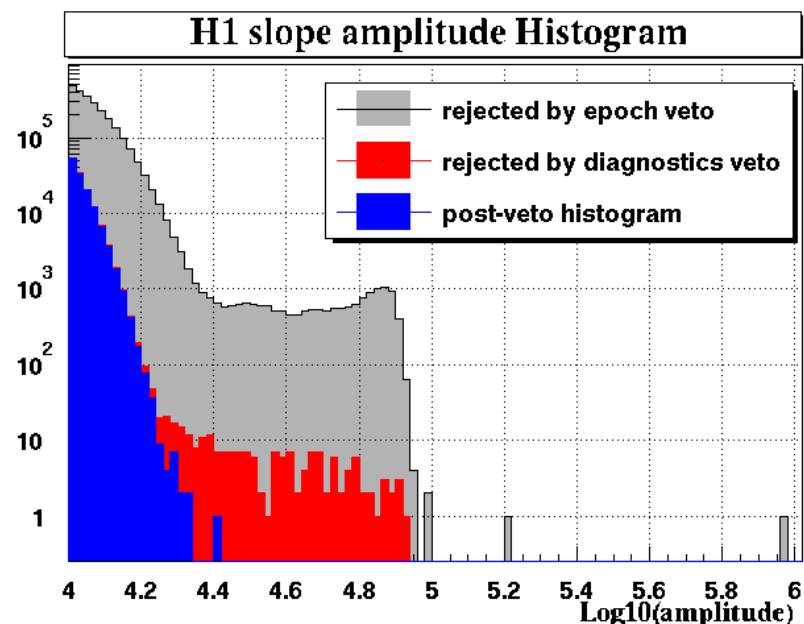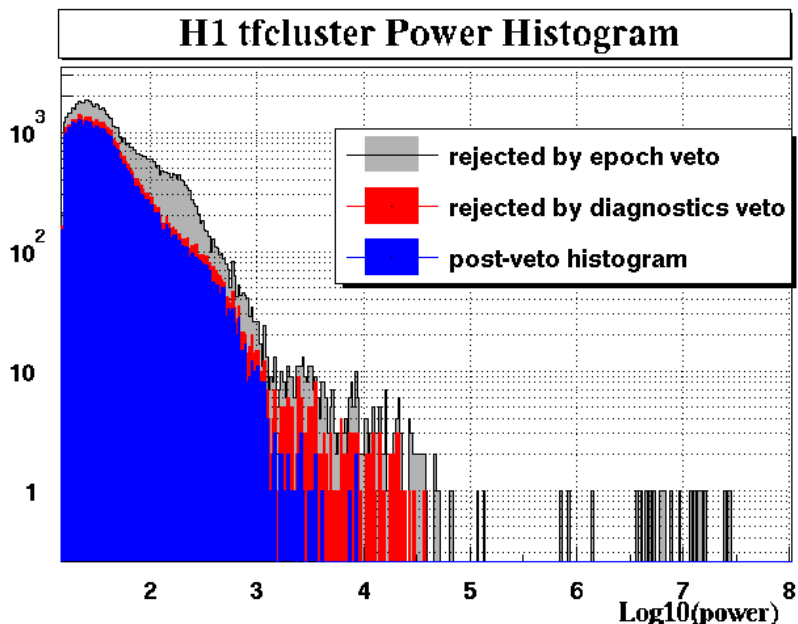
Veto lag plots

Threshold
4
6
9
10
12
14
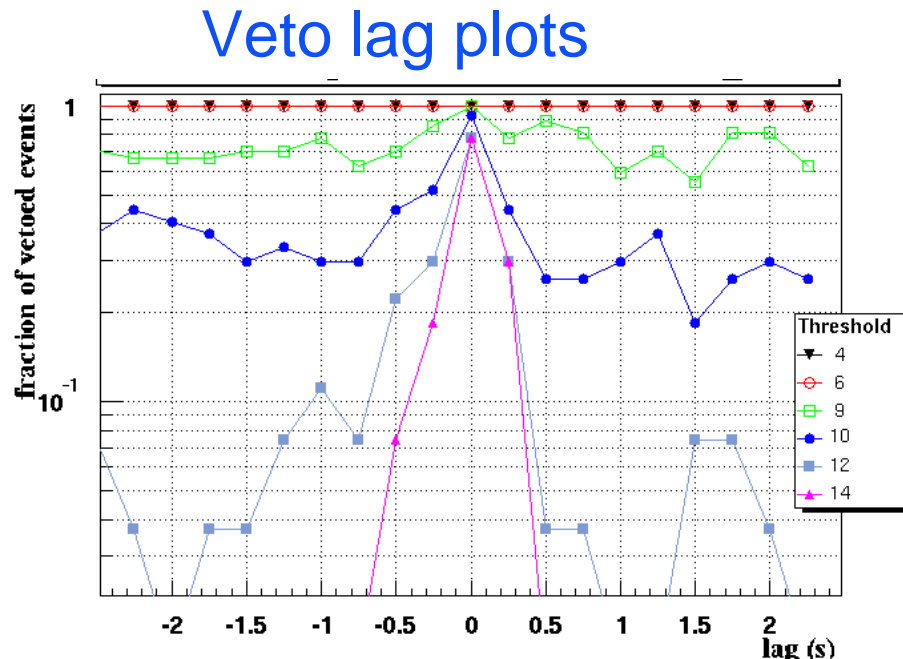
ε_V-τ plots parametrized by the veto threshold.
Use the curves to compare veto channels.
Chose threshold: trade off efficiency, deadtime, accidentals

Effect of the veto
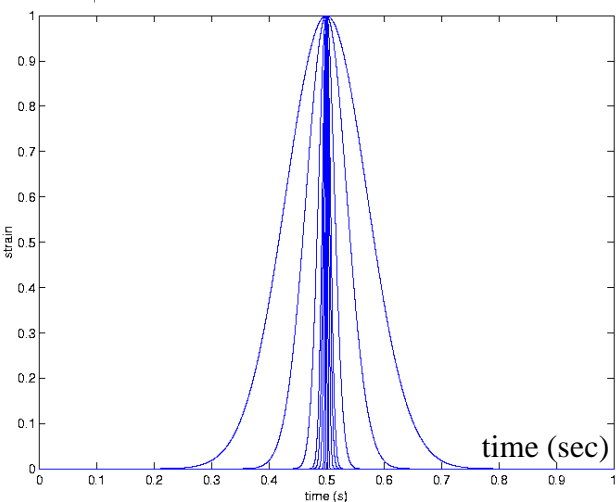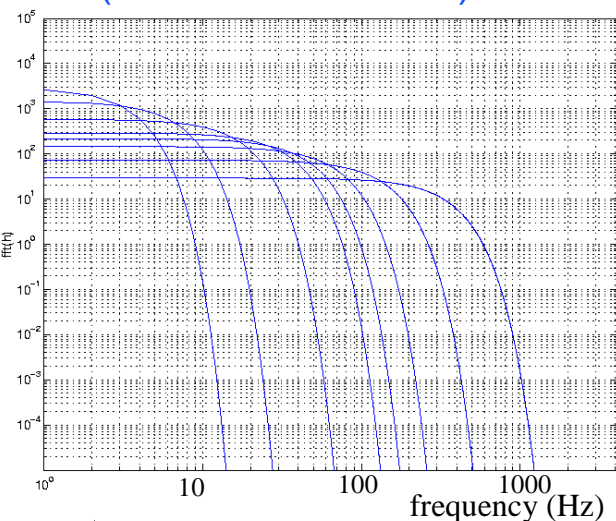## (LHO-4k example, continued)

LHO-4k histogram; ~ 90 hours triple coincidence data, ~60 hours after epoch veto
Vetoed tails/outliers with < 0.5% deadtime
Importance of ETG threshold setting

For S1, the same procedure yielded a veto for LLO-4k, but not for LHO-2k

Simulations

Gaussians
(*ad-hoc* broadband)

Sine-Gaussians
(*ad-hoc* narrowband)

f_0=554 Hz
$\tau = 3.6$ ms

Purpose:

Probe the detector response to *ad-hoc* waveforms.

Method:

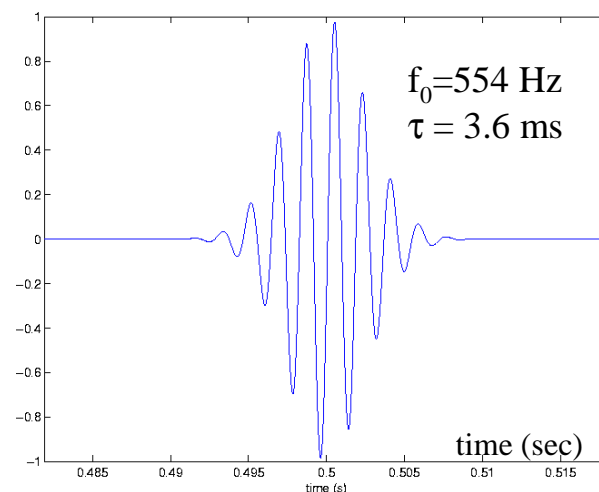Inject signal in the data stream. Retrieve it with the analysis pipeline.
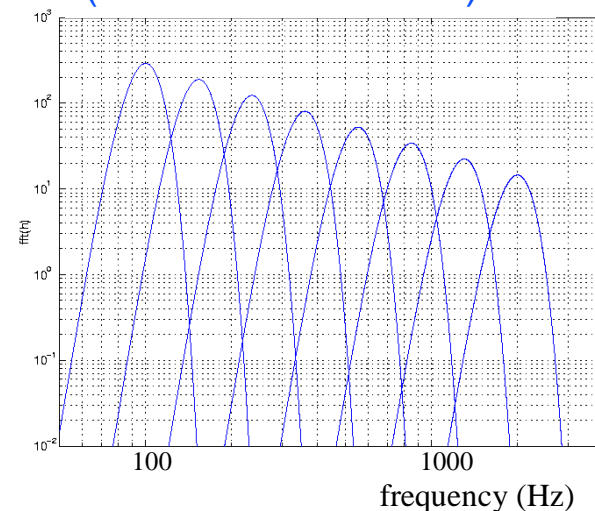
Waveforms:

Gaussians ($\leq$ 1ms)
Sine-Gaussians (Q=9)

No real astrophysical significance but well defined waveform, duration, amplitude

$\Rightarrow$ Use several amplitude to obtain efficiency vs strength curves

GWDAW, December 18 2002

Multi-IFO Coincidence

Noise always generates false signal events

• Set threshold to acceptable false rate

• Trade: better false rate, worse sensitivity to real signals

• Tails, non-stationarity can drive threshold up for same false rate

• Thresholds tuned using response to ad-hoc simulated waveforms in the S1 playground

Real signal events are correlated across Detectors, while (almost) all false events are not

$\Rightarrow$ multi-interferometer coincidence is a powerful tool to suppress the false rate

Sine-gaussian Q~9, f0 = 554 Hz Detection Efficiency - tfcluster

L1
H1
H2
Triple Coincidence
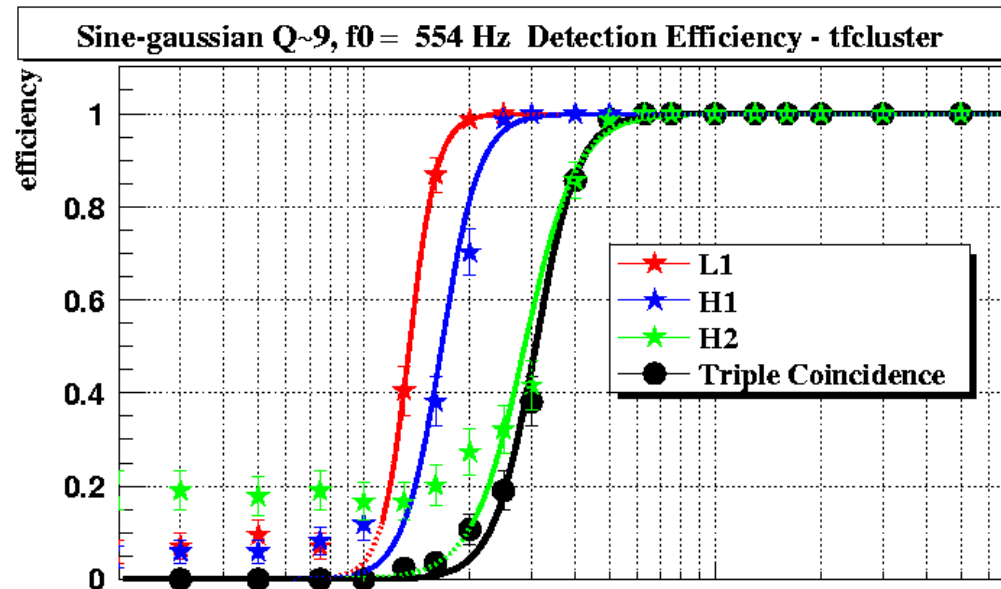
$\Rightarrow$ Require temporal coincidence between interferometers to increase sensitivity at fixed false rate *(match other characters?)*
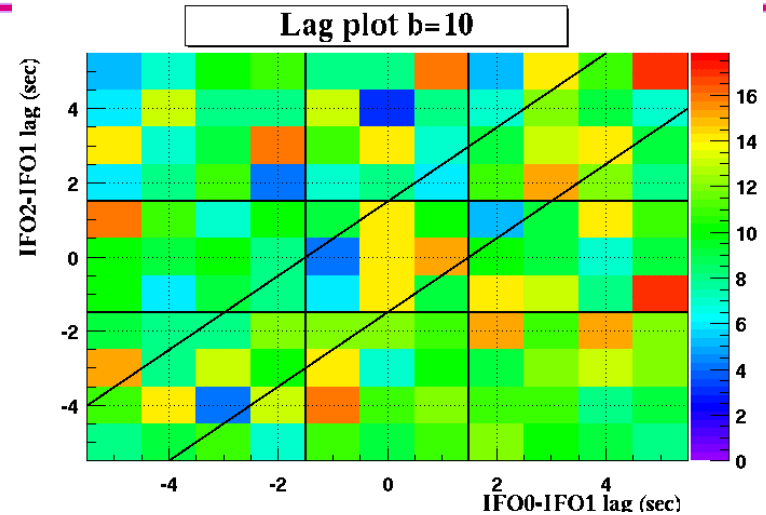
Background and Upper Limits

Background calculation:

• Introduce time-lags between pairs of IFO's and repeat the pipeline analysis $\Rightarrow b_i$

• Calculate expected background due to accidental coincidences by taking the average: $b = \Sigma b_i / N$

• Require at least 2 sec between each pair of IFO's

Shown here: toy model / example
Poissonian background, purely accidental, with mean b=10.

Upper limit on excess events:
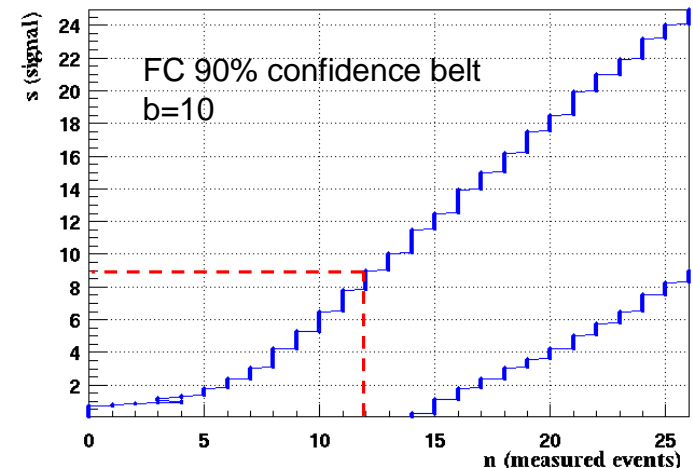
Feldman-Cousins statistics

b = average expected background
n = events in coincidence at zero lag
Get limits on the signal from the confidence belt constructed with background b
Shown here: confidence belt for b=10

Approaching an Upper Limit

- Simulation produces single-IFO efficiency curves, for optimal direction/polarization *(red, blue, green dashed, in the figure shown here)*
- Assume isotropic source population and fold in the antenna pattern *(red, blue, green continuous)*
- Combine the three detectors' response *(black)*

$\Rightarrow$ <u>Efficiency curve</u>: $\varepsilon(h_0)$

(waveform dependent!)

Shown here: 1 ms gaussian waveform

$$\text{Rate}_{max}(h_0) = \frac{\text{Upper limit on excess events}}{\varepsilon(h_0) \times \text{Live time}}$$

Bound on the rate of detected bursts from fixed-strength sources on a fixed-distance sphere centered around Earth

<u>Next steps (still under study)</u>:

Astrophysically motivated limits (depth distribution of sources)

Model-dependent limits

Efficiency vs strength curves - 1 ms gaussians, TFCluster

LLO-4k:
Zenith
Sky average

LHO-4k:
Sky average

LHO-2k:
Sky average

Combined average efficiency for triple coincidences

- - - LLO4K
— <LLO4K>
- - - LHO4K
— <LHO4K>
- - - LHO2K
— <LHO2K>
— LLO4K*LHO4K*LHO2K

Peak amplitude of simulated signal (h_0)