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>

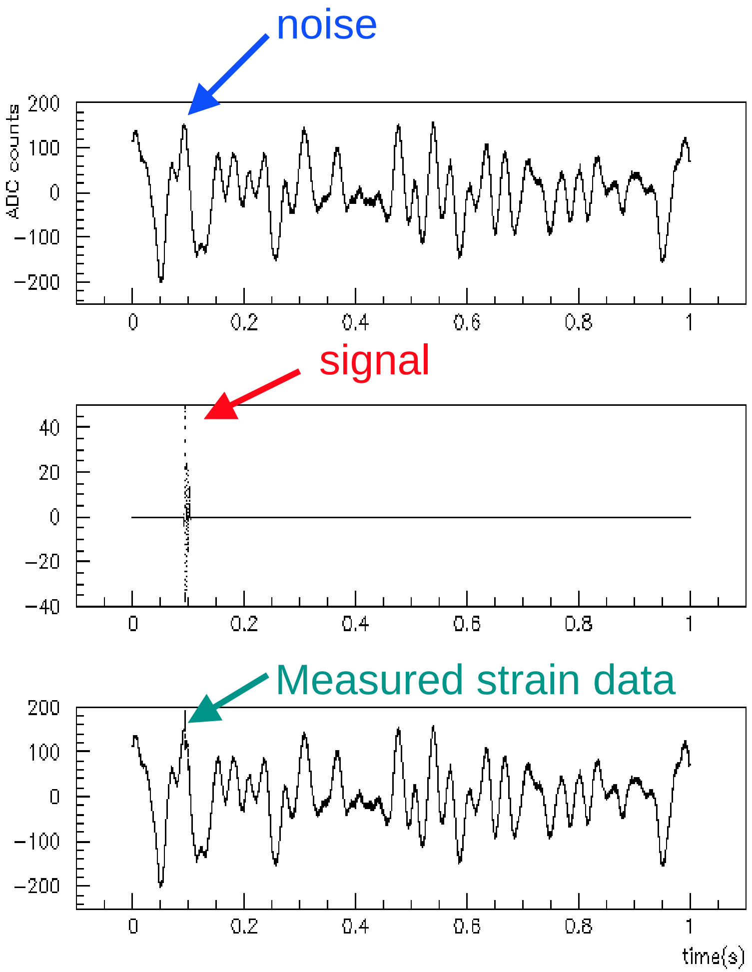
Complication: <u>unknown signal morphology</u>

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)



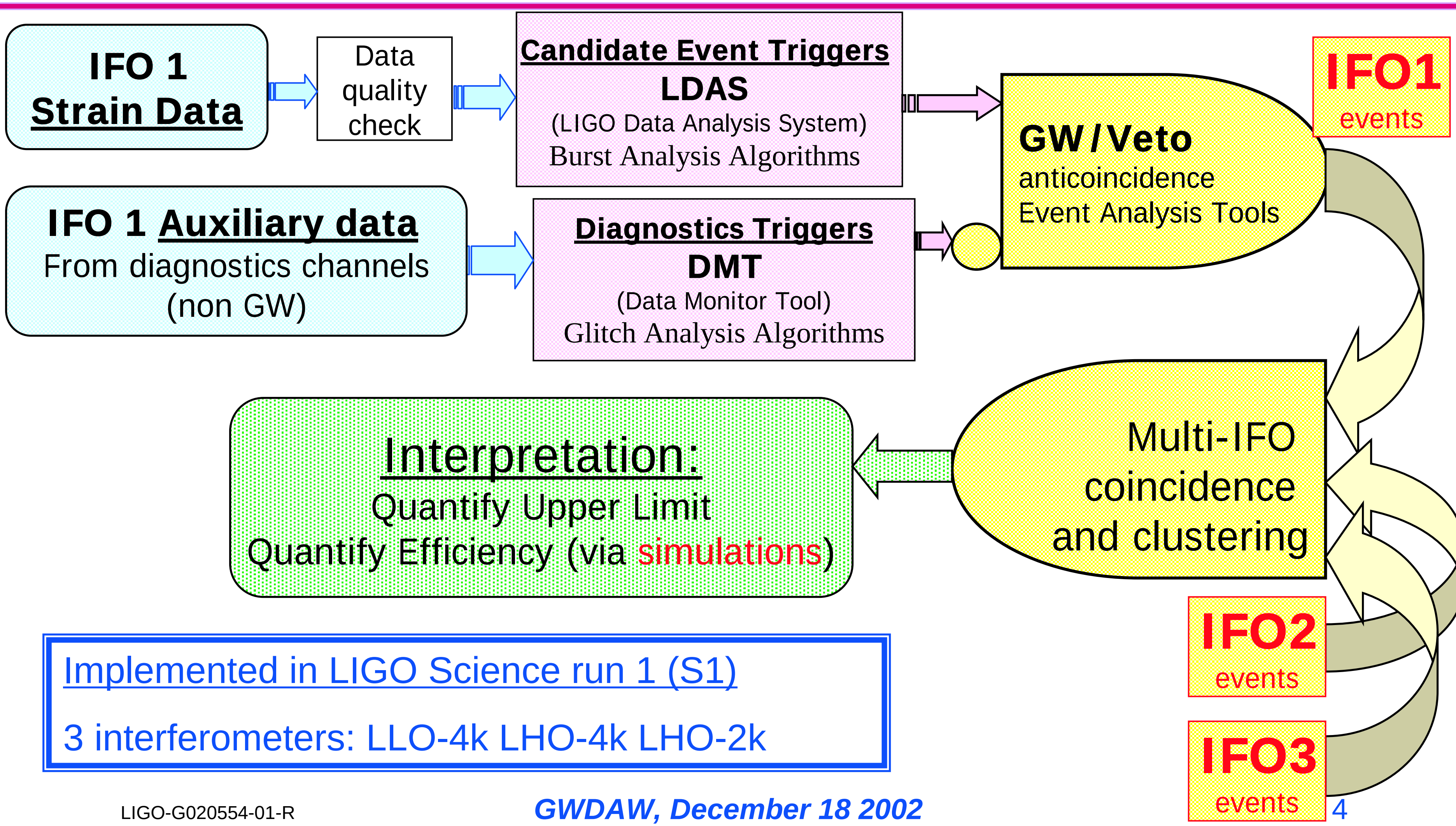
<u>Method:</u>

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%

LIGO

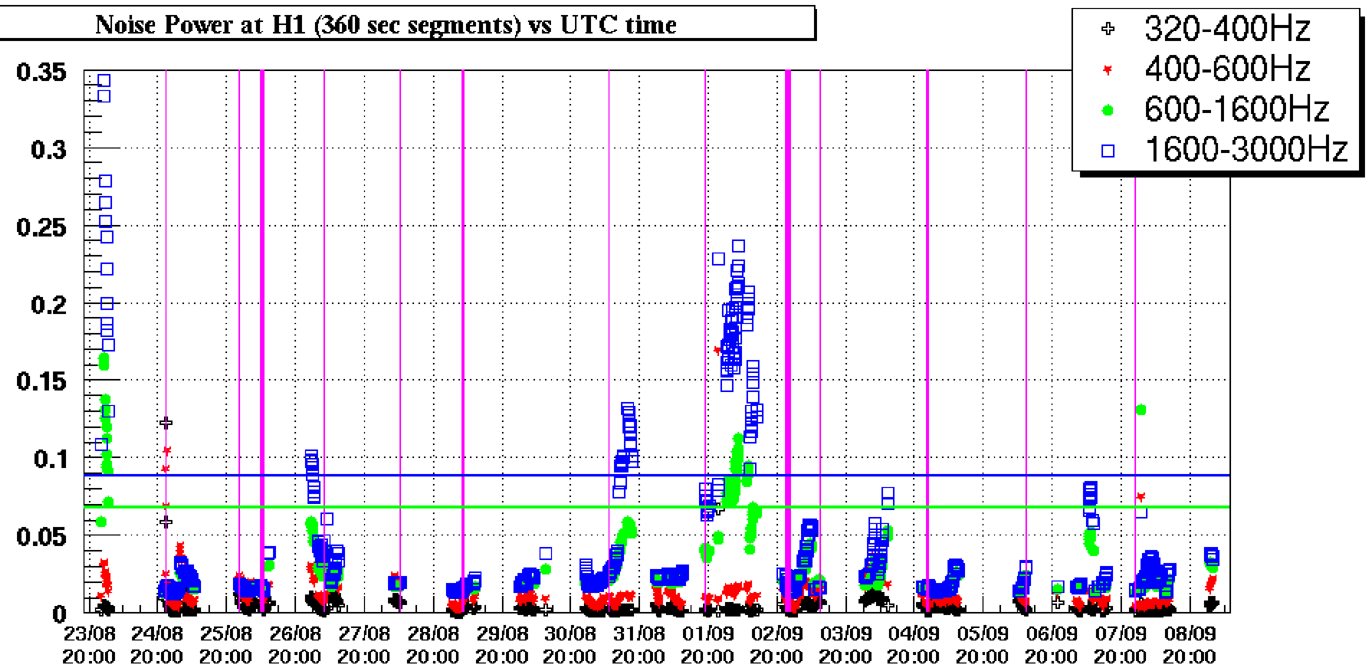
Burst Analysis Pipeline



Implemented in LIGO Science run 1 (S1)

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

Non-Stationarity and Epoch Veto



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?

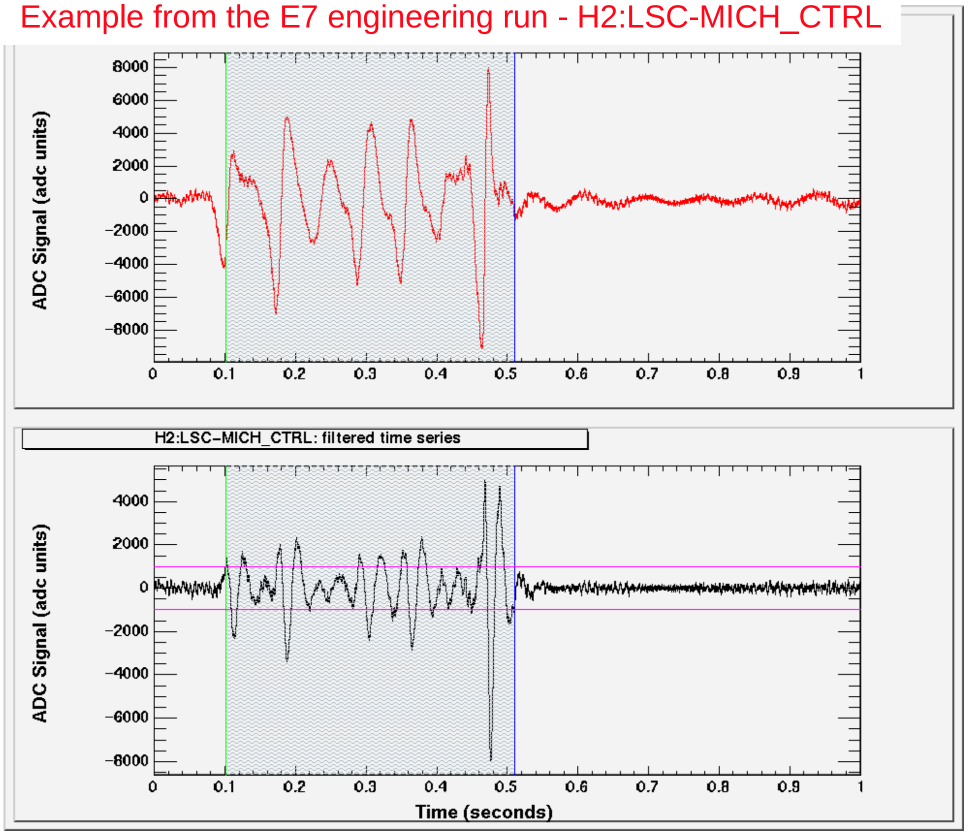
- **"Slope"**
  - *Time domain* search: evaluate "best line" through interval (~1 ms) of data. When the slope exceeds threshold, generate a trigger. (N. Arnaud et al. Phys.Rev. D59 (1999) 082002)
- **"TFCLUSTERS"**
  - Search the *time-frequency plane* for clusters of pixels with excess power (Sylvestre, gr-qc/0210043, 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

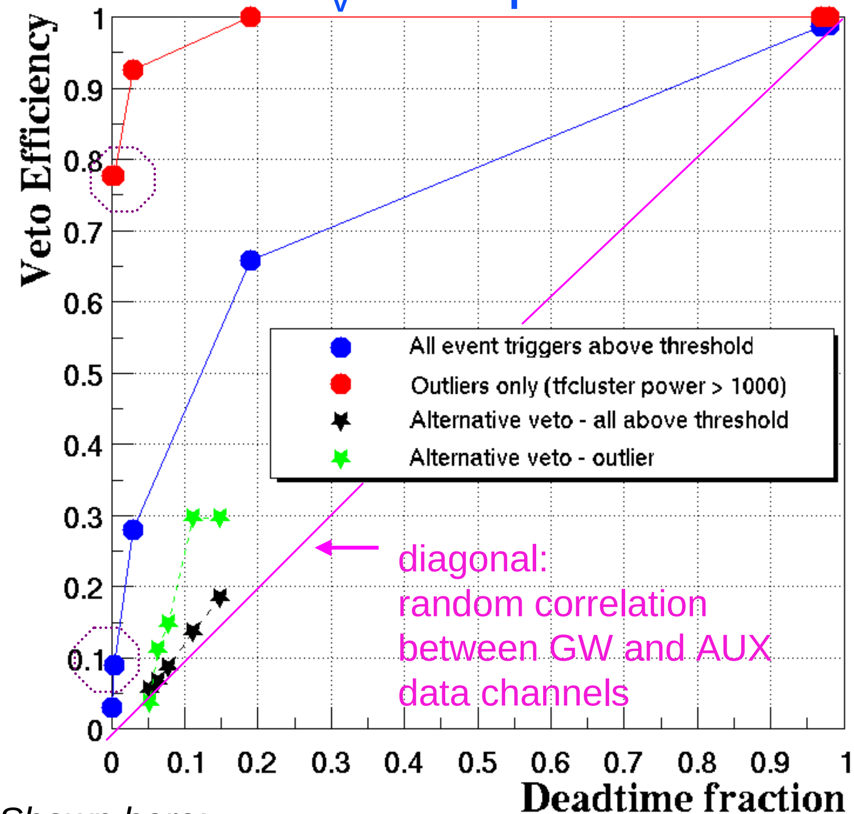
glitch finders: absGlitch/GlitchMon
on auxiliary channels
absolute threshold in time domain

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



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

ϵ_V vs τ plots



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

Definitions:

Veto efficiency $\epsilon_V = N_{vetoed}/N_{detected}$

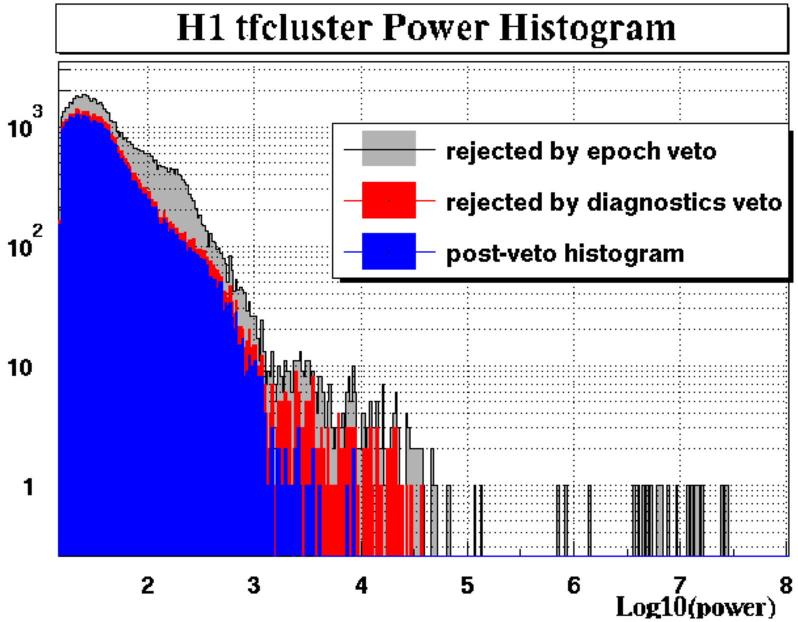
Deadtime fraction $\tau = T_D/T$

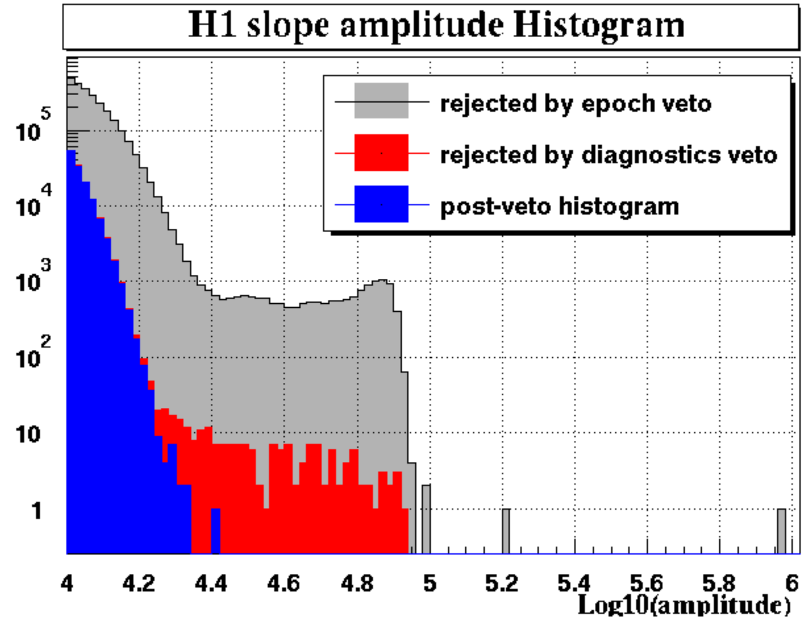
T = measurement time

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

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

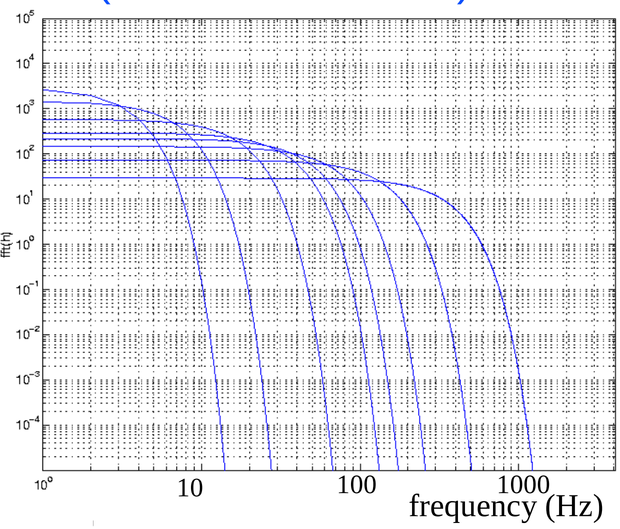
Vetoed tails/outliers with < 0.5% deadtime

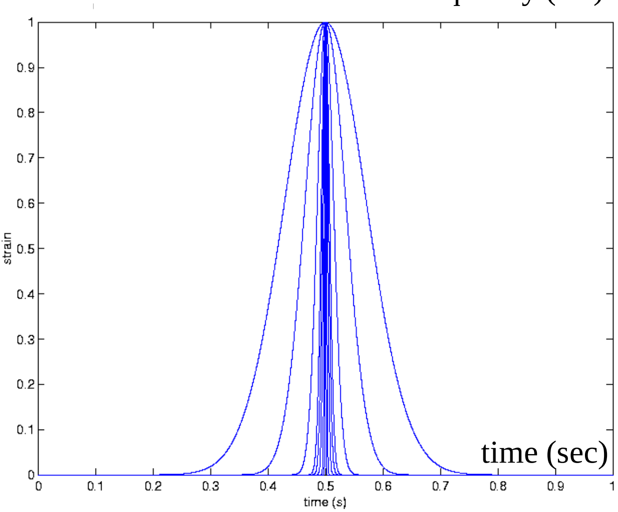
Importance of ETG threshold setting

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

Simulations

Gaussians
(*ad-hoc* broadband)





Purpose:

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

Method:

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

Waveforms:

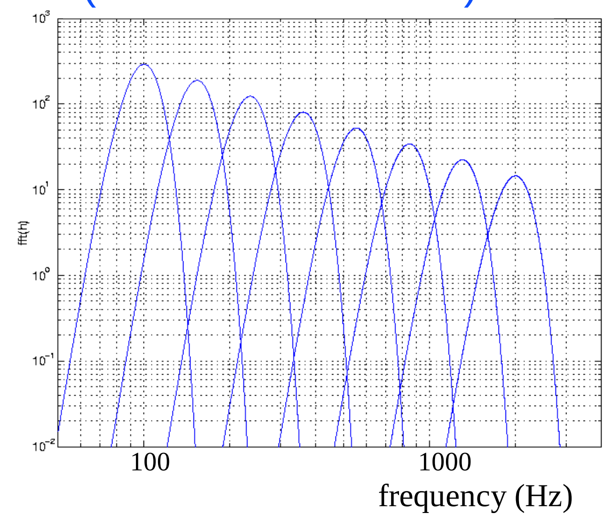
Gaussians (≤ 1ms)
Sine-Gaussians (Q=9)

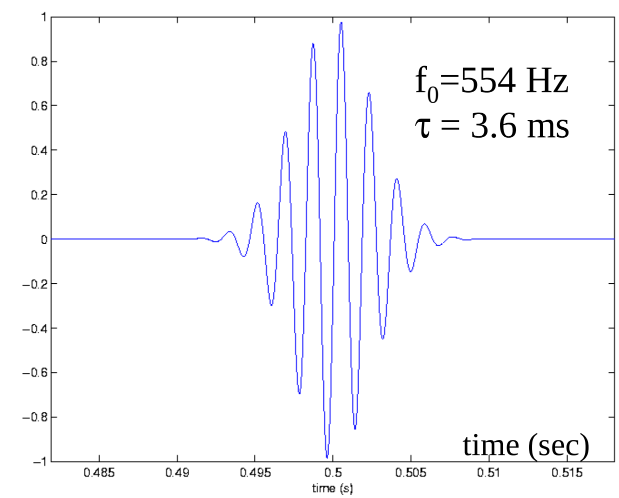
No real astrophysical significance but well defined waveform, duration, amplitude

⇒ Use several amplitudes to obtain efficiency vs strength curves

GWDAW, December 18 2002

Sine-Gaussians
(*ad-hoc* narrowband)

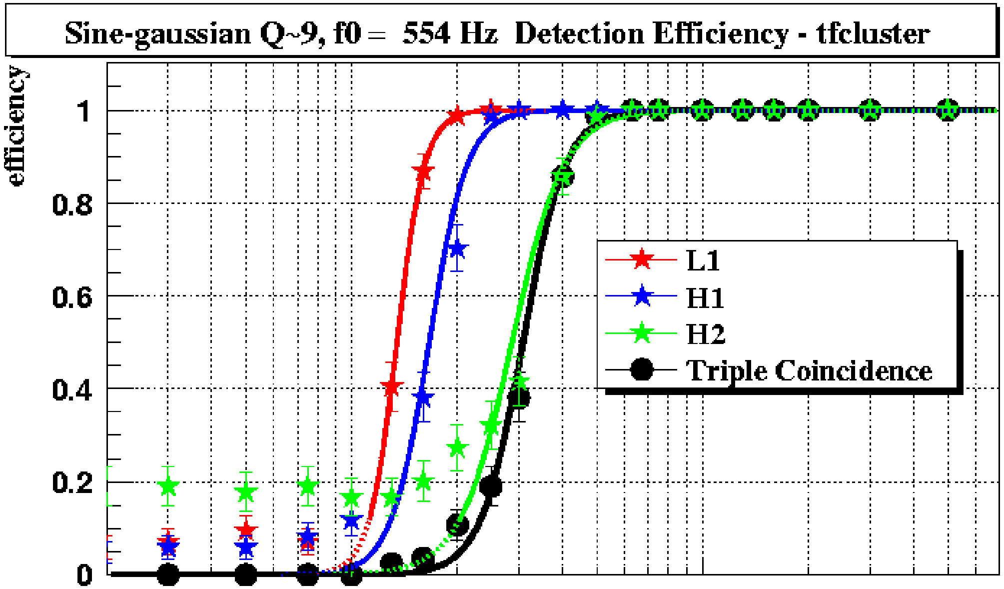




Multi-IFO Coincidence

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

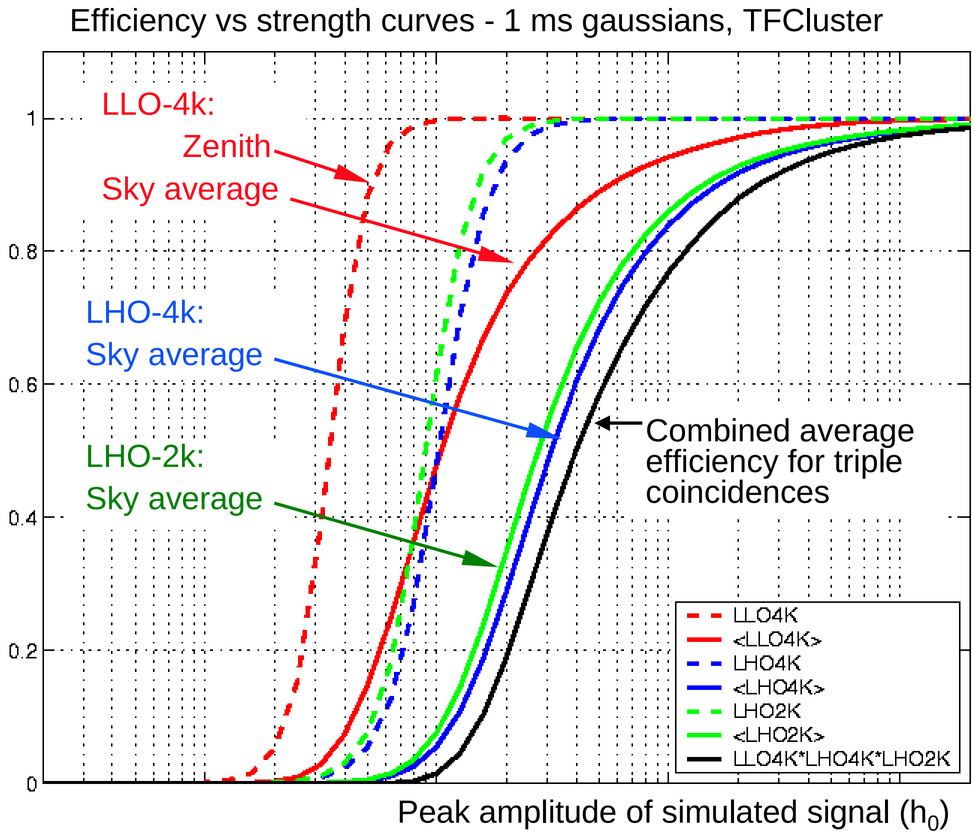
⇒ multi-interferometer coincidence is a powerful tool to suppress the false rate

> ⇒ Require temporal coincidence between interferometers to increase sensitivity at fixed false rate *(match other characters?)*

Combined efficiency curve

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

⇒ Efficiency curve: $\varepsilon(h_0)$
(waveform dependent!)
Shown here: 1 ms gaussian waveform



Background and Upper Limits

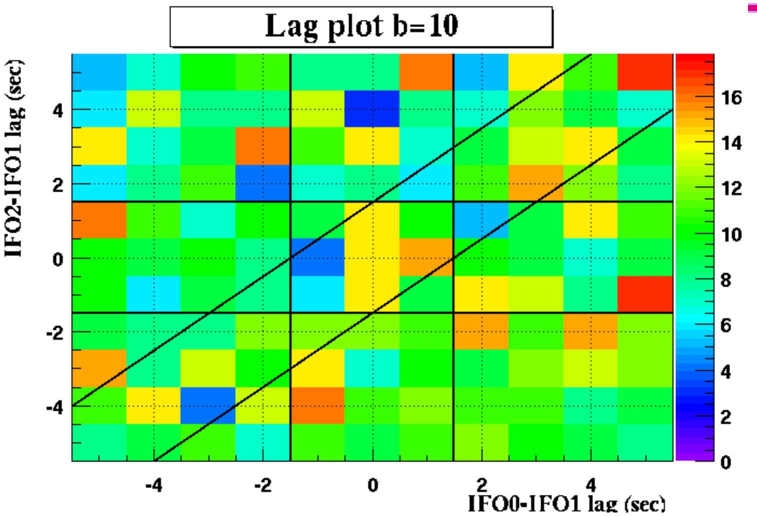
Background calculation:

• Introduce time-lags between pairs of IFO's and repeat the pipeline analysis ⇒ 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:

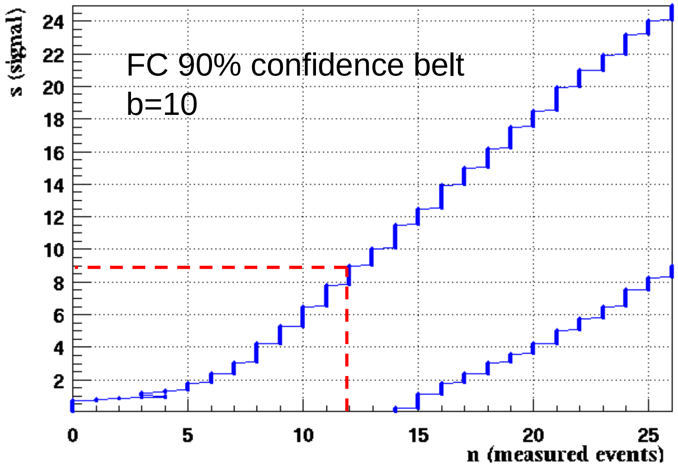
Feldman-Cousins statistics

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

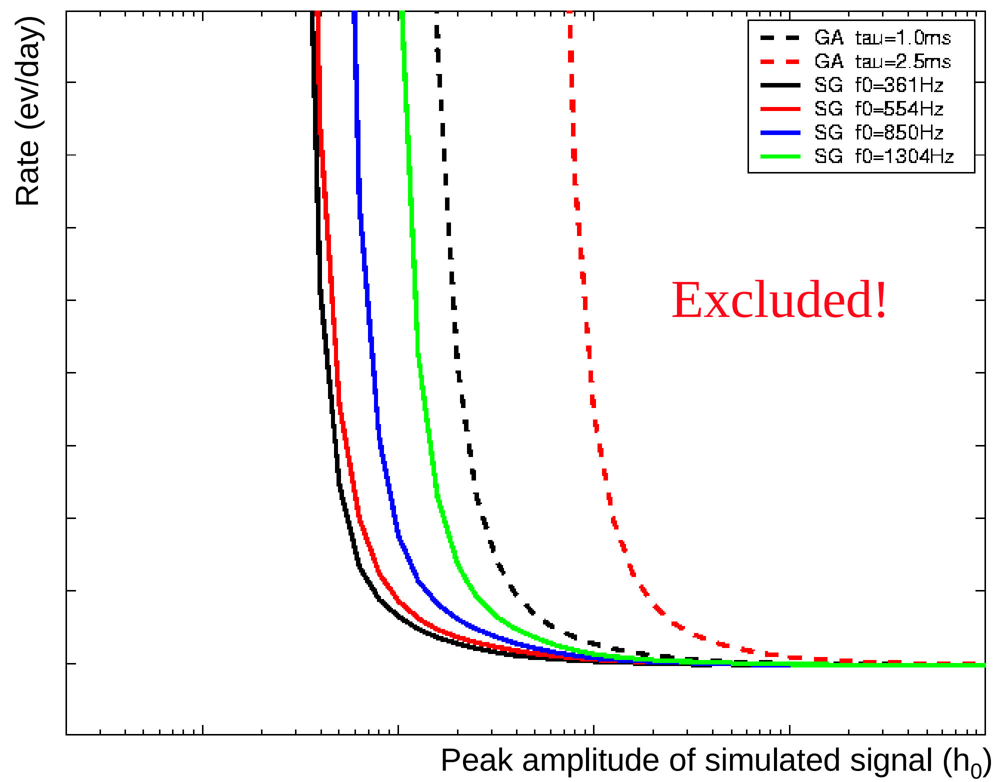


Approaching an Upper Limit

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

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

90% CL rate vs strength exclusion curves - TFCLUSTERS



Next steps (still under study):

Astrophysically motivated limits (depth distribution of sources)

Model-dependent limits