Gravitational wave burst vetoes in the LIGO S2 and S3 data analyses

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Introduction

- LIGO has been taking data in Science Mode in two different runs in 2003/2004 : S2 (feb14/apr14) and S3 (oct31/jan9)
- Gravitational wave bursts were searched in both runs looking for signals of short duration (< 1 sec) and elevated strength in the LIGO best sensitivity frequency band (100 – 1100Hz)
- Given the various noise sources in the detector and in the environment, in order to maximize the sensitivity of the search while keeping the false alarm rate low, data quality cuts (done on the data sample, before being analyzed) and event by event vetoes (which eliminate single candidate events from the final sample) were investigated

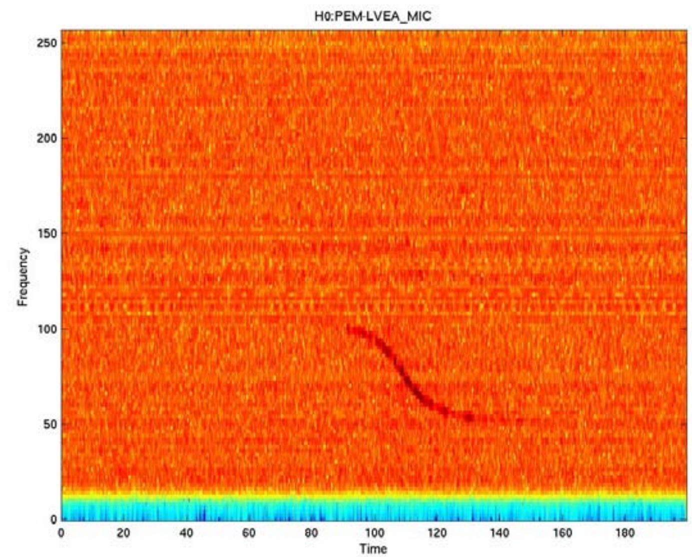
Data Quality

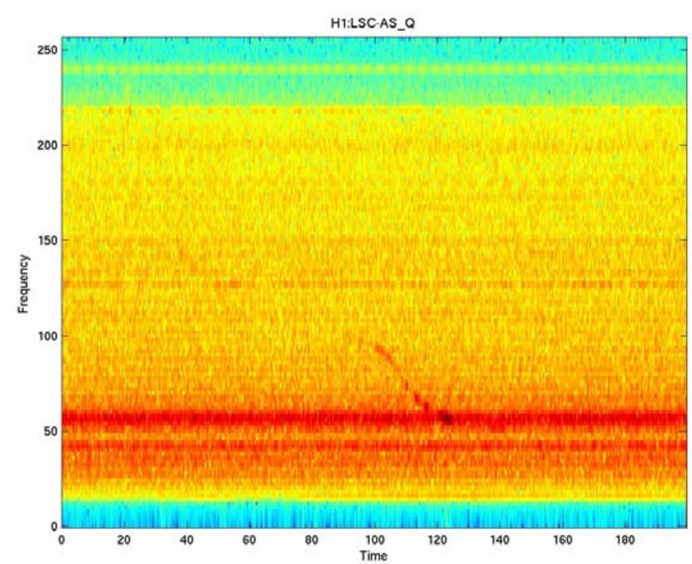
- Several factors can compromise the quality of the data enough to make it unsuitable for data analysis.
- In S2 and S3 we have observed:
  - DAQ and synchronization related problems (S2: ~0.01%);
  - Timing and missing data (S2: ~0.2%);
  - Periods of continued noise in a frequency band (S2: <1%);
  - Missing or low calibration lines (S2: ~2%);
  - Abnormal dust levels (S3);
  - Seismic noise (S3);
  - Acoustic noise (S3);
- Once recognized, time stretches in which the data quality is too low, can be flagged and eliminated from the analysis.

- It is to be noted that from S2 to S3, the detector behavior has improved making environmental factors responsible for most data quality cuts

The Acoustic Coupling

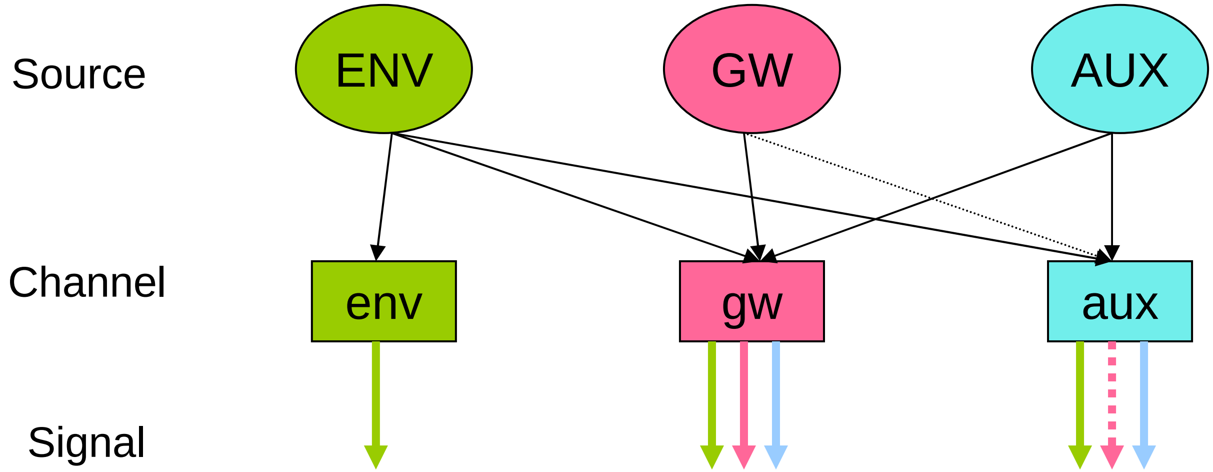
- Noise associated to airplanes flying over the sites
- Old problem, observed from the first LIGO engineering runs at Hanford
- Recent observations in the S2 data lead us to worry about it again
- The sensitivity of the instrument requires to consider it as a veto or, better, a data quality cut
- On the other hand improvements in the acoustic isolation of the instruments should prevent most of these signals to filter in the gravitational wave channel in the S3 run





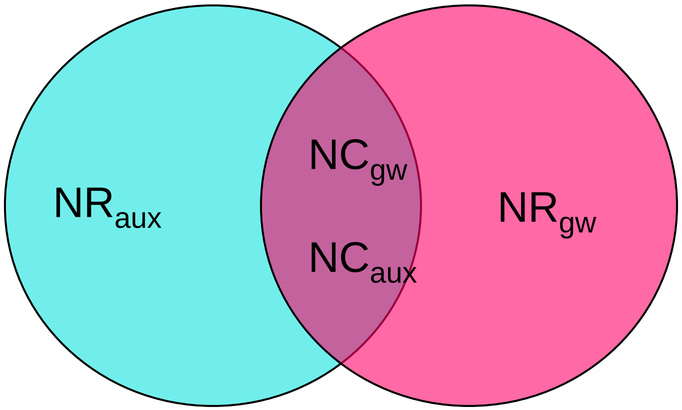
Plots by K.Rawlins (MIT)

Event by Event Veto



A signal in the gravitational wave channel could be caused by different reasons: environmental disturbances, transient noise in the detector and…gravitational waves!

Veto jargon



Playground: 10% of the data sample used to tune analysis and excluded from the analysis

- $N_{aux} = NC_{aux} + NR_{aux}$; $N_{gw} = NC_{gw} + NR_{gw}$
- Efficiency = NC_{gw} / N_{gw}
- Success Ratio or Use Percentage = NC_{aux} / N_{aux}
- DeadTime = $(\Sigma\ \Delta t_{aux})$ / Total Playground duration
- Effective DeadTime = Loss of efficiency in detecting a gravitational wave burst – computed using simulated waveforms

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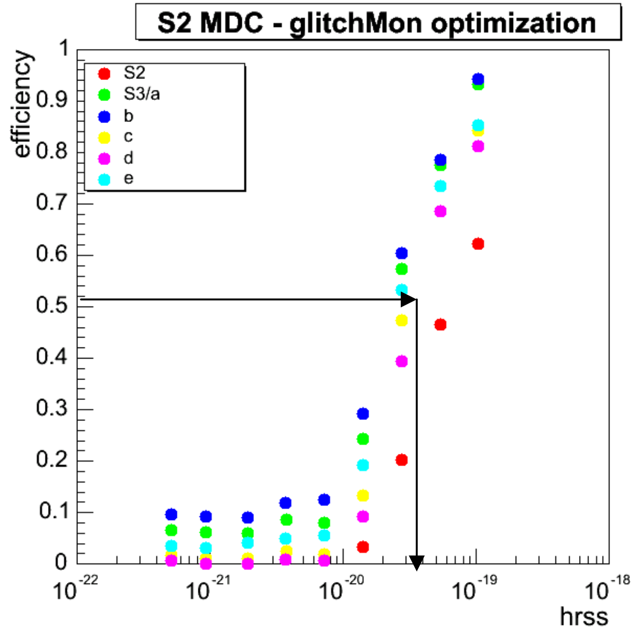
Glitch finding algorithms

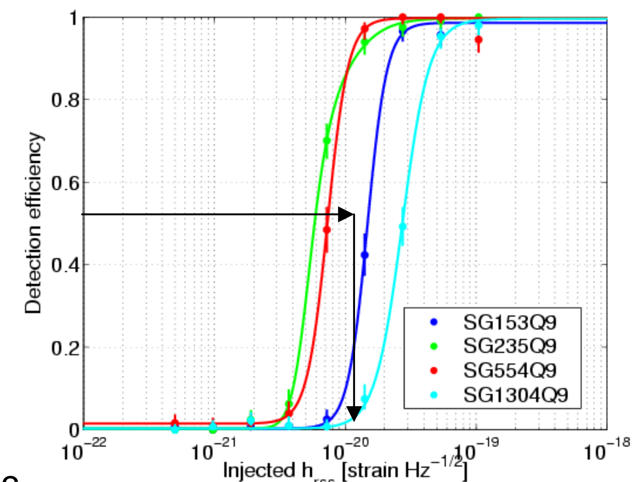
- **glitchMon** (author: M.Ito)
  reliable but needing a long tuning process to optimize its parameters. Has been used in the S2 analysis.

- **kleineWelle** (authors: L. Blackburn, S. Chatterjii, E. Katsavounidis)
  is a wavelet based algorithm (presented at last GWDAW), practically self tuning.

- Both algorithms have been tested on simulated signals added to the detector noise (in particular, optimally oriented sinegaussians) to check for their efficiency.

- kleineWelle proved to be more efficient than glitchMon and has been adopted for the S3 analysis





Plot by L.Blackburn (MIT)

Veto search in S2

- Online search using glitchMon generated triggers. This search helped us mostly in defining a pool of interesting channels and shaping the tools to be used for the offline search.

- Offline search: extended run over the S2 playground in order to find a good veto channel. Numerous combinations of channel filtering and significance thresholds considered.

  - L1: LSC-AS_DC (channel recording the DC level of the light out of the anti-symmetric port) not filtered, showed interesting coupling with the gravitational wave channel, not enough to be chosen as a veto.
  - H1 and H2: no interesting candidates found

- Eventually no veto has been adopted in the S2 search

Veto search in S3

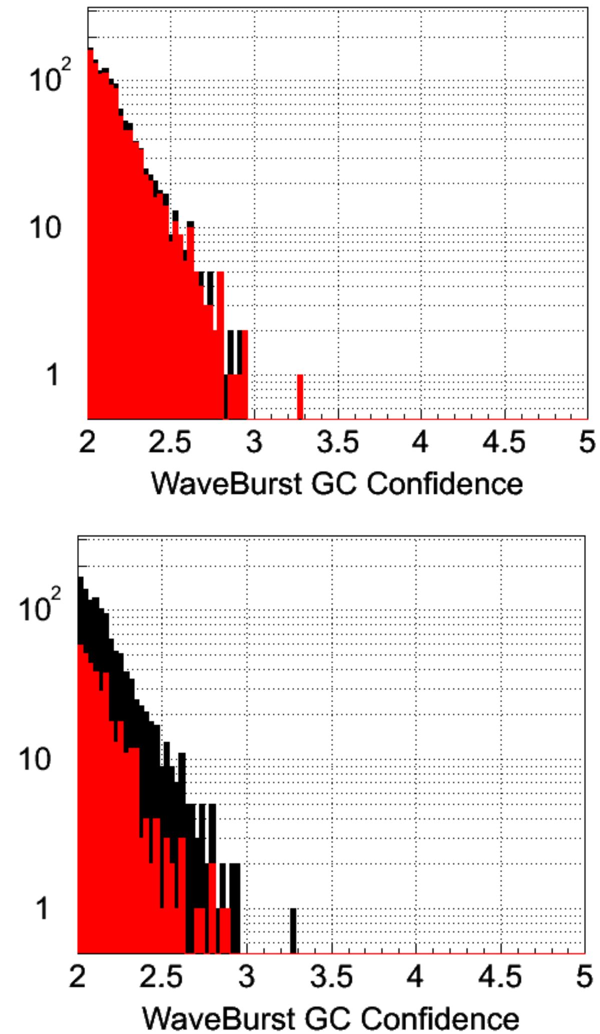
- Need to make the search more robust: optimize glitch finding algorithm
  - From glitchMon (time based algorithm) to kleineWelle (time-frequency wavelet based algorithm)
- Respect to S2, better detector performance, expect a different role for environmental channels
  - Try to use co-located instruments (H1/H2 at Hanford) to select environmental and site related noise
- Need to focus on channels that are efficient in vetoing loudest candidate events (non gaussian tails in the events distribution)
- Note: vetoes are developed by studying single IFOs but are applied to triple coincidence events so not always a good veto for single IFO events shows the same “goodness” for triple coincidence candidate events (as it is the case for the S2 and S3 analyses).

Veto candidates in S3

- **L1:** looked at AS_I/AS_Q correlations as suggested by inspiral group studies. Not so compelling results.

- **H1:** Also for this IFO checked the AS_I/AS_Q conditional veto, not efficient enough to justify adoption (eff = 7.5%, deadtime = 0.03%). Actually found AS_I by itself a very interesting alternative but doubts about its safety prevent us from considering it acceptable

H1



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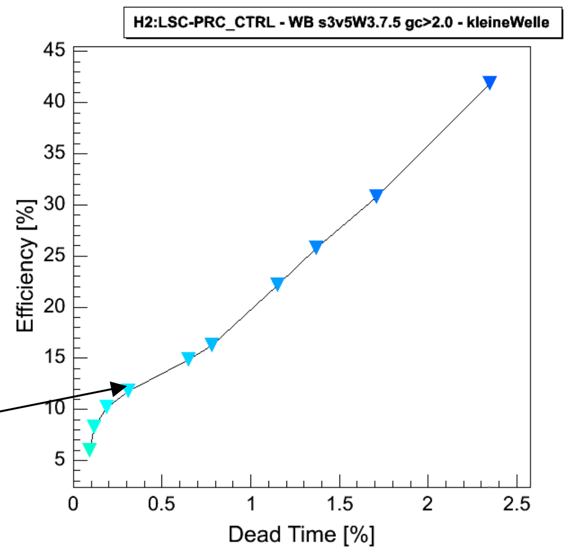
Plots by L. Cadonati (MIT)

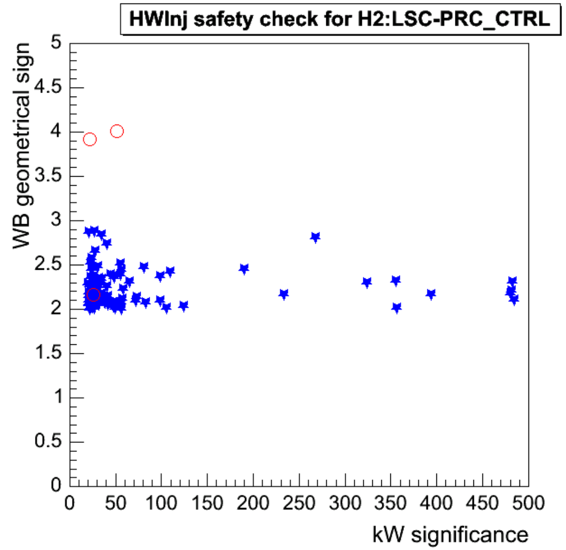
H2:LSC-PRC_CTRL

H2: several interesting channels. Veto proposed: H2:LSC-PRC_CTRL (control signal in the power recycling cavity) high-pass filtered at 70Hz, with a threshold of 200 in kW significance.



Efficiency = 12%
Deadtime = 0.3%
Effective deadtime = 0.5-2.2%
Use percentage = 3.44 %

The safety of the channel has been assessed using the HW injections – and checking whether the excitation in the mirror, simulating a gravitational wave burst could couple to the PRC_CTRL channel



Detection strategy

- Data quality cuts and vetoes can be considered sufficient in an upper-limit type of analysis
- In a detection oriented analysis we will need to reconsider some of these concepts. During the S2 analysis we started considering what to do in case of suspected detection, defined as 1 or more events surviving at the end of the pipeline.
- Our strategy in that case will be to go back to the environmental and auxiliary channels data around the times of the events and do an eyes-wide open analysis. Among the actions will be:
  - Look at the environmental channels first!
  - Go back to the auxiliary channels, as far as they are justified (able to produce a signal in the gravitational wave channel) and safe, and relax the threshold/change the filtering.
  - Decide the limits of this new veto search "a priori".

- We have actually tested a procedure according to these rules in a 'fire drill' in the S2 analysis.

Summary

- During the S2 and S3 gravitational wave burst data analyses, an important effort has been made in order to find efficient ways to clean the data from known noise sources
- Methods to isolate bad quality data or select effective vetoes have been studied and applied in both analyses
- Improvements in the methods (glitch finding algorithm) and in the channel selection process have been made going from S2 to S3, resulting in a more automated and productive search
- A veto has been proposed for S3, and a set of data quality cuts will be applied to the data analysis
- Plans for S4 and beyond: moving the veto search more and more in real-time with the data taking and make it a diagnostic tool

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