All-Sky Burst Searches for Gravitational Waves at High Frequencies

F. Salemi, AEI Hannover
for the Ligo Scientific Collaboration and the Virgo Collaboration

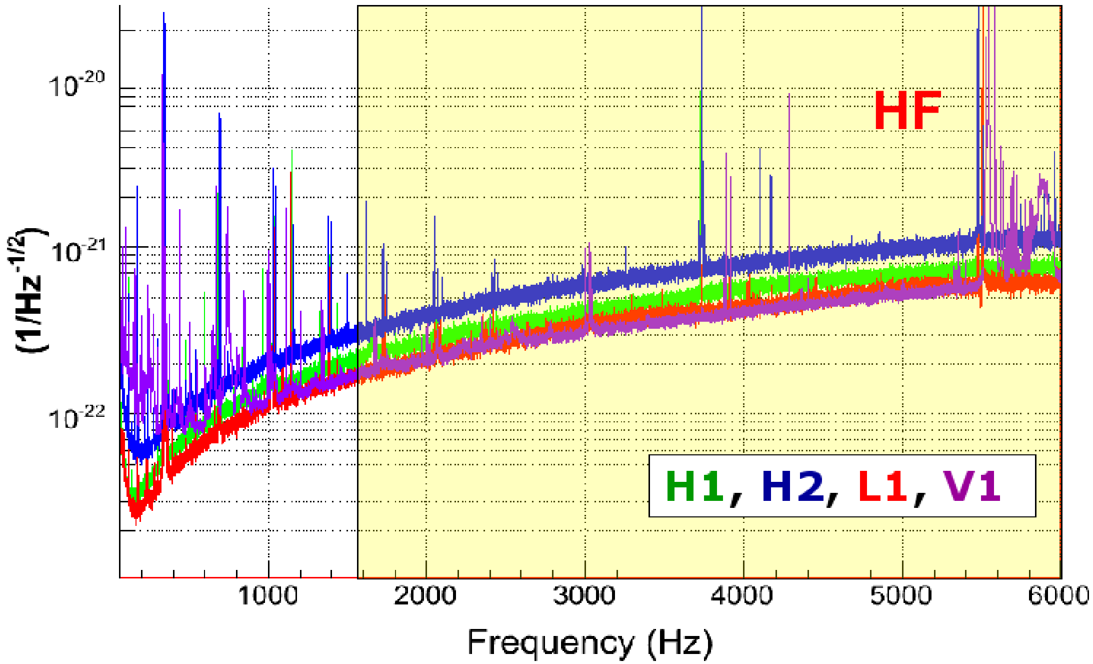
AMALDI8 Conference, New York
23 June '09

Document Number **LIGO-G0900529-v7**

High Frequency (HF) Burst Searches

During S5/VSR1 we have conducted all-sky burst searches extending the frequency range up to 6 kHz (see S5y1 high-f: arXiv:0904.4910
S5y1 low-f: arXiv:0905.0020)

- **PRO**: use existing pipelines, less glitchy data, search a frequency with a large number of potential sources (see next slide), Virgo effectively comparable to H1 and L1
- **CONTRA**: Lower sensitivity range of detectors
- **2 independent searches:** the first year of S5 (**S5Y1**) has been analyzed with a correlation follow-up of coincident single detector triggers(Q-pipeline + CorrPower), the second year of S5 + VSR1 (**S5Y2/VSR1**) has been analyzed with a coherent pipeline (cWB)



Search bandwidth:

1-6 kHz

> 1 kHz to keep an overlap with standard searches (<2kHz)

< 6 kHz technical bound set by LIGO calibration

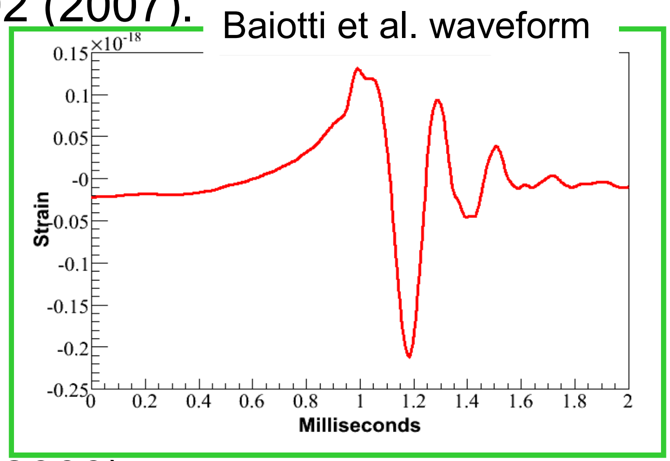
Transient GW sources at a few kHz

- **Neutron star collapse scenarios resulting in rotating black holes**

L. Baiotti *et al*. Phys Rev. Lett. **99**, 141101 (2007).
L. Baiotti *et al*. Class. Quant. Grav. **24**, S187 (2007).

- **Nonaxisymmetric hypermassive neutron stars resulting from neutron star-neutron star mergers**

R. Oechslin and H.-T. Janka, Phys. Rev. Lett. **99**, 121102 (2007).



- **Neutron star f-modes**

B.F. Schutz, Class. Quant. Grav. **16**, A131 (1999).

- **Neutron stars undergoing torque-free precession**

J.G. Jernigan, AIP Conf. Proc. **586**, 805 (2001).

- **Low-mass black hole mergers**

K.T. Inoue and T. Tanaka, Phys. Rev. Lett. **91**, 021101 (2003).

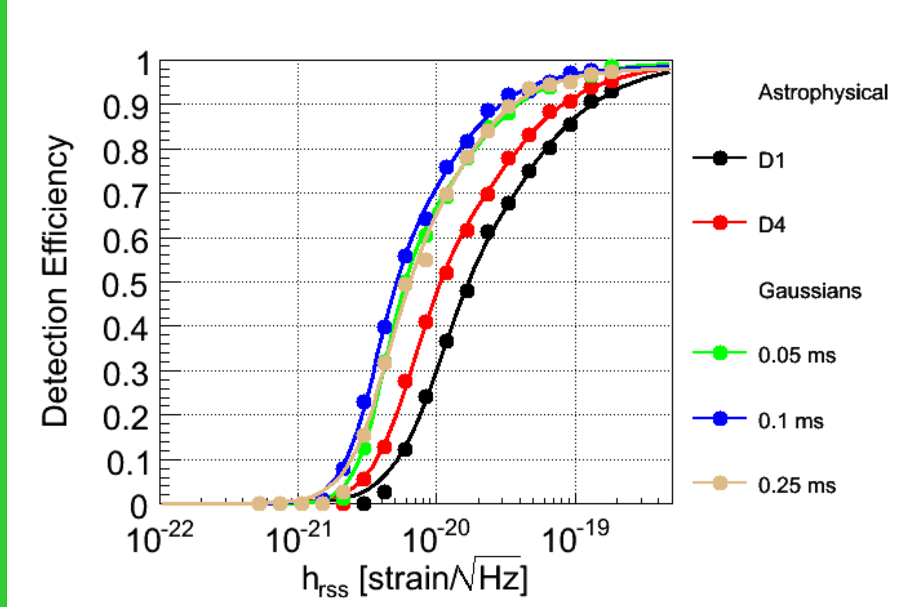
- **SGRs**

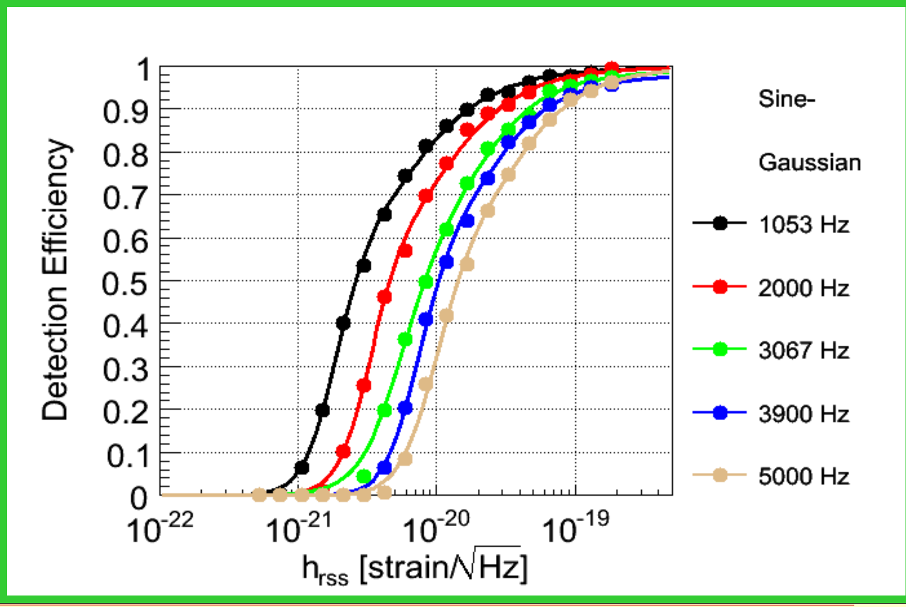
J.E. Horvath, Modern Physics Lett. A **20**, 2799 (2005).

S5Y1 HF search: intro

- Based on QPipeline, with cross-correlation followup
- Run on triple-coincident H1, H2 and L1 data (**155.5 days**)
- Also check for loud events in H1H2 only time
- Tuned on background sets from 100 lags of L1 w.r.t. H1H2
- Cuts on single site energy, cross-correlation factor Γ corresponding to a **false alarm probability of ~10%** (~**0.25 year** $^{-1}$)
- Used similar data quality/vetoes as low frequency

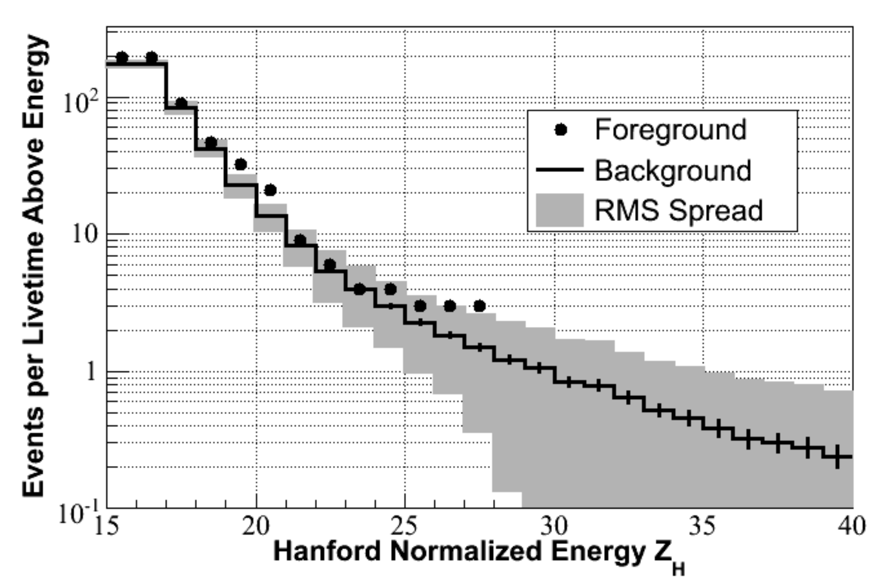
See Brennan Hughey's poster for more details

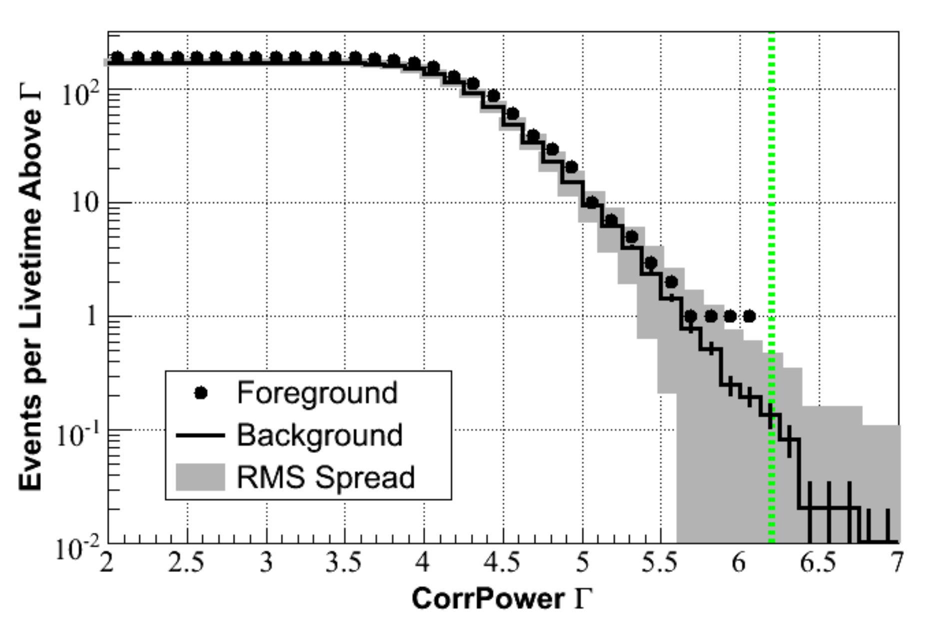


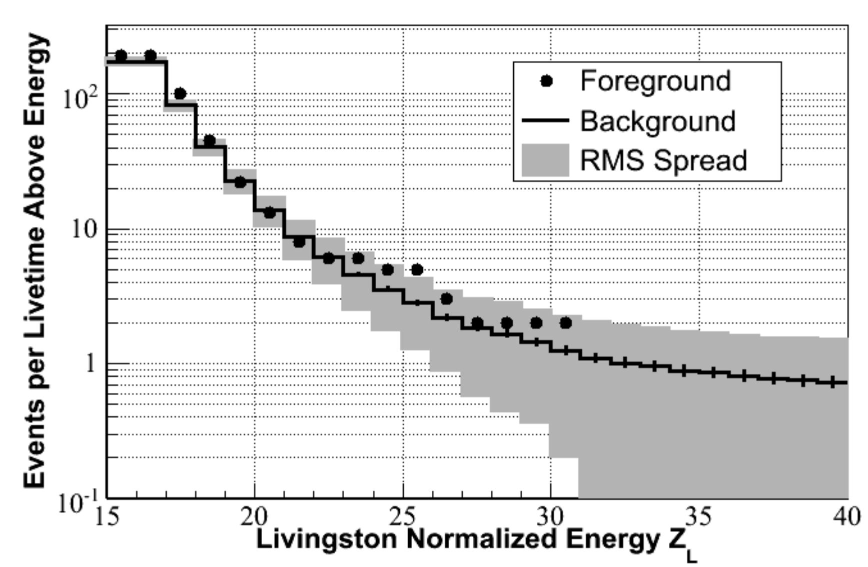


S5Y1 HF search: trigger distributions

Cumulative distributions of sub-threshold events for
- Cross-correlation measure CorrPower
- Hanford energy distribution
- Livingston energy distribution

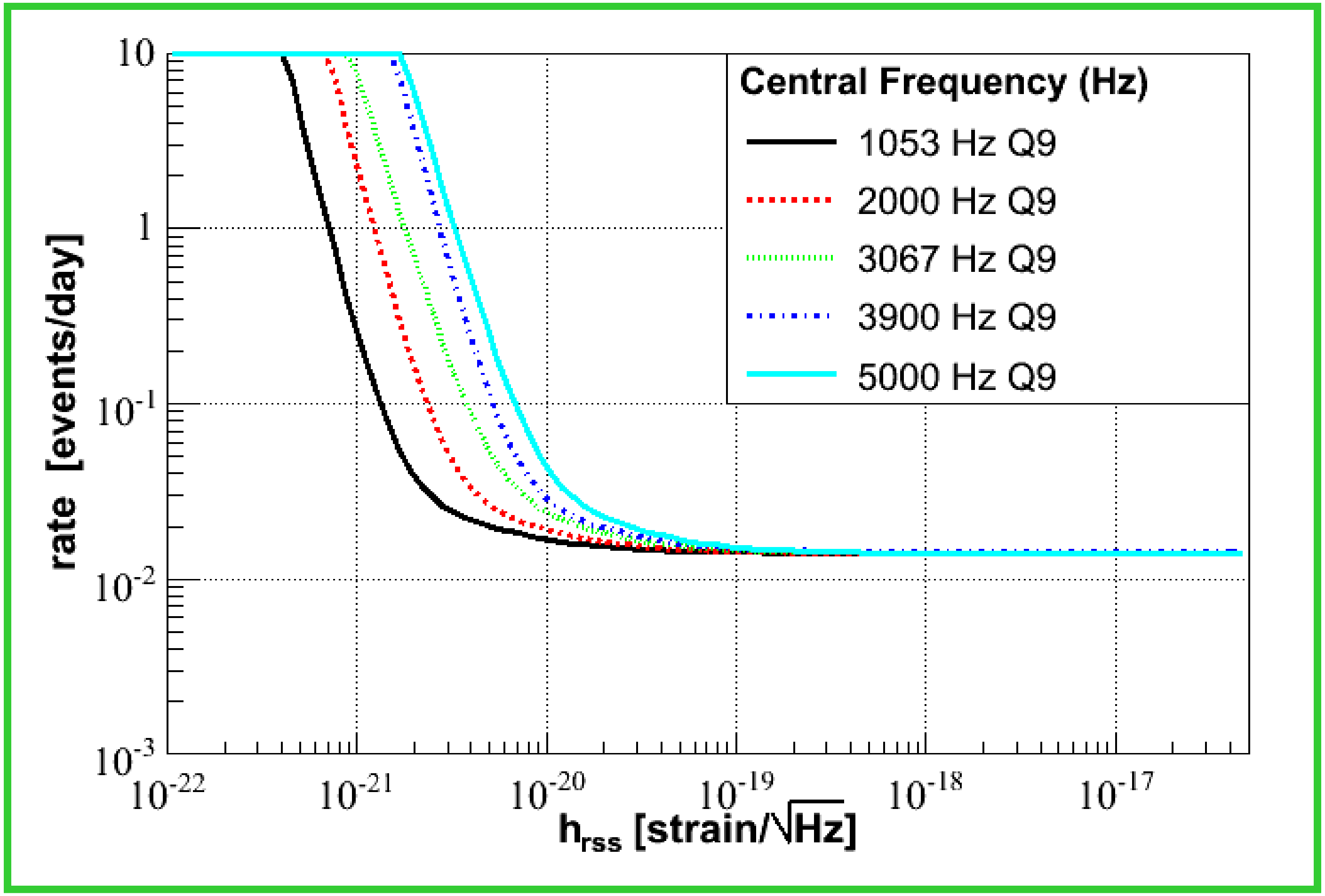






S5Y1 HF search: Upper Limits

90% Confidence Level Upper limit curves for various Sine-Gaussians Q=9 (adjusted for uncertainties)



S5Y2/VSR1 HF search: cWB Pipeline

Coherent Waveburst: event selection and reconstruction by constrained maximization of Likelihood.

Main settings specific to this search:

- Inputs h(t) resampled at 12.8 kHz
- Multi-resolution: 400Hz x 1/800 s, 200Hz x 1/400 s, ..., 12.5Hz x 1/25 s
- Search for events (clusters) limited within 1.28-6.0 kHz

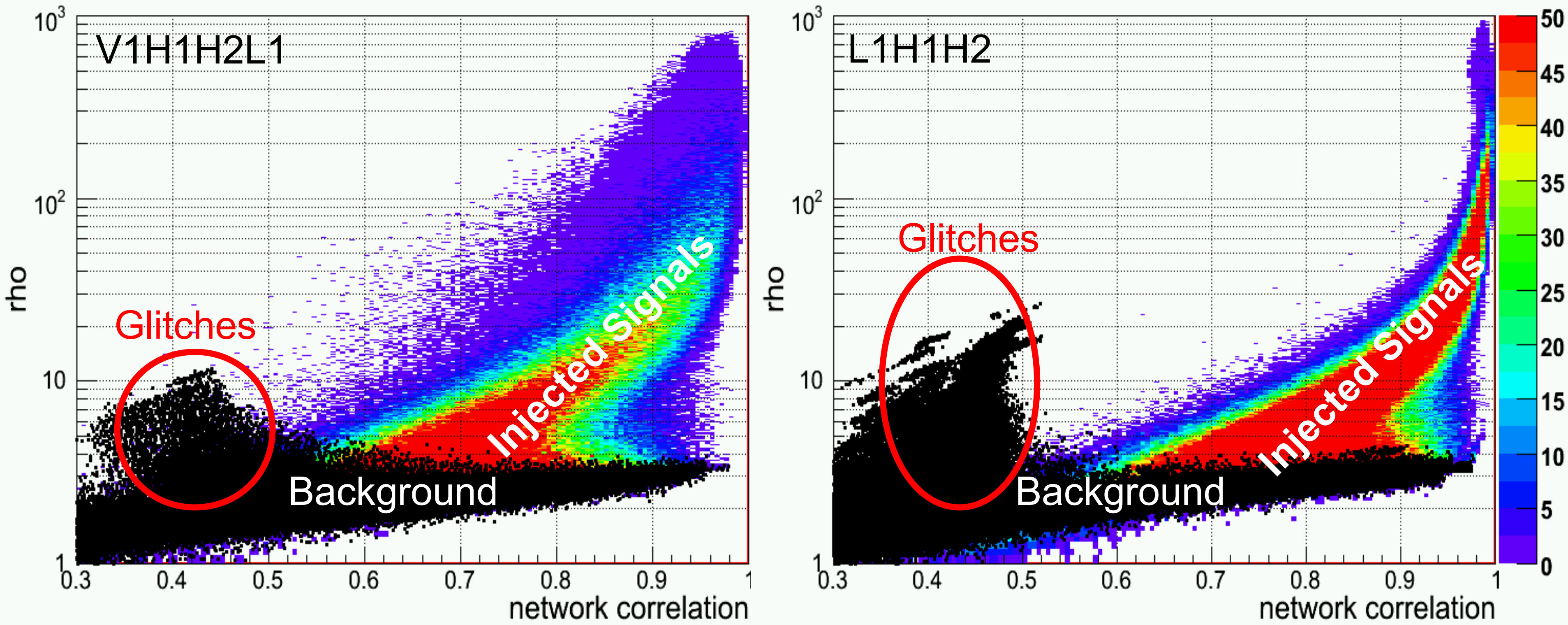
Two main test-statistics to select events for detection:

- Network correlation coefficient:

$$Netcc = \frac{|E_{cor}|}{|E_{cor}| + NullEnergy} < 1 \qquad where\ SNR^2 = E_{cor} + E_{incoherent}$$

- rho: $$\rho = \sqrt{\frac{E_{cor}\, Netcc}{Ndetector}}$$

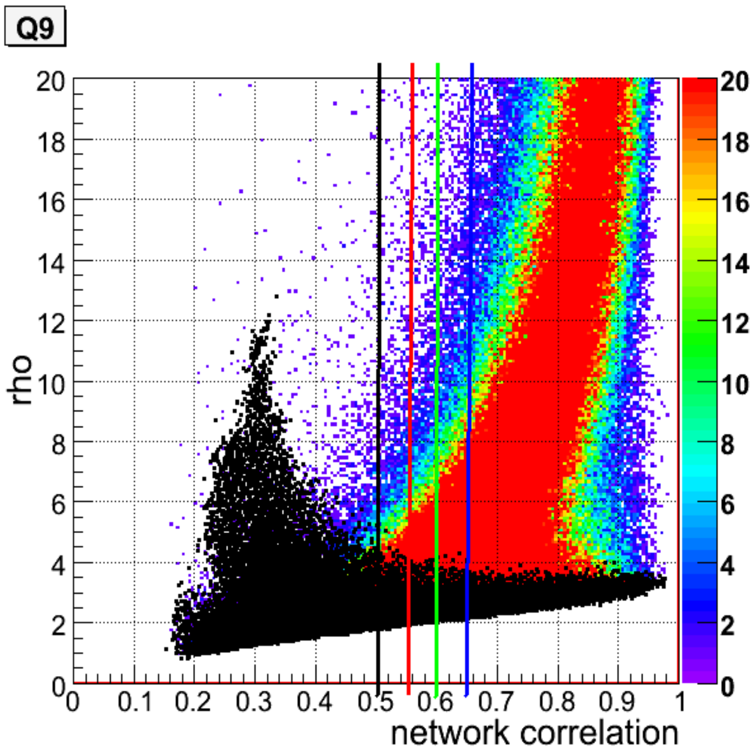
RHO vs NetCC: background+signals (SGQ9)

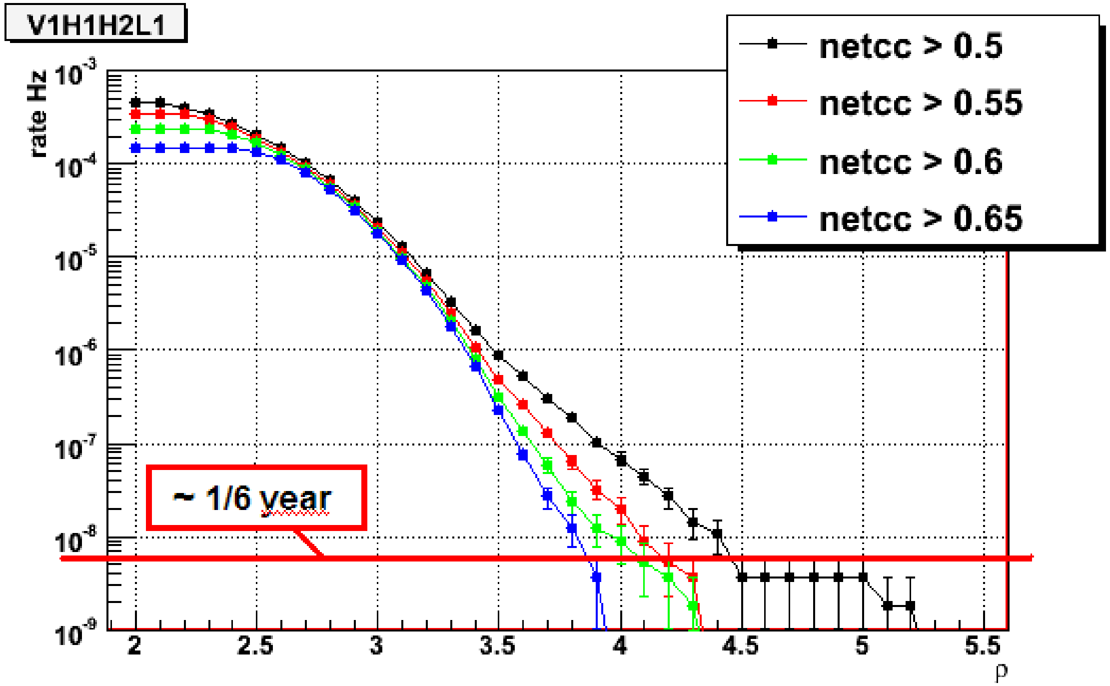


• Background scatterplots (black) compared to recovered injections color-density plots for V1H1H2L1 (left) and L1H1H2 (right)

• Adding a fourth detector (Virgo) helps in reducing the significance of large single detector glitches (i.e. large rho, small netcc)

Tuning sample with SGQ9: V1H1H2L1





- Blind null hypothesis test with **target false alarm at ~5 E-9 Hz = 1/6 years**
  - This level is satisfactory for a preliminary selection of candidate events, but not enough to qualify a GW candidate
- The tuning procedure sets the thresholds in netcc and ρ as 2 straight orthogonal lines by choosing among a small number of finite steps increments (0.05 for netcc and 0.1 for ρ)
- The algorithm: for a given False Alarm rate, choose the combination {netcc; ρ} which produces the lowest SGQ9 Hrss90%: in this case, {0.6;4.3}

S5/VSR1 HF search: background and signal injections

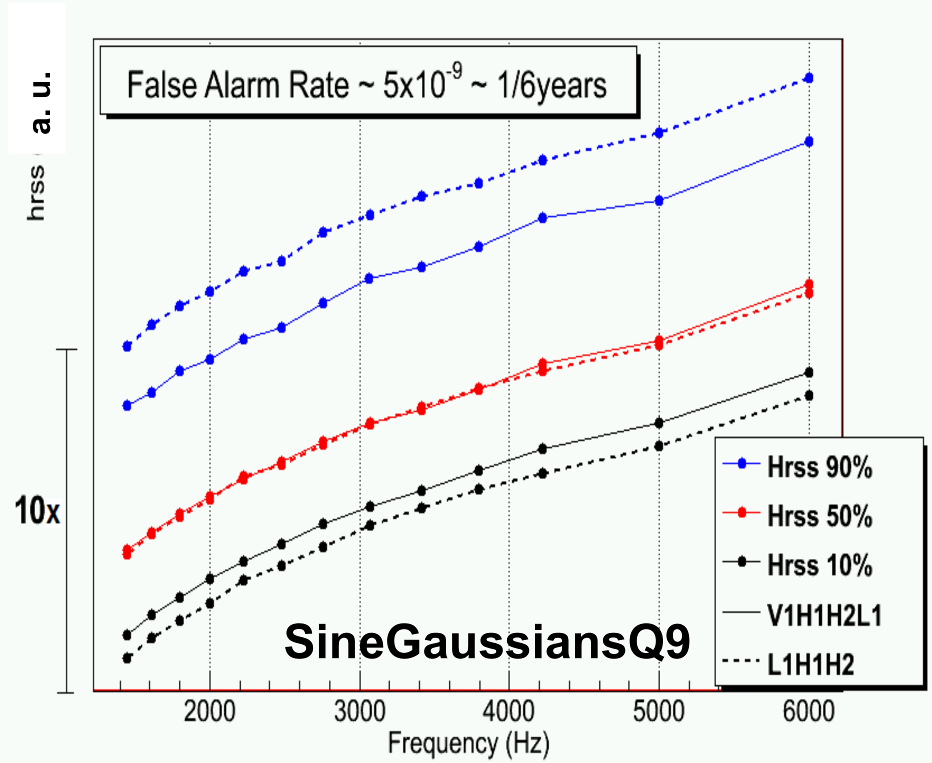
- Background (BKG) and False Alarm Rate (FAR) estimation:

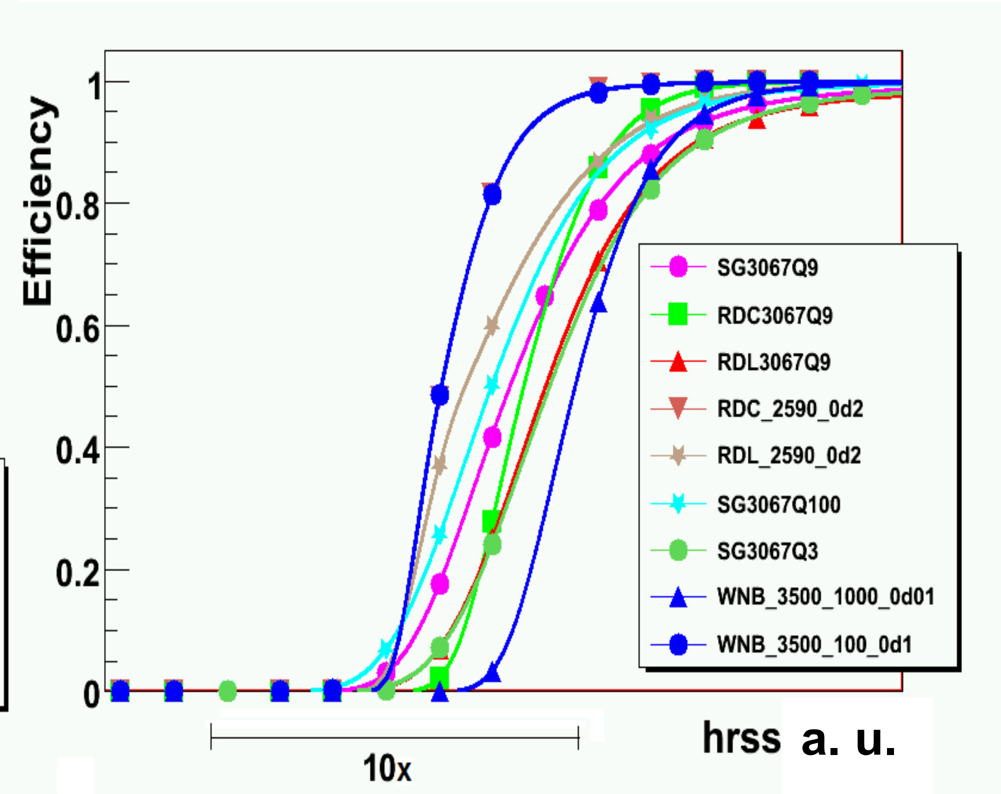
Network Configuration	Live Time [days]	BKG [years]	FAR [year^{-1}]
V1H1H2L1	68.1	17.6	0.17
L1H1H2	121.2	31.7	0.09
V1H1H2	15.6	3.7	0.27
V1H1L1	4.2	3	0.33
H1H2	35.5	17.2	0.23

TOT = 244.5 days **10% FA prob.**

- Efficiency studies:
  - **SineGaussian Q9** (13 central frequencies): all-purpose testing set
  - **SineGaussian** waveforms **Q 3** and **Q 100** linearly polarized **:** test sensitivity to shorter/longer waveforms
  - **White Noise Bursts** with band/duration =100 Hz / 0.01 s and 1000 Hz / 0.1 s : test "extreme case" efficiencies
  - **Ringdown** waveforms tau=0.2 s linear and circularly polarized: sensitivity to NS f-modes related to Soft Gamma Repeaters
  - **Numerical SN core collapse** to BH, waveforms D1 and D4 (Baiotti et al., PRD 71, 024035 (2005))
  - **RingDown Q9** linearly and circularly polarized: calibrate the sensitivity to short Damped Sinusoids with respect to Sine Gaussian

S5Y2/VSR1 HF search: efficiency studies





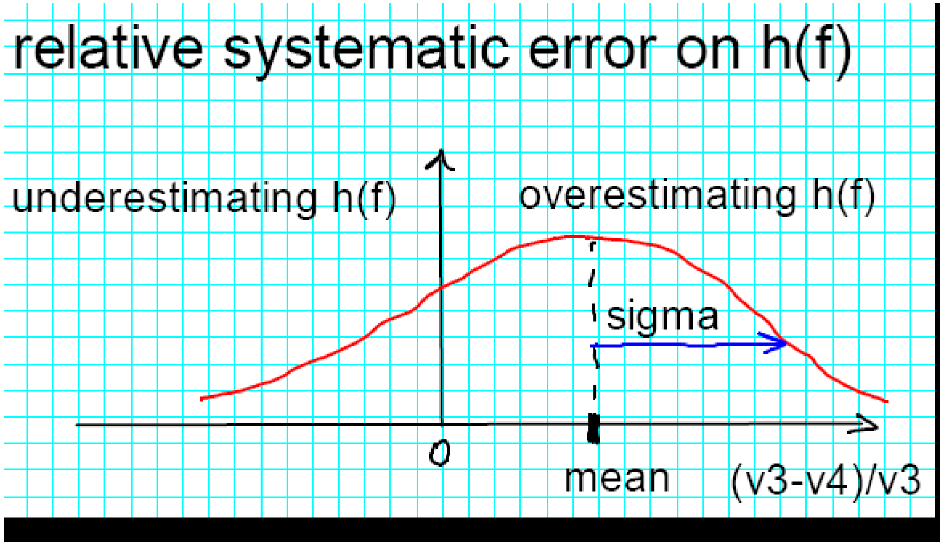
- Detection efficiency varies for the different injection frequencies, scaling with detector sensitivity, as expected.
- The asymptotic efficiency (hrss90%) results are better by a factor 40% for the network including Virgo, due to the better sky coverage achieved with a 3rd site.
- Various Waveforms at ~3 kHz (different polarization and bandwidth) show the typical range of variation of the efficiency curves.

S5/VSR1: Calibration systematics (1/2)

Pipelines used LIGO h(t) data before the final release was available.

Main calibration systematics:

- **LIGO**s (frequency dependent)
  Mean offset = (V3-V4)/V4 for h(f) **Standard deviation** on HrecV4 h(f)
- **Virgo**
  Mean offset = 0 **Standard deviation** on HrecV2 < 6%



Resulting Correction to 64 – 2048 Hz searches and to S5Y1 HF search:
constant factor on hrss, i.e. scale the hrss values in the the upper limit by **+11%** for all detector configurations and waveforms

S5/VSR1: Calibration systematics (2/2)

2 – 6 kHz search: situation is more critical w.r.t Low Frequency due to:

- higher calibration uncertainties (H1 sigma on amplitude goes up to 24% in 4-6kHz)
- coherent search ⇒ also differential mis-calibration of detectors are important (in particular H1 vs H2)

⇒ **Monte Carlo methods are needed to fold the effect of calibration systematics in the detection efficiency**

1. model amplitude relative systematic uncertainties as gaussian distributed at each detector (and frequency band)
2. perform MDC injections on reference data (JW1) with a relative correction of the injected amplitude sampled from the models (independent samples per each injection)
3. compute the resulting detection efficiency
4. rescale the results from reference data (JW1) to the entire observation time

⇒ **this estimate of detection efficiency marginalized over the systematic uncertainties should be used to produce HF upper limits**

Preliminary results

⇒ **V1H1H2L1** SineGaussian Q9 detection efficiency curves including calibration systematics: the increase of hrss50% is in the range **3%-8%**

⇒ **L1H1H2** SineGaussian Q9 detection efficiency curves including calibration systematics: the increase of hrss50% is in the range **4%-12%**

Summary

- LIGO/Virgo burst analysis extended up to 6 kHZ
- The S5Y1 HF: no GW candidates
- S5Y1 HF Burst Search paper available on arXiv: gr-qc/0904.4910
- S5Y2/VSR1 HF Burst Search with cWB
  - We are working on folding in Calibration systematics via MonteCarlo sofware injections
  - Internal review expected to be completed during next few months
  - Results to be published within the S5Y2/VSR1 burst paper (together with low freq burst searches)
- We will continue to look for HF signals with cWB in the off-line searches during S6