Search for gravitational waves from compact binary systems in the third and fourth LIGO science runs

Thomas Cokelaer

for the LIGO Scientific Collaboration

Cardiff University, U.K.

APS April Meeting, Jacksonville, FL 16 April 2007,

LIGO-G070229-00-Z

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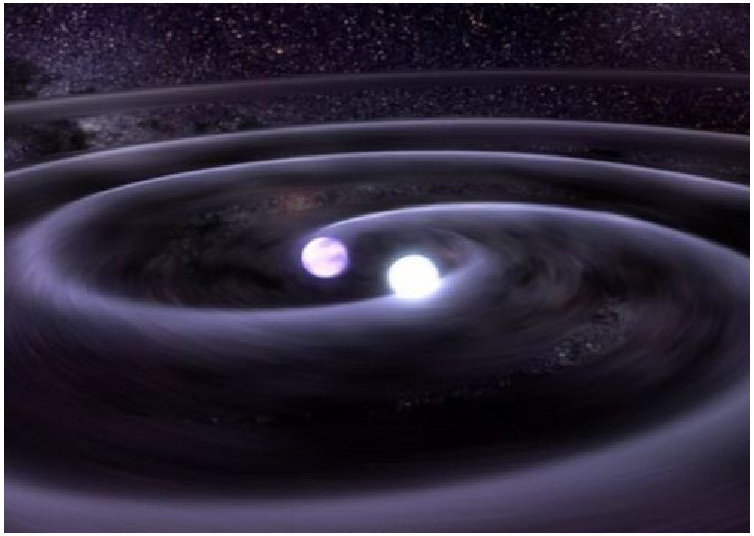

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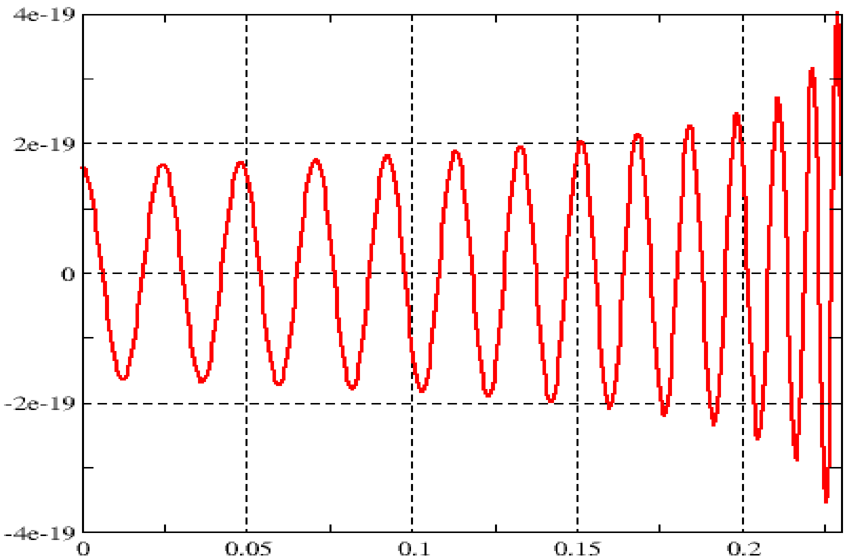
For which waveforms are available (allow to use optimal detection method)



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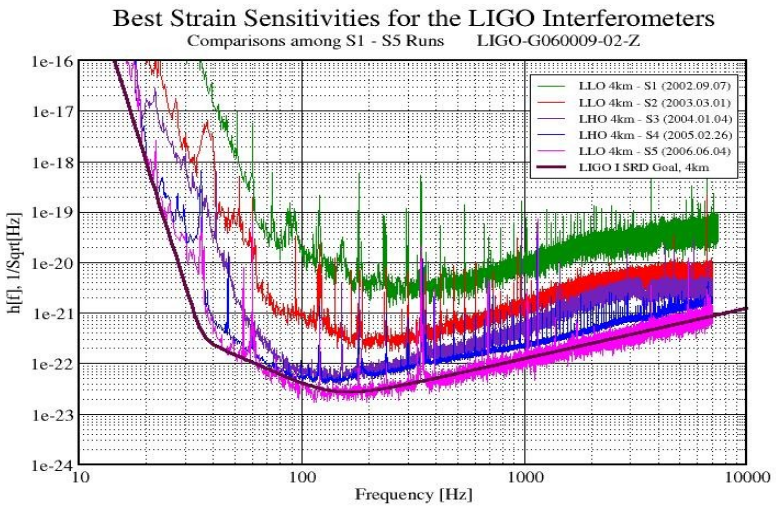
Into the third and fourth LIGO science runs



The LIGO data

<u>S3 science run :</u>

31st October 2003 to 9th January 2004.

<u>S4 science run :</u>

22nd February 2005 to 24th March 2005.

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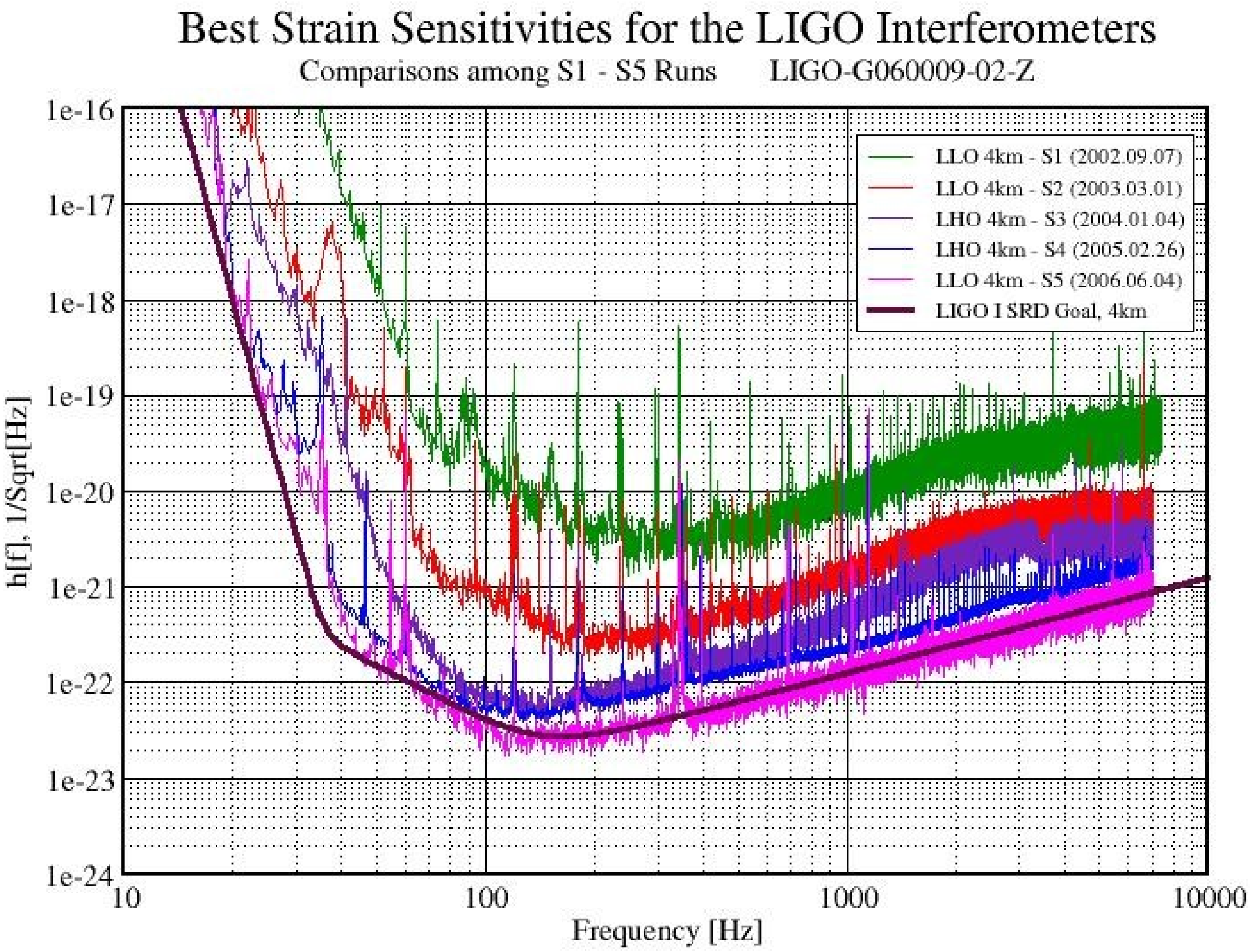


S4 science run :

22nd February 2005 to 24th March 2005.

3 Searches

1-Primordial black holes (PBH)

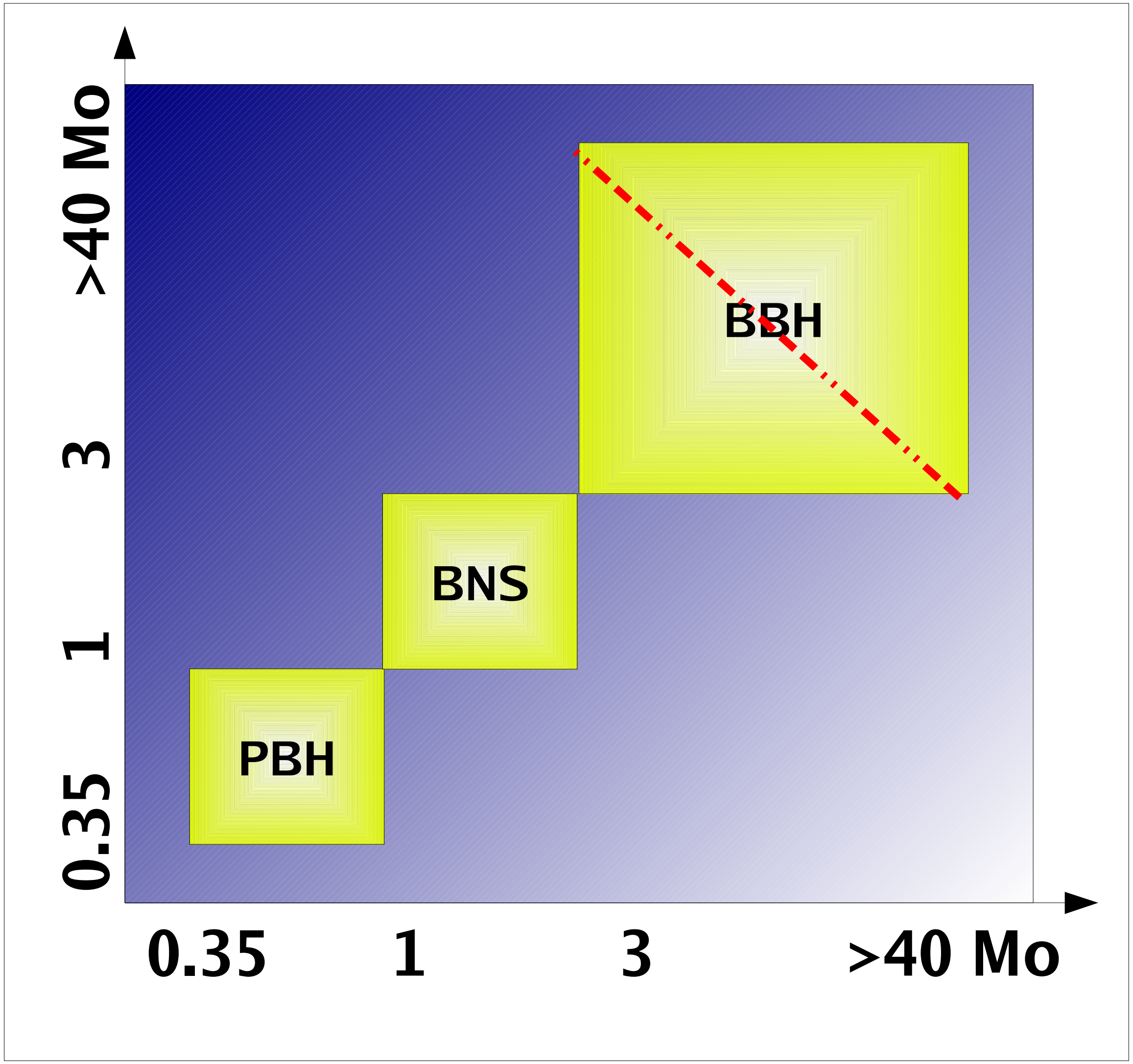
m1, m2 in [0.35,1] solar mass.

2-Binary neutron stars (BNS)

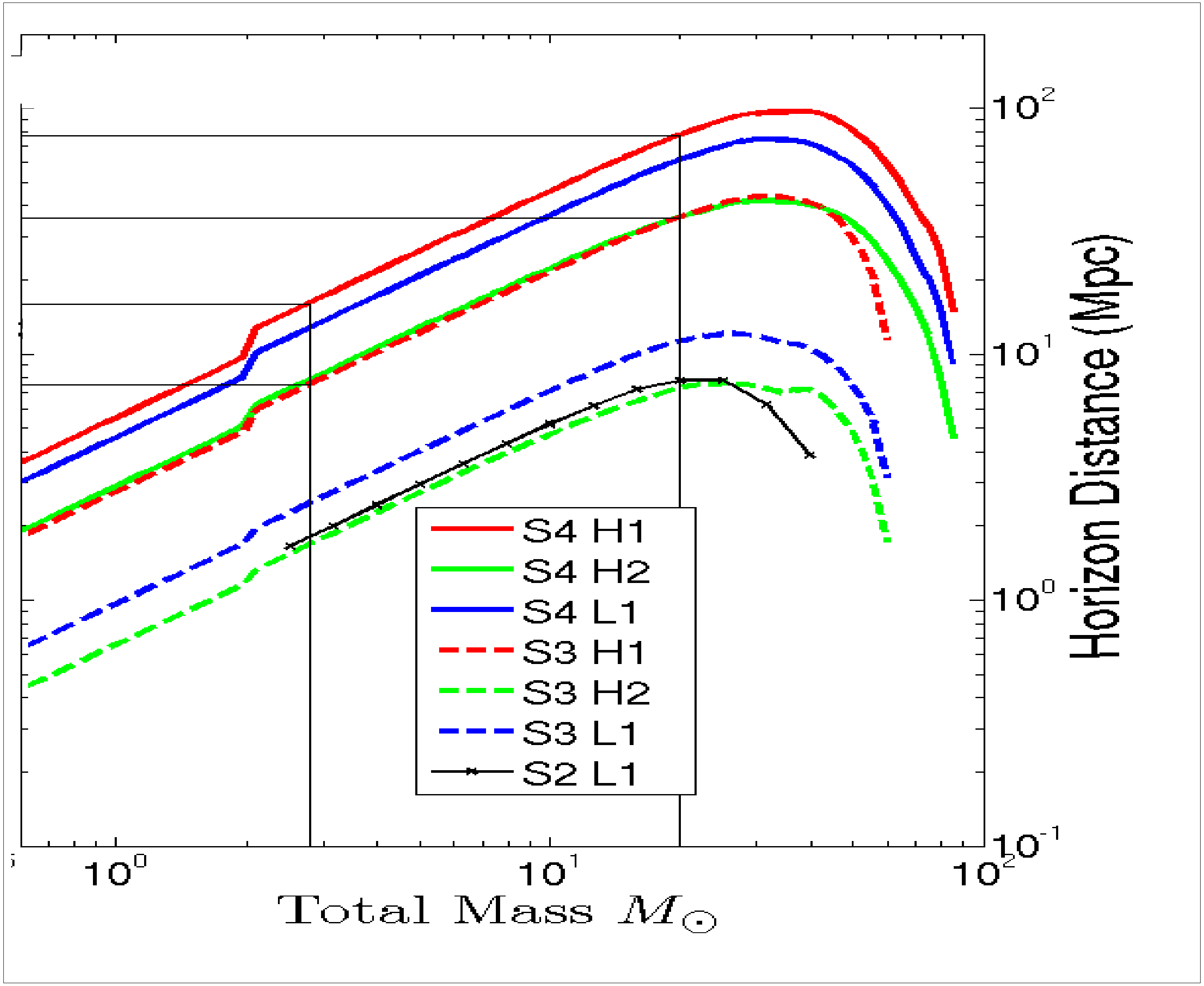
m_1, m_2 in [1.0, 3.0] solar masses.

3-Binary Black Holes (*BBH*) :

m_1, m_2 in [3.0, 80.0] solar masses with total mass less than 80 solar masses.



Expected horizon distance



Search Pipeline and Results

The search pipeline in a nut shell

Input data in coincidence only

Require 2 detectors in coincidence . Increases our confidence in a detection.

The search pipeline in a nut shell

Input data in coincidence only

Filter each data set (3)

Discrete bank so as to obtain 95% of the optimal SNR.

The search pipeline in a nut shell

Input data in coincidence only

Filter each data set (3)

Impose coincidences and apply vetoes (instrumental, signal based ...)

Using simulated signals to tune the parameters.

The search pipeline in a nut shell

Input data in coincidence only

Filter each data set (3)

Impose coincidences and apply vetoes (instrumental, signal based ...)

Compare coincident triggers to expected background.

Expected background estimated by shifting one data set with respect to the other.

The search pipeline in a nut shell

Input data in coincidence only

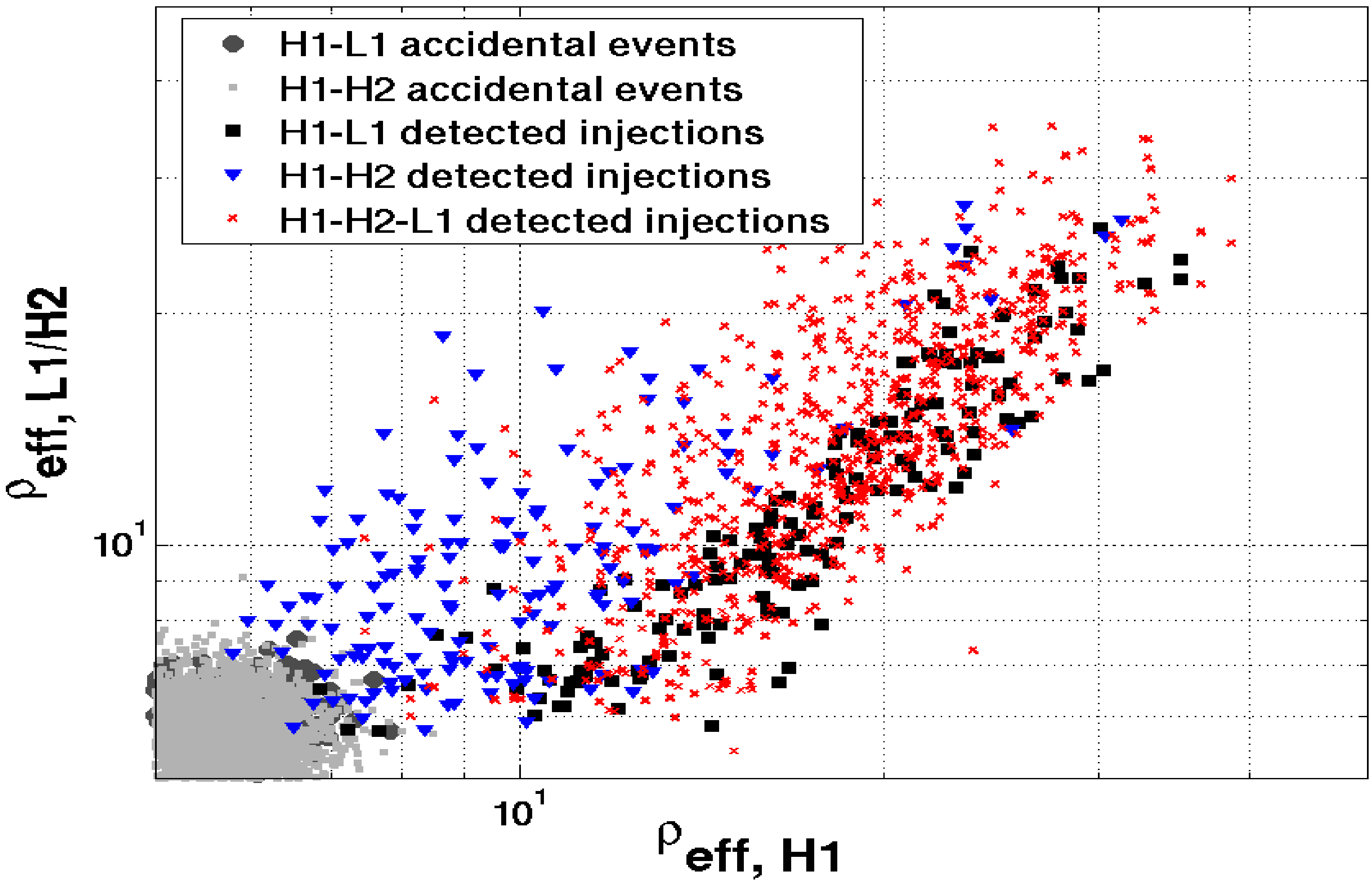
Filter each data set (3)

Impose coincidences and apply vetoes (instrumental, signal based ...)

Compare coincident triggers to expected background.

→ Follow up of candidates

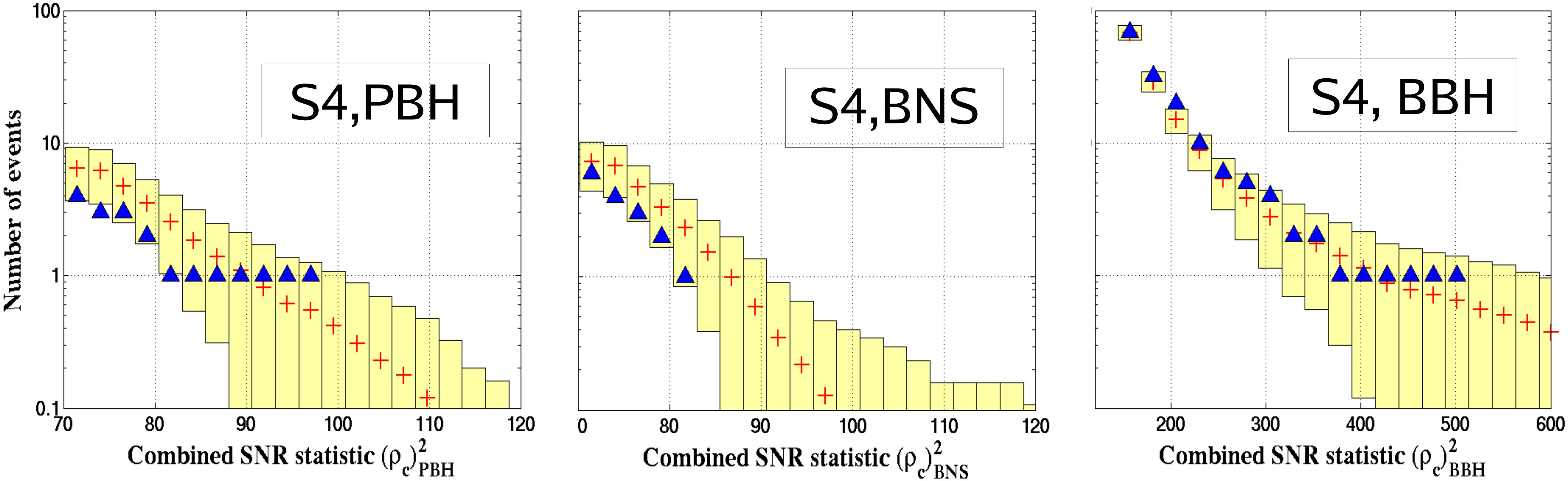
Example (S4 BNS)



S4 Results

Coincident triggers consistent with expectation in S4 science runs

Preliminary results



Follow up loudest coincident triggers and candidate events (if any).

S3 Results

Coincident triggers consistent with expectation in S3 runs for BNS and PBH

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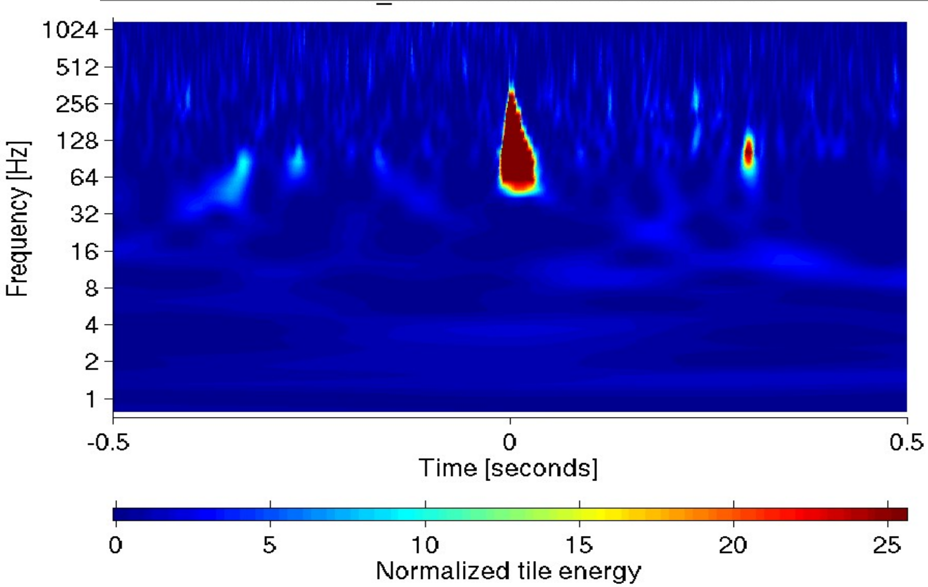
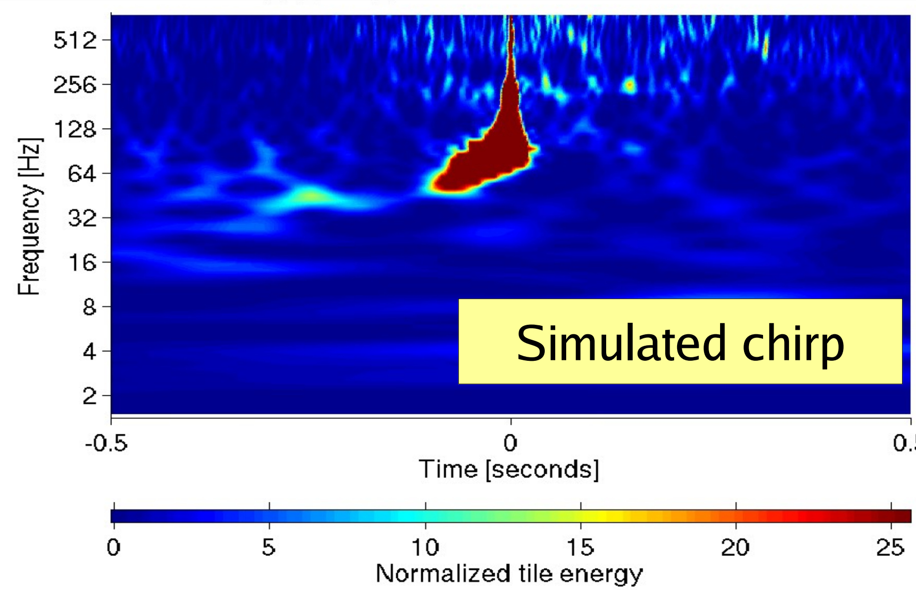
In the S3 BBH search, a double coincident trigger (H1/H2) found above background estimate (5 sigmas), and large SNR (150 in H1). BUT
(1) No chirp-like pattern.

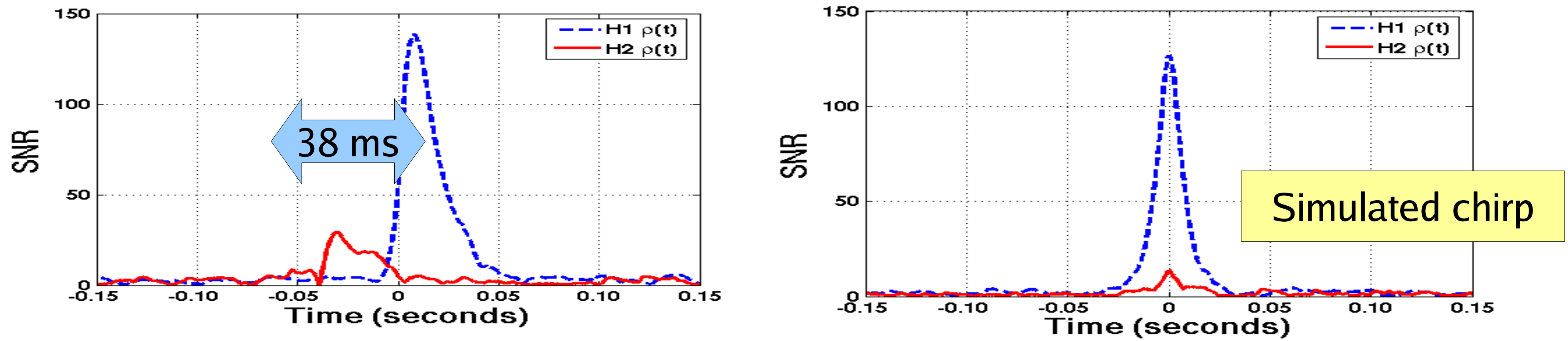




S3 Results

Coincident triggers consistent with expectation in S3 runs for BNS and PBH

In the S3 BBH search, a double coincident trigger (H1/H2) found above background estimate (5 sigmas), and large SNR (150 in H1). BUT (2) difference in arrival time is large (38ms whereas expectation is 0 with 6.5ms std).



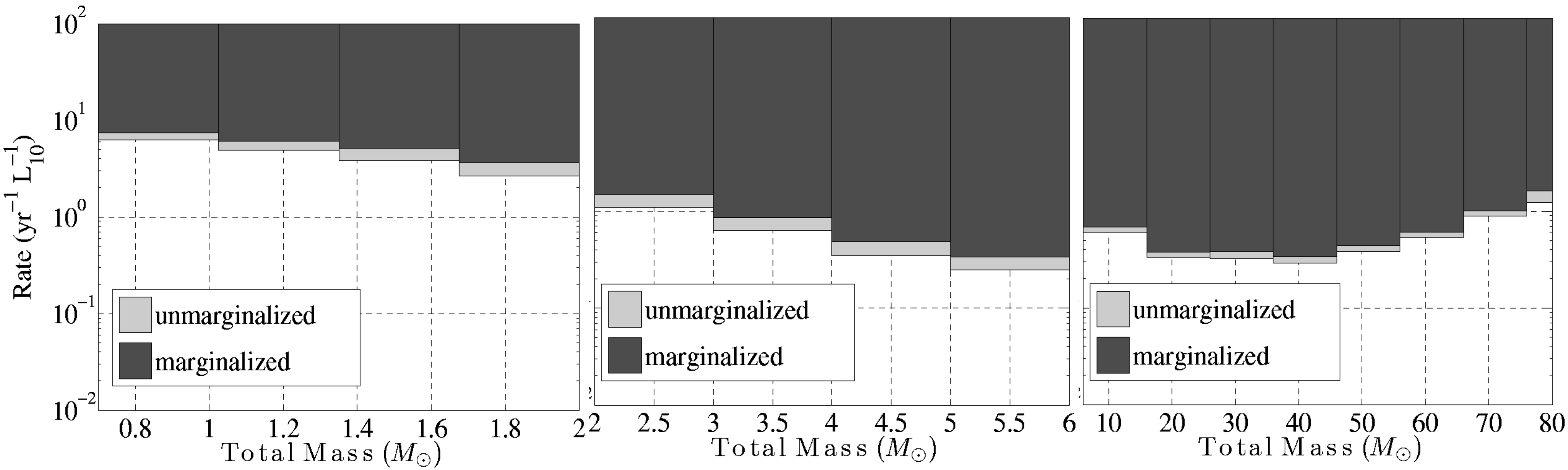
Serious candidate but not a plausible GW signal.

Preliminary results

Upper limits

S4 Upper limit results (1)

1 - Uniform Mass Distribution



Preliminary results

S4 Upper limit results (2)

2 – Gaussian Mass Distribution

PBH binary assuming Gaussian distribution around a 0.75-0.75 solar mass system: $4.9\, yr^{-1} L_{10}^{-1}$

BNS assuming Gaussian distribution around a 1.4-1.4 solar mass system: $1.2\, yr^{-1} L_{10}^{-1}$

BBH assuming a Gaussian distribution around a 5-5 solar mass system: $0.5\, yr^{-1} L_{10}^{-1}$

$L_{10} = 10^{10} L_{\odot}$
= 0.6 Milky Way Equivalent Galaxy.

Preliminary results

Conclusions

No detection of GW signal from coalescing compact binaries neither in S3 nor in S4.

Upper limits on merger rates :

$4.9\ yr^{-1} L_{10}^{-1}$ for PBH binaries

$1.2\ yr^{-1} L_{10}^{-1}$ for BNS (expected: $[10-170]10^{-6} yr^{-1} L_{10}^{-1}$)

$0.5\ yr^{-1} L_{10}^{-1}$ for BBH (expected $[0.06-6]10^{-6} yr{-6} L_{10}^{-1}$)

Status of the analysis : Mature search pipeline; we can clearly identify simulated events at a SNR = 8 .

Present and Future :

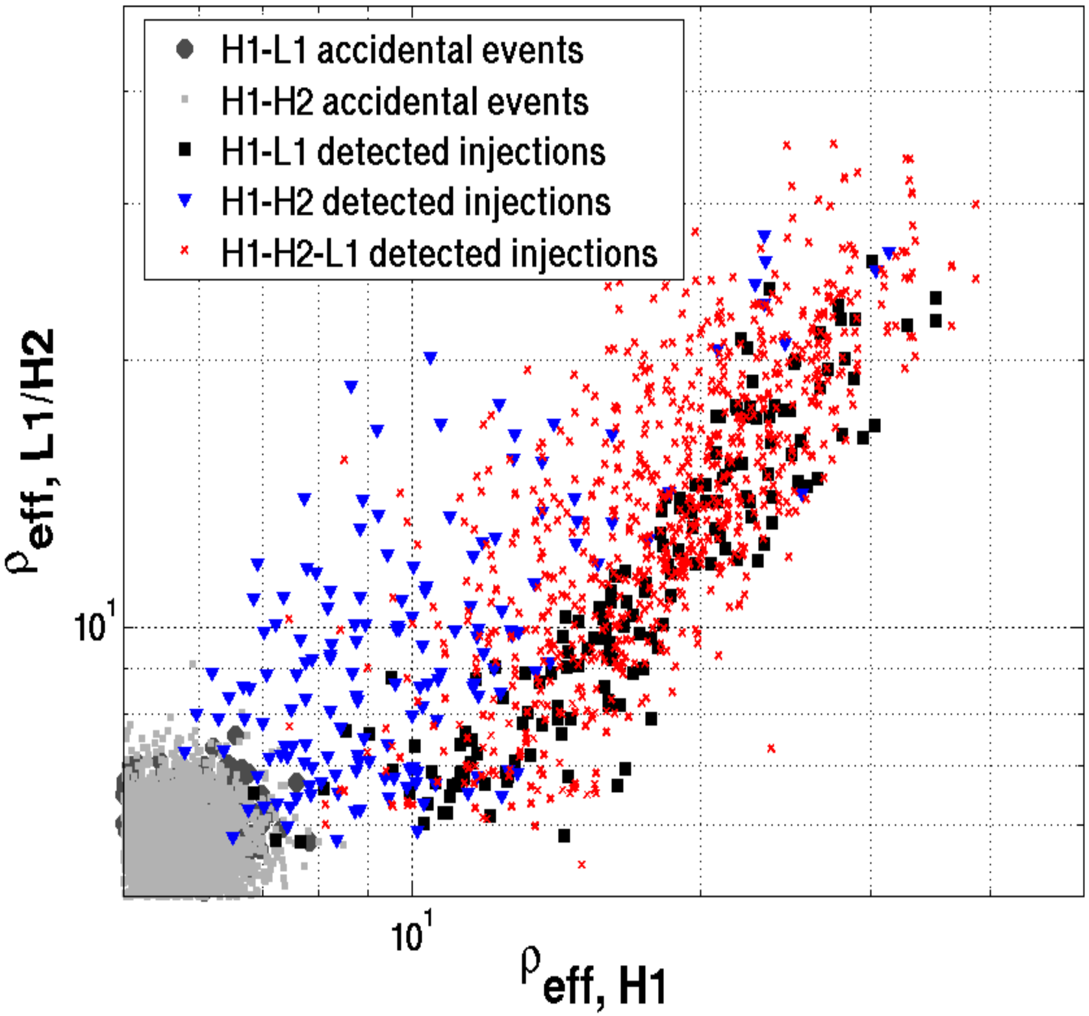
Apply the developed tools to S5 and future science runs.

Extras

Effective SNR (BNS and PBH)

In PBH and BNS search, we use an effective SNR, that is a statistic which well separates the background triggers from simulated injections. It is defined by

$$\rho_{\text{eff}}^2 = \frac{\rho^2}{\sqrt{\left(\frac{\chi^2}{\text{DoF}}\right)\left(1+\frac{\rho^2}{250}\right)}}$$



Expected horizon distance

The horizon distance is the distance at which an optimally oriented and located binary system can be seen with a given signal to noise ratio:

$$D_\rho(Mpc) = \frac{A}{1\mathrm{Mpc} \times \rho} \times f(m_1, m_2) \times \int_{F_L}^{f_{cut}} \frac{f^{-7/3}}{S_h(f)} df$$

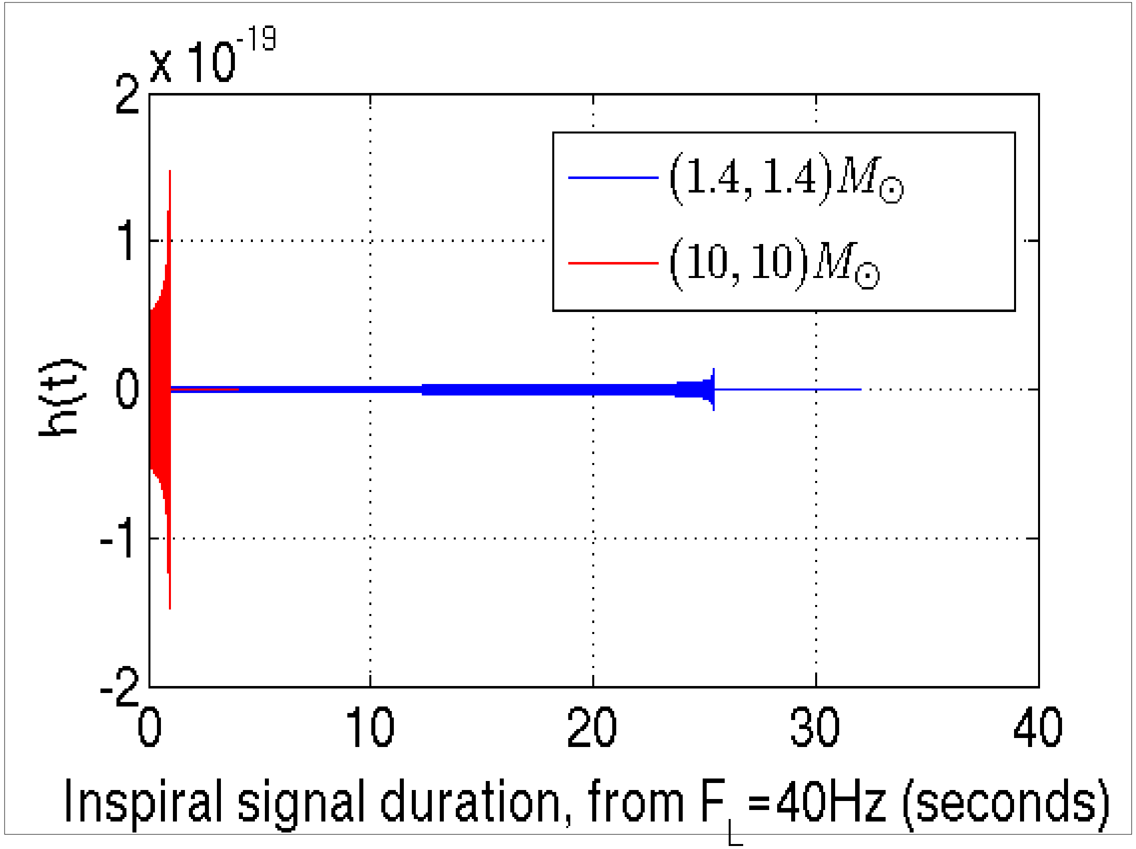
It is a measure of the range of detection based on real data. This is not the search. It is useful for sanity check of the search algorithms.

Target waveforms

The gravitational-wave signal can be modeled, and represented by :

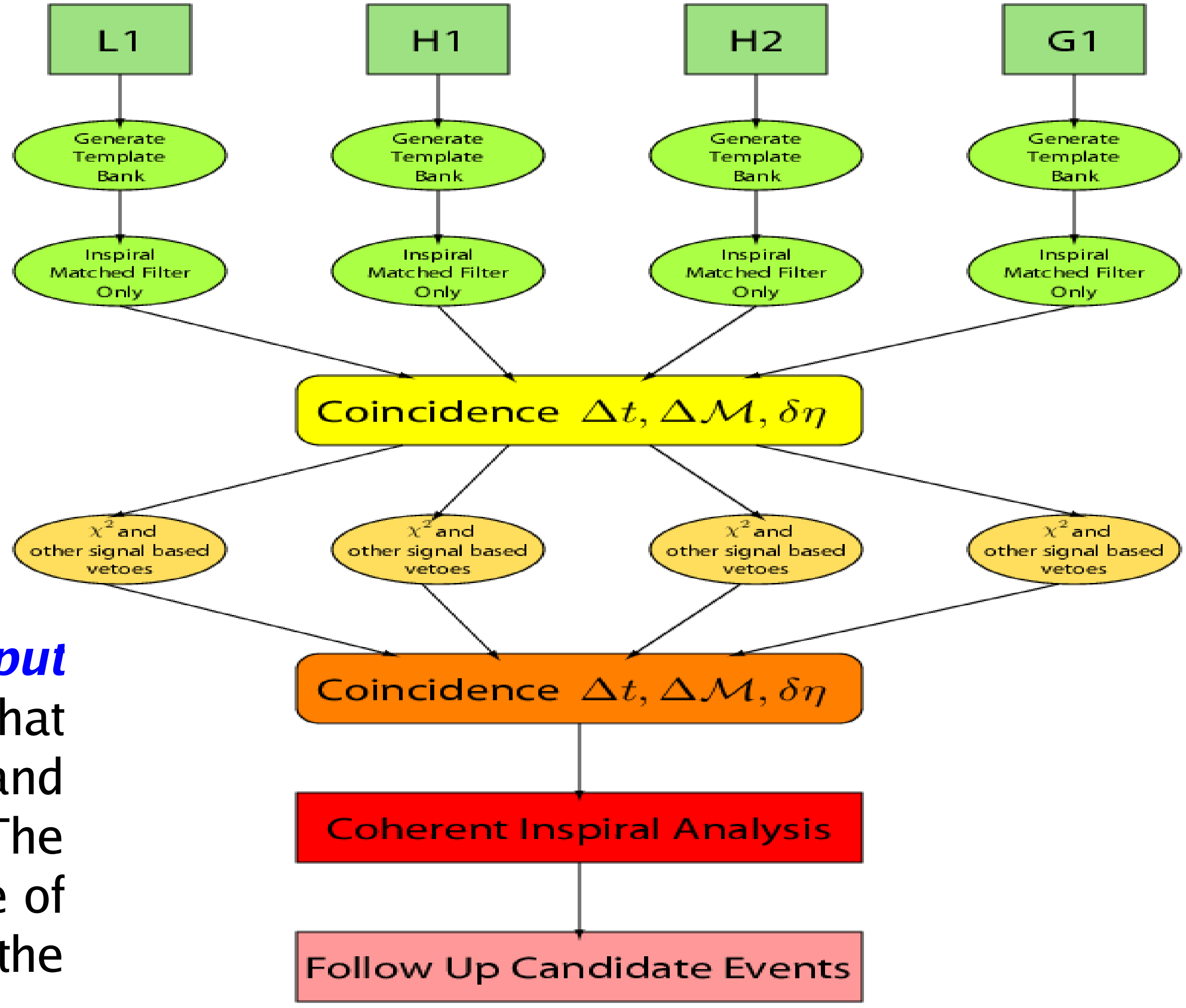
$$h(t) = \frac{1Mpc}{D_{\text{eff}}}\left[h_c(t)\cos\Phi + h_s(t)\sin\Phi\right]$$

- The **amplitude** and **duration** of $h_{c,s}(t)$ depend on the masses, $\mathbf{m_1}$ and $\mathbf{m_2}$, and the lower cut-off frequency F_L
- No spin effects.
- D_{eff} contains the physical distance and orientation of the binary system.



Search pipeline and Coincidence

Coincidence at the input stage: a list of time intervals where at least two detectors operate in science mode.



Coincidence at the output stage: we keep triggers that are coincident in time and mass parameters. The coincidence reduces the rate of triggers and increases the confidence in detection.

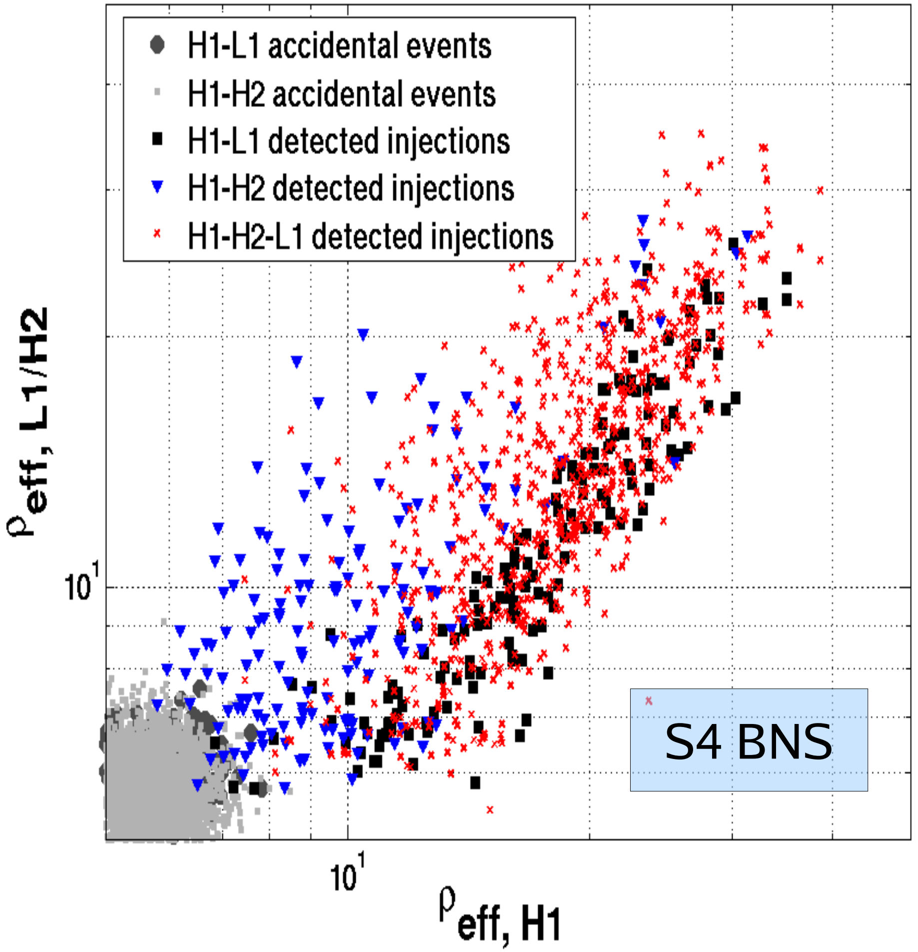
Background and simulations

The search requires the pipeline to be used in 3 different ways:

1-Injections: we can tune the search parameter such as coincidence windows to be sure not to missed any real GW event.

2-Background estimation: we time-shifts the data from the different detectors so as to estimate the accidental rate of triggers. Each search used 100 time-shifts.

3-Results: Finally, we analyse the data (no injections, no time shifts). The resulting triggers constitute the ***in-time coincident triggers, or candidate events.***



Difference between PBH binary, BNS and BBH search

- Templates based on second order restricted to post-Newtonian waveforms, in the stationary phase approximation, for the PBH and BNS searches, and phenomenological templates for BBH search.
- Chi square used in the BNS and PBH searches ***only*** :
  - reduces background significantly.
  - Allows to use an effective SNR that well separates background and simulated events.

In-time and time-shifted coincident triggers

From each search (PBH, BNS and BBH), a list of in-time coincident triggers is available. These triggers need to be compare with the background estimate, which is made over 100 realisations (time-shifted).

If an in-time coincidence triggers is above estimate background, then it is a candidate event, and needs follow-ups