

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

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1)- Overview

- **Target waveforms : BNS, BBH, PBH.**
- **Data description : S3 and S4 LIGO science runs.**

2)- The Search :

- **Expected horizon distances**
- **Search pipeline**
- **Background estimation**

3)- The S3 and S4 data results

4)- Upper limits

5)- Conclusion

Overview

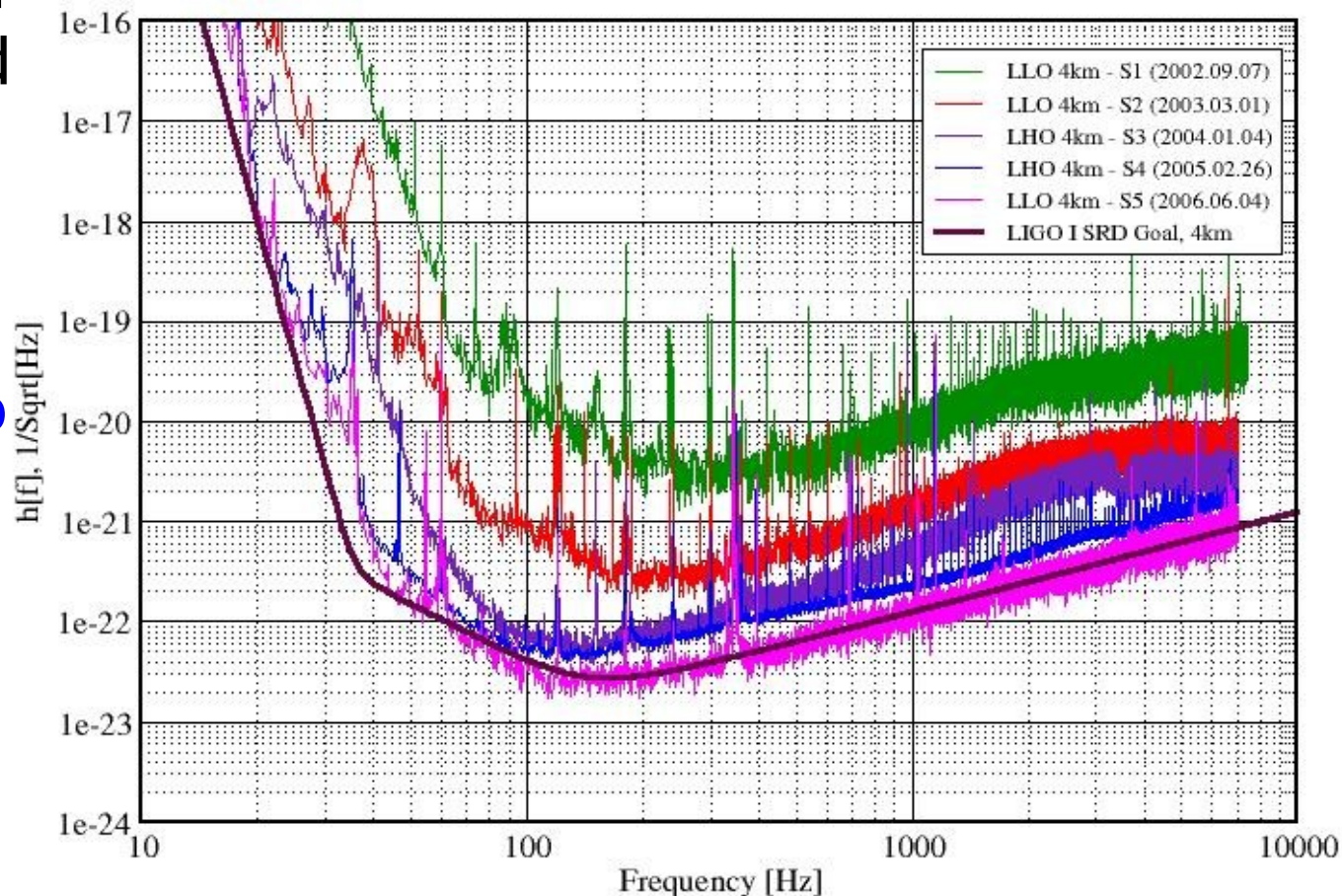
We searched for GW in the third and fourth science runs.

S3 science run :
31st October 2003 to
9th January 2004.

S4 science run :
22nd February 2005
to 24th March 2005.

Best Strain Sensivities for the LIGO Interferometers

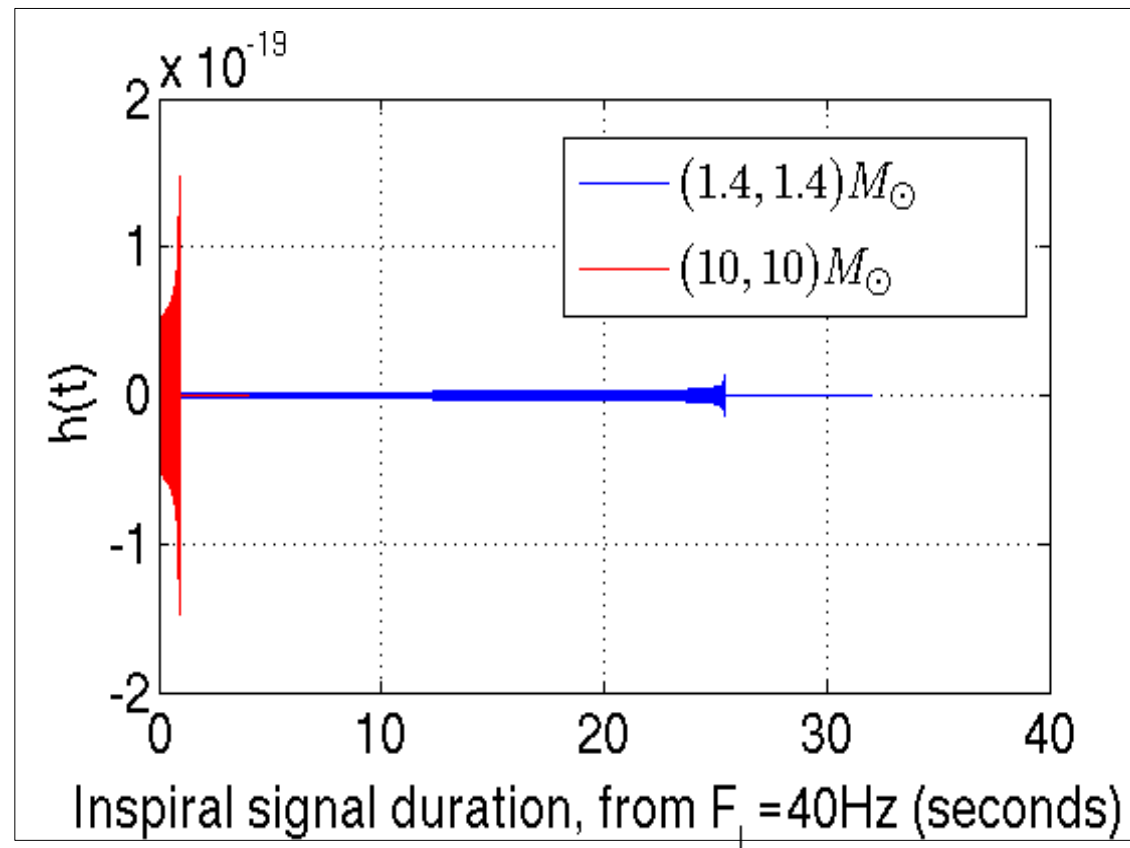
Comparisons among S1 - S5 Runs LIGO-G060009-02-Z



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

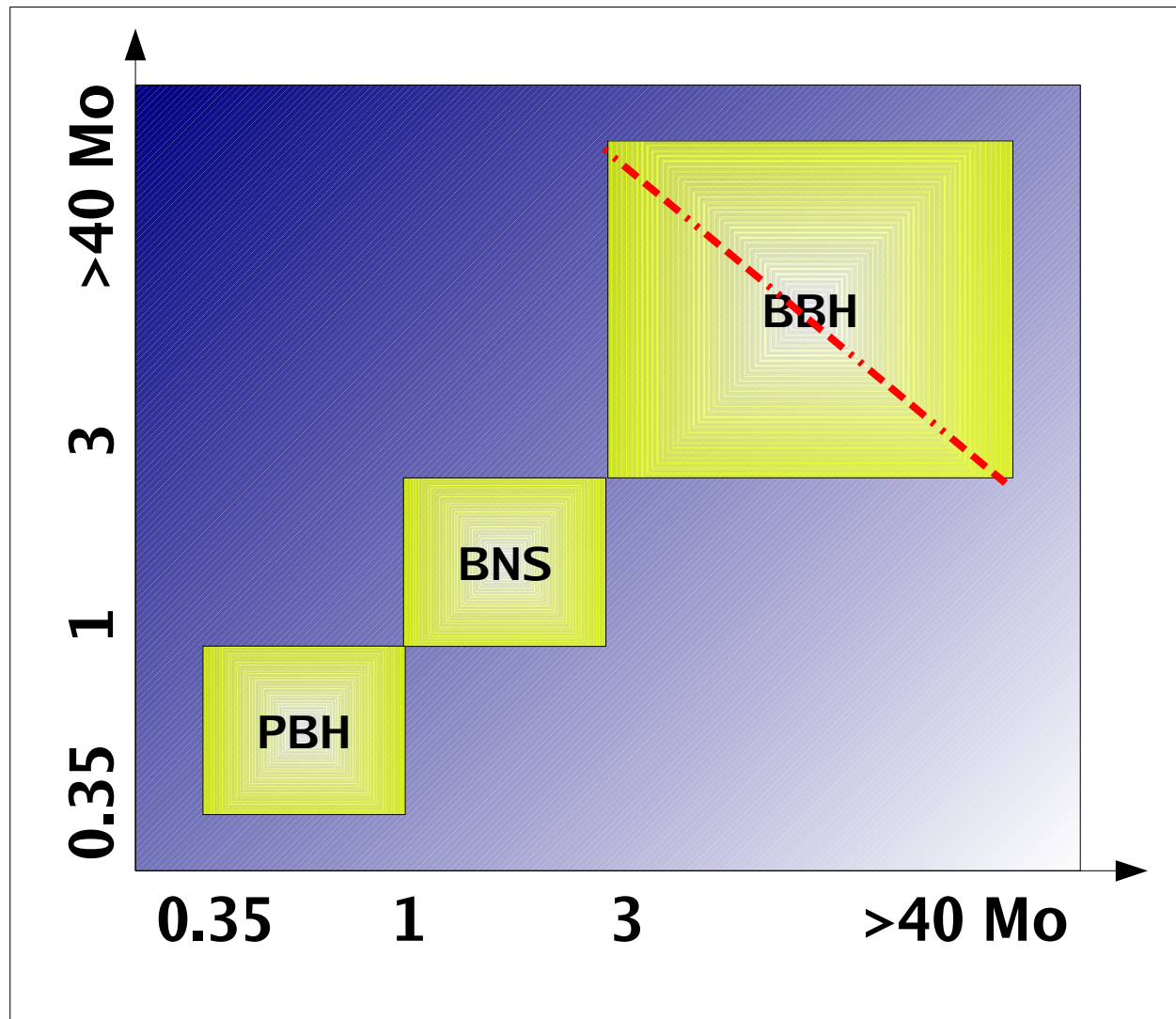
$$h(t) = \frac{1Mpc}{D_{\text{eff}}} [h_c(t) \cos \Phi + h_s(t) \sin \Phi]$$

- The **amplitude** and **duration** of $h_{c,s}(t)$ depend on the masses, m_1 and 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.



We searched for inspiralling compact binaries:

- Primordial Black Holes binaries (**PBH** binaries) : m_1, m_2 in $[0.35, 1.0] M_\odot$.
- Binary neutron stars (**BNS**): m_1, m_2 in $[1.0, 3.0] M_\odot$.
- Binary Black Holes (**BBH**) : m_1, m_2 in $[3.0, 80.0] M_\odot$ with total mass less than $80 M_\odot$.

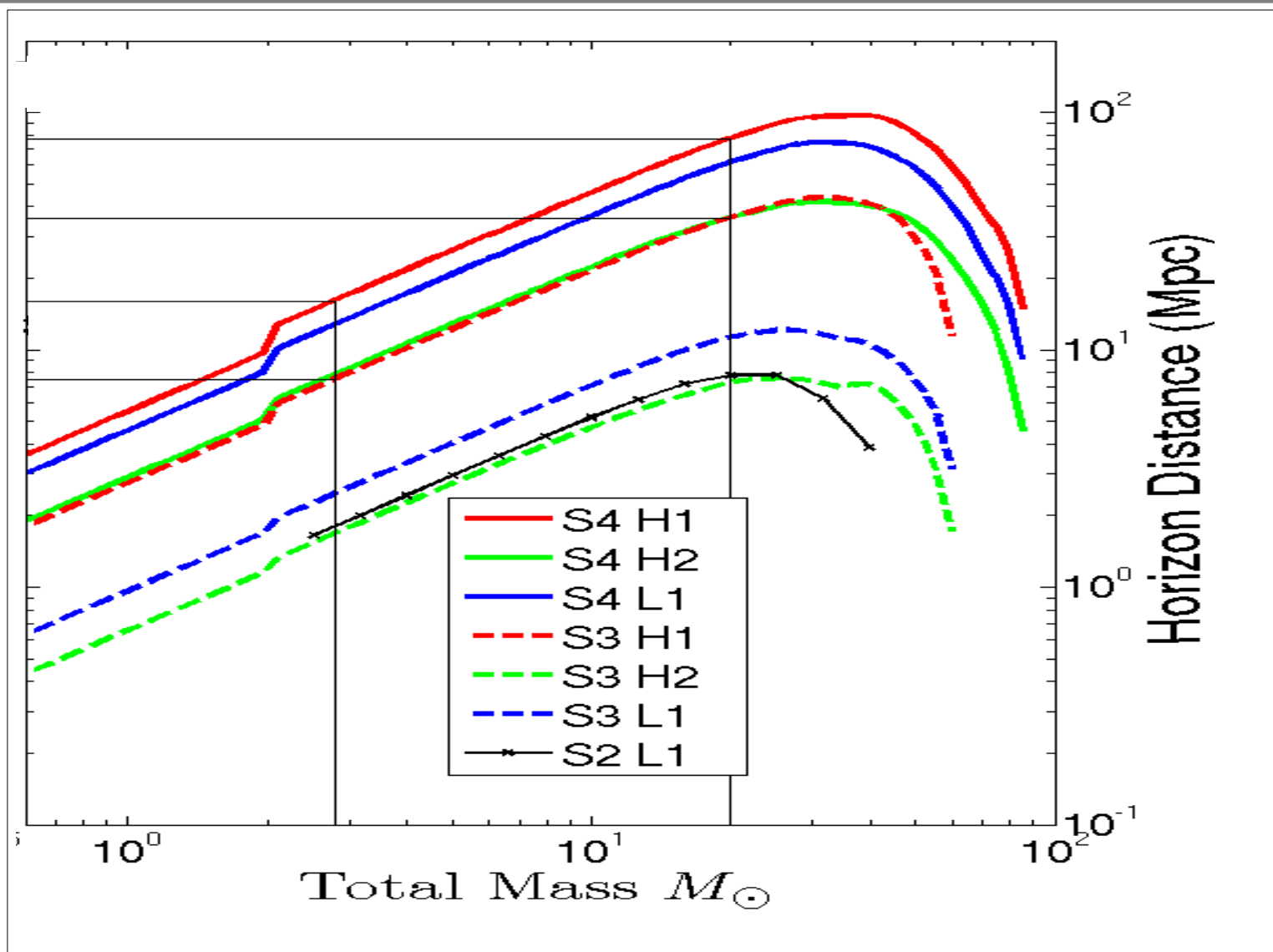


The search

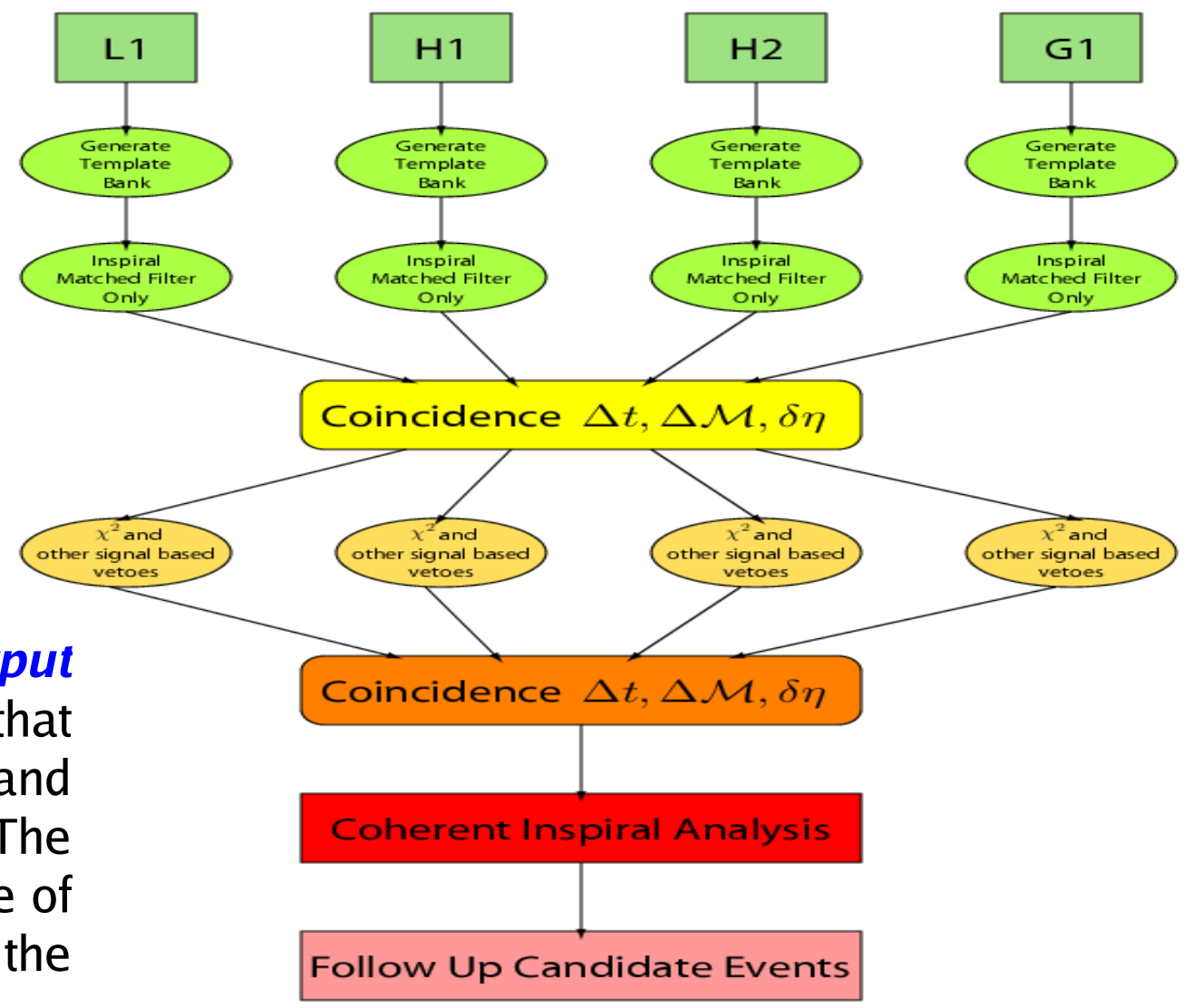
The horizon distance is the distance at which an optimally oriented and located binary system can be seen with a given signal to noise ratio:

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

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.



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



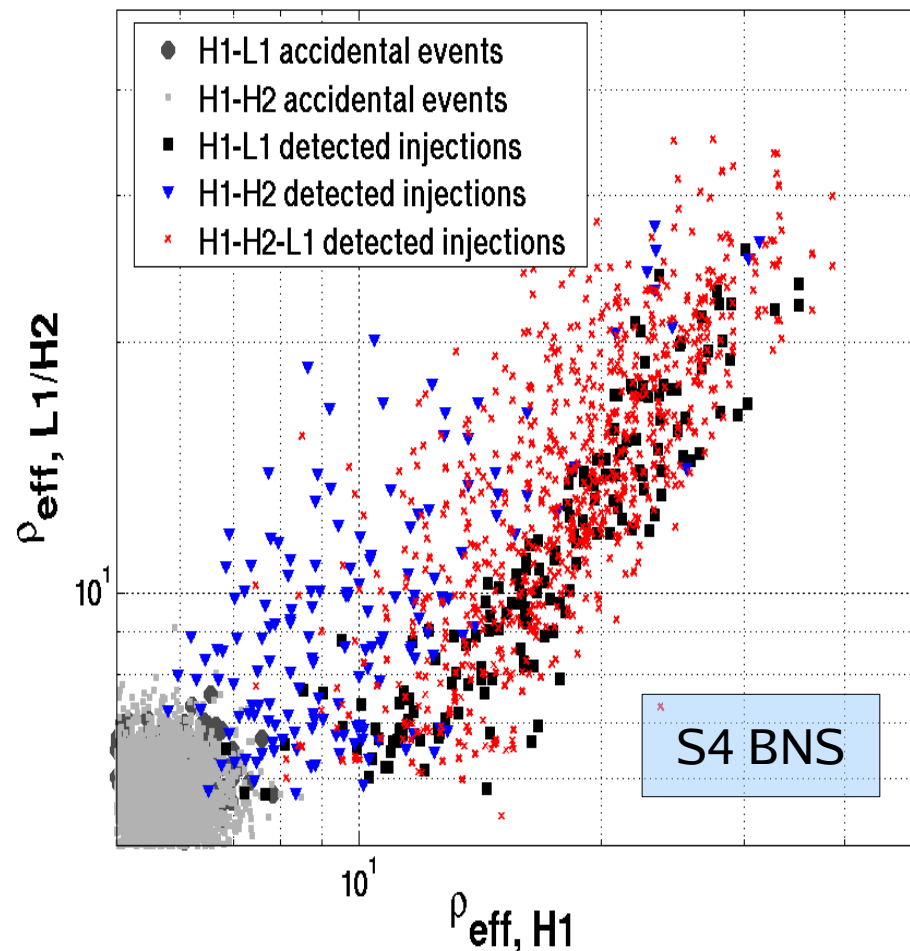
Coincidence at the output stage: we keep triggers that are coincident in time and mass parameters. The coincidence reduces the rate of triggers and increases the confidence in detection.

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 miss any real GW event.

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

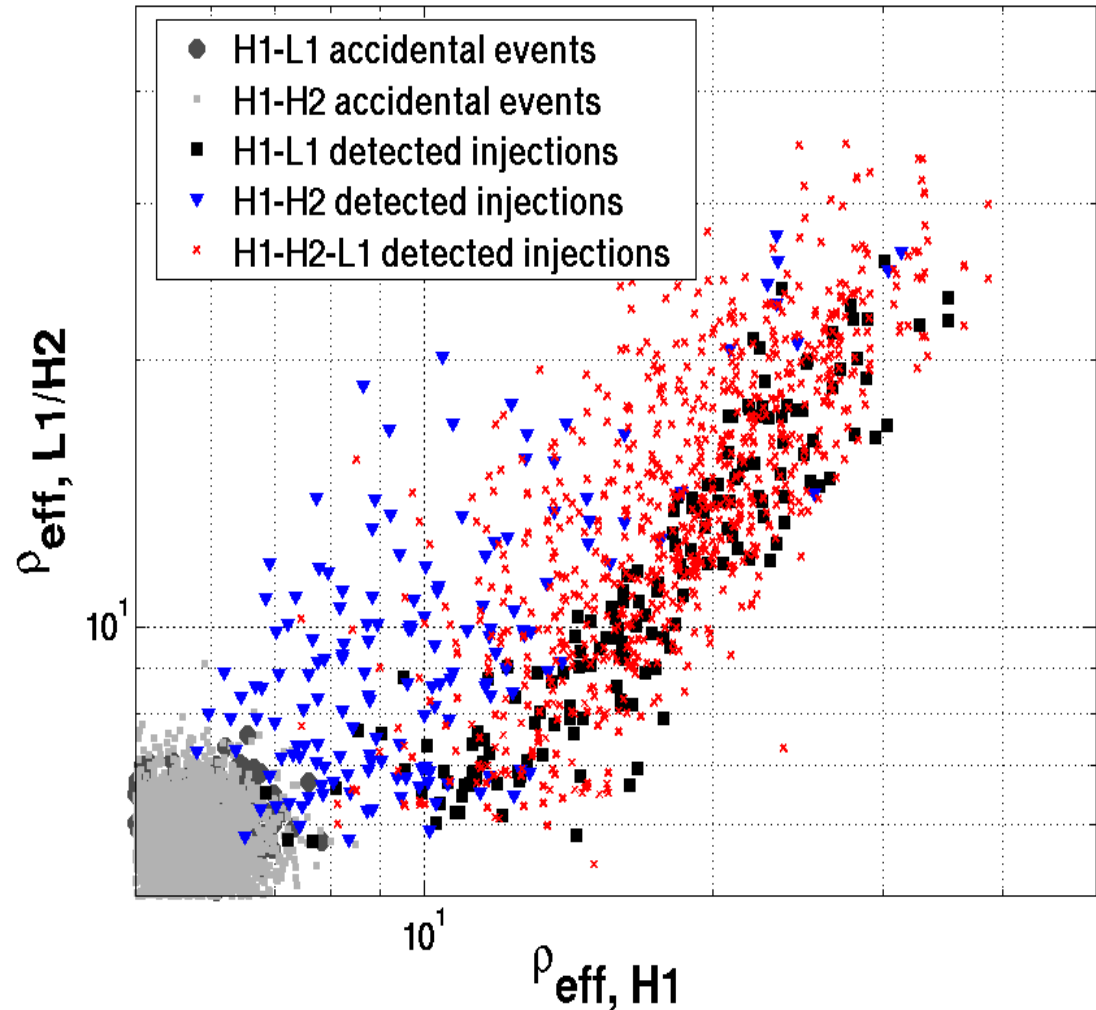
3-Results: Finally, we analyse the data (no injections, no time shifts). The resulting triggers constitute the *in-time coincident triggers, or candidate events*.



- 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.

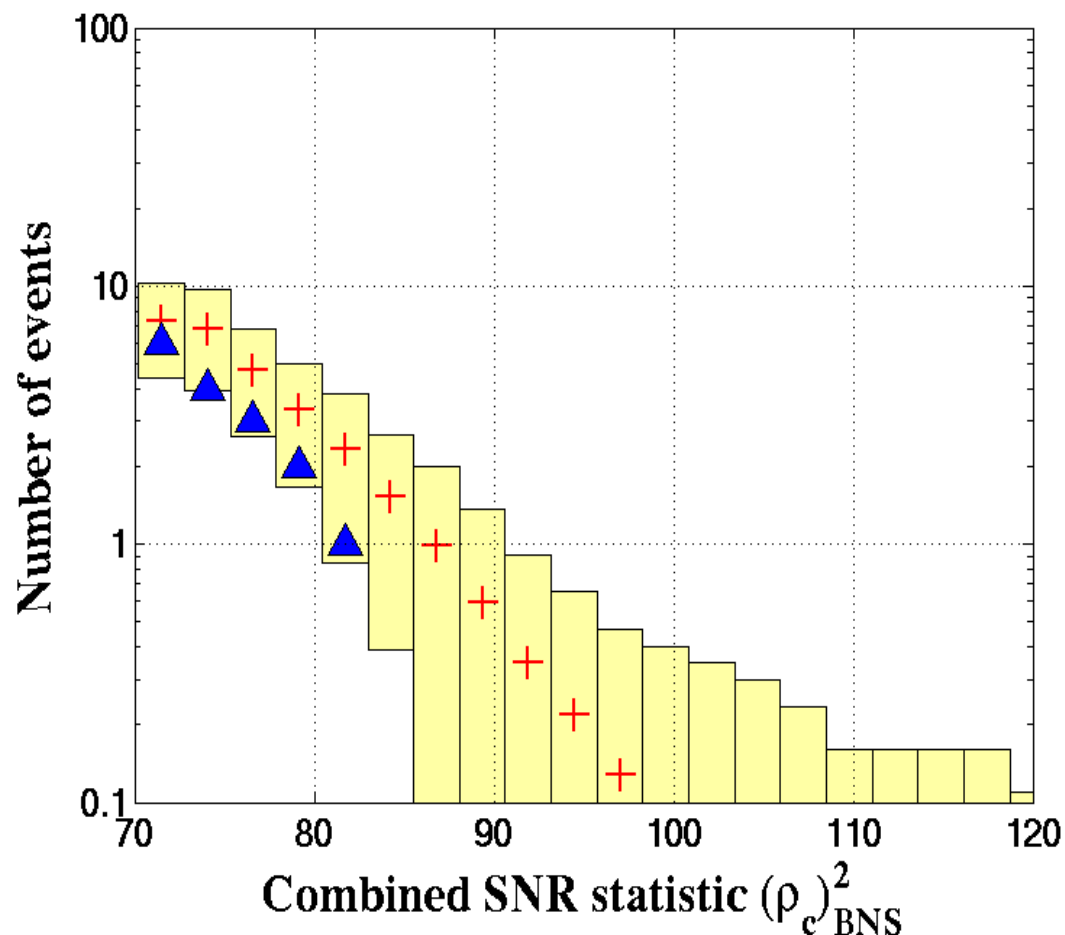
In PBH and BNS search, we use an effective SNR, that is a statistic which well separates the background triggers from simulated injections. It is defined by

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



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

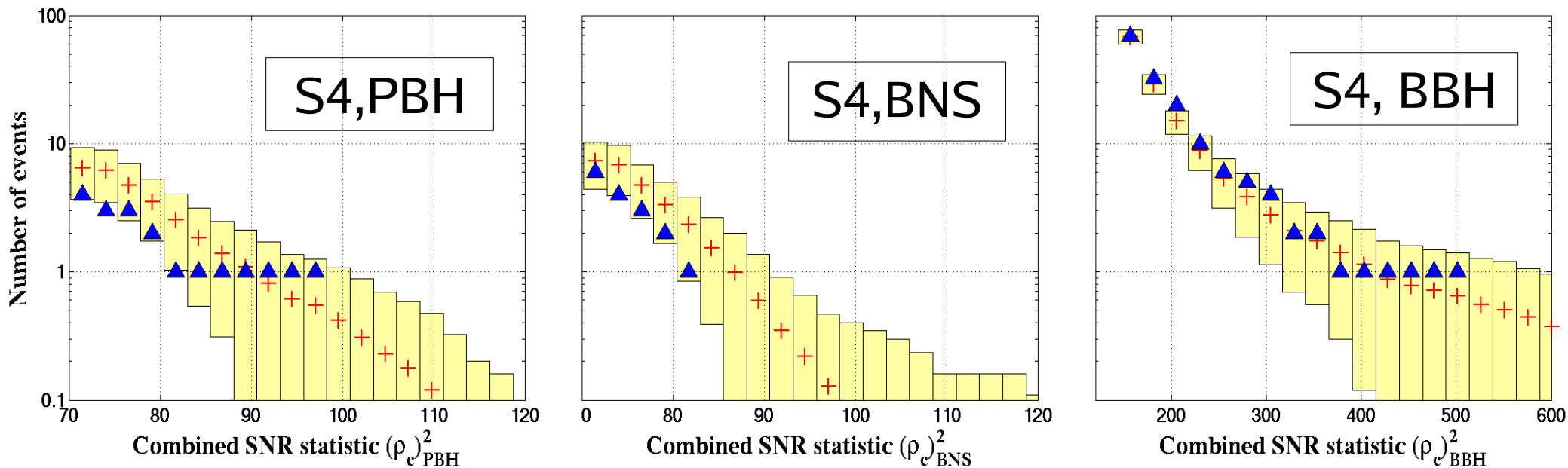
If an in-time coincidence triggers is above estimate background, then it is a **candidate event**, and needs **follow-ups**



Results

PBH, BNS and BBH, in S3 and S4 show that distribution of in-time coincidence triggers is consistent with expectation, except for the S3 BBH (next slide).

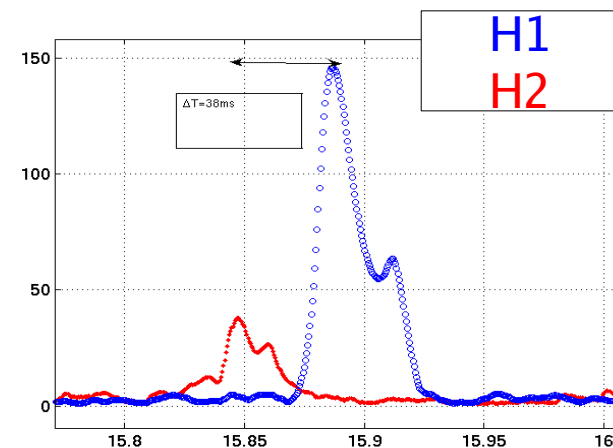
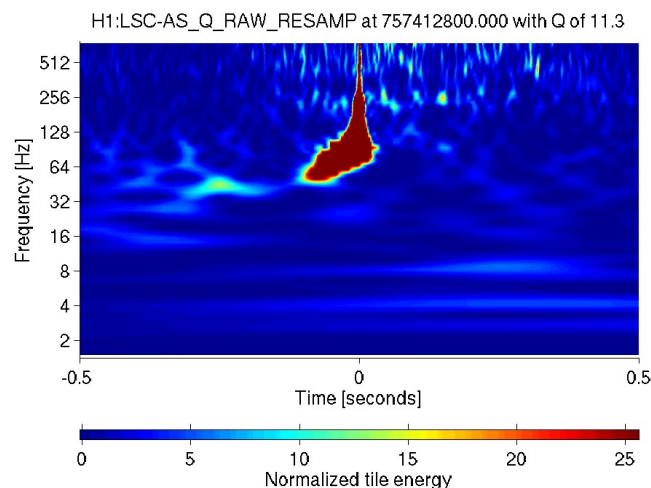
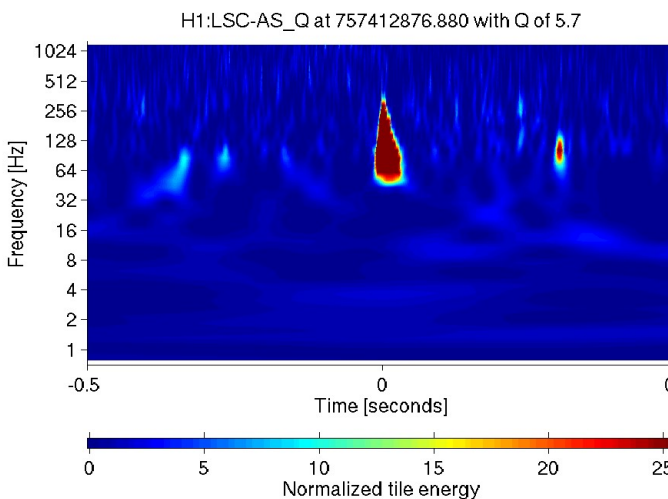
Preliminary results



Follow ups are needed for candidate events, if any. Irrespective of the list of possible candidates, we follow up the loudest coincidence triggers.

In S3 BBH search, 1 coincident trigger (H1/H2) found above estimated background (5 sigmas) with large SNR (150 in H1). Consistent with injections (same SNR, similar SNR time series). Using physical template families, we estimated the chisq, which did not reject the candidate.

- BUT
- (1) very high mass and therefore short time duration.
 - (2) No chirp-like time-frequency pattern (see 2 TF plots below).
 - (3) very wide time-shifts between H1 and H2 (see figure below) of 38ms whereas expectation gives a mean of zero and std of 6.5ms.



Serious candidate but not a plausible GW signal. Preliminary results

No

Upper limits

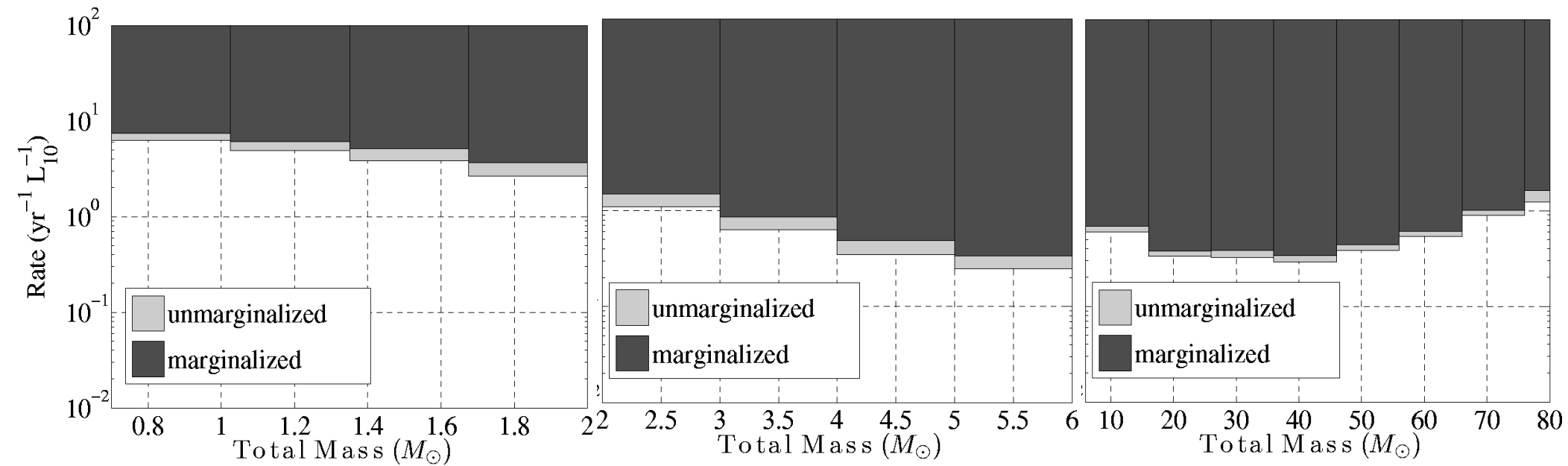
The Bayesian upper limit calculation is based on

- The detection efficiency at the loudest event (how many injections found with combined SNR above the largest in-time coincidence triggers).
- The estimated background.
- A galaxy population
- Time analysed (about 520 hours in S4)
- systematics errors such as Monte-Carlo errors, waveform inaccuracy, calibration errors...

We used only results from the best sensitive run, namely S4

1- Uniform distribution

Preliminary results



2- Gaussian distribution

Preliminary results

- **PBH binary** assuming Gaussian distribution around a 0.75-0.75 solar mass system:

$$4.9 \text{ yr}^{-1} L_{10}^{-1}$$

- **BBH** assuming a Gaussian distribution around a 5-5 solar mass system:

$$0.5 \text{ yr}^{-1} L_{10}^{-1}$$

- **BNS** assuming Gaussian distribution around a 1.4-1.4 solar mass system:

$$1.2 \text{ yr}^{-1} L_{10}^{-1}$$

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

Conclusion

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

Upper limits on merger rates :

$4.9 \text{ yr}^{-1} L_{10}^{-1}$	for PBH binaries
$1.2 \text{ yr}^{-1} L_{10}^{-1}$	for BNS (expected: $[2-120] 10^{-6} \text{ yr}^{-1} L_{10}^{-1}$)
$0.5 \text{ yr}^{-1} L_{10}^{-1}$	for BBH (expected $[0.4] 10^{-6} \text{ yr}^{-1} L_{10}^{-1}$)

Status of the analysis :

Mature BNS and PBH search pipeline. We can clearly identify simulated events at a SNR = 8 .

We will use PN template Families to cover the BBH in the future searches so as to reduce the background rate.

Present and Future :

Apply the tools developed on S5 and future science runs.