LIGO

Search for Low Mass Binary Coalescences in LIGO's S5 and Virgo VSR1 Data.

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LIGO-G0900543-v4

Outline

- What are we searching for?
- How are we searching?
- Results.
- Future...

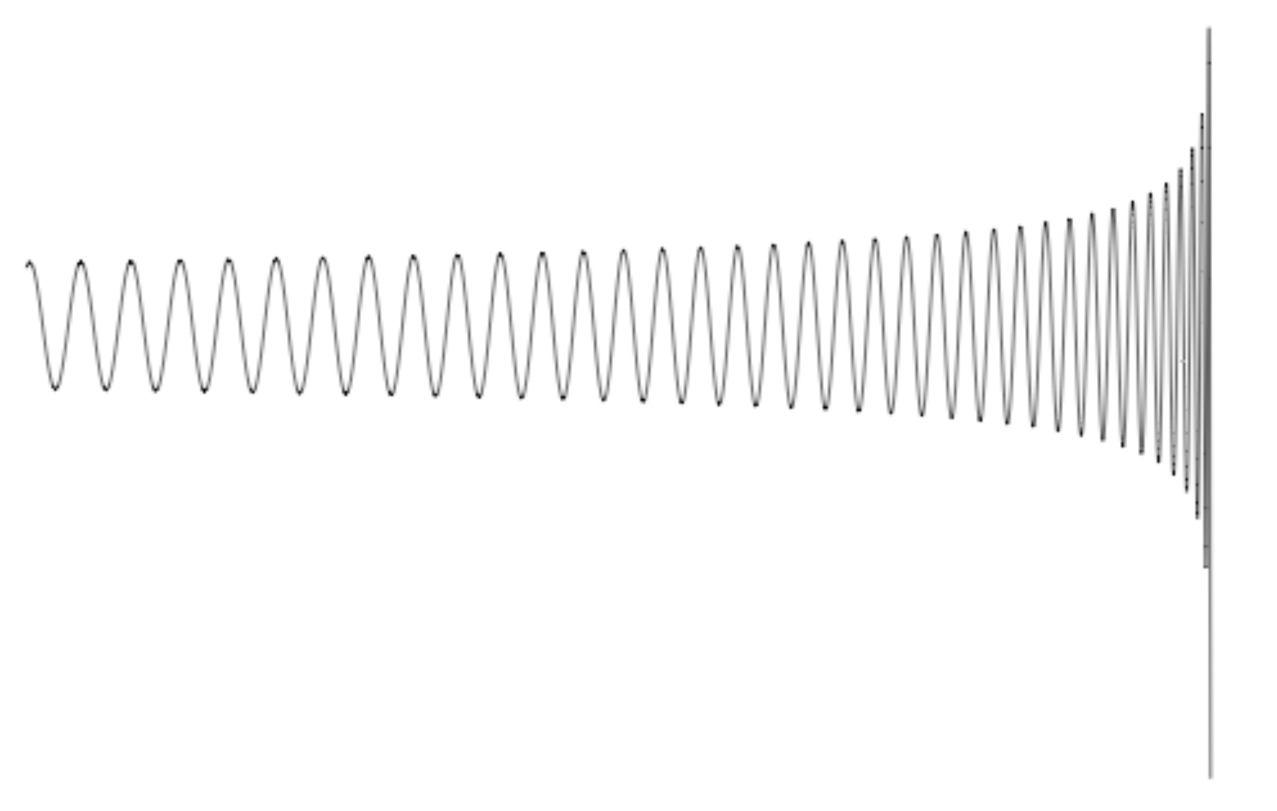
LIGO-G0900543

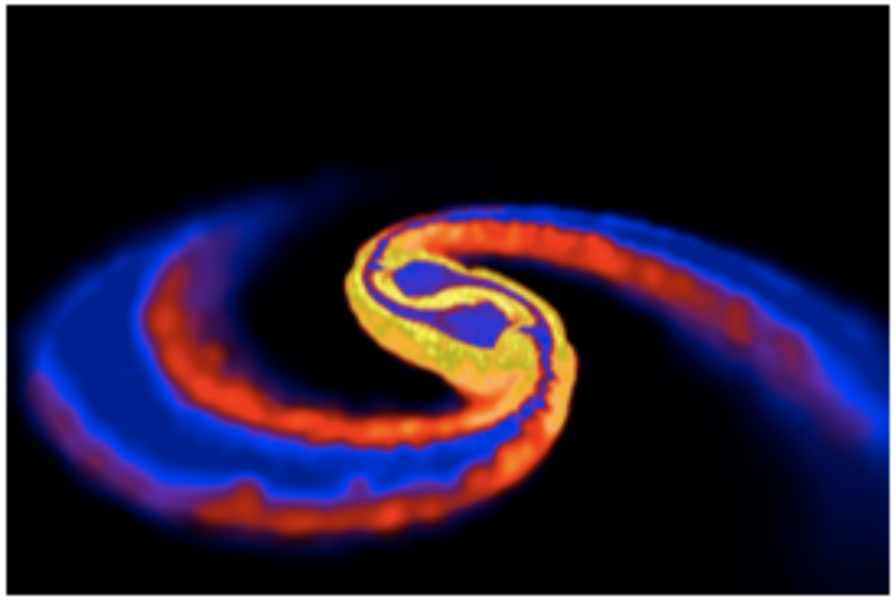
Sources the search is targeting

- Binary systems of massive compact objects in close orbits: neutron stars (NS) and/or black holes (BH) with a total mass of between 2-35$M_\odot$, with a minimum component mass of 1$M_\odot$

  Separate high mass search with 25$M_\odot$ < M_{TOTAL} < 100 $M_\odot$ – (Craig Robinson's Talk).

- Orbits decay by radiating energy as gravitational waves.
- Objects eventually collide and merge.





NS–NS merger. Credit: Daniel Price and Stephan Rosswog

The LIGO S5 & Virgo VSR1 science runs

- LIGO S5 science run, November 2005 – October 2007:
  - Detectors operating at design sensitivity.
  - 3 detectors at 2 sites, Hanford, WA and Livingston, LA.

- Virgo VSR1 science run coincided with the last 5 months of S5.
  - Based in Cascina, Italy.
  - Similar sensitivity to Hanford 2km.

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The search for low mass compact binary coalescences

- The search is divided into 3 separate searches:
  - S5 1st Year Search
    - Paper is published **Phys. Rev. D 79, 122001 (2009)**.
    - Set new constraints on the rate upper limits.
    - 0.40 years coincident and non-vetoed data.

    DONE

  - S5 12-18 Month Search
    - Paper available **arXiv:0905.3710v1**
    - The data after the first year, but before VSR1.
    - Less data, but increased sensitivity.
    - 0.25 years coincident and non-vetoed data.

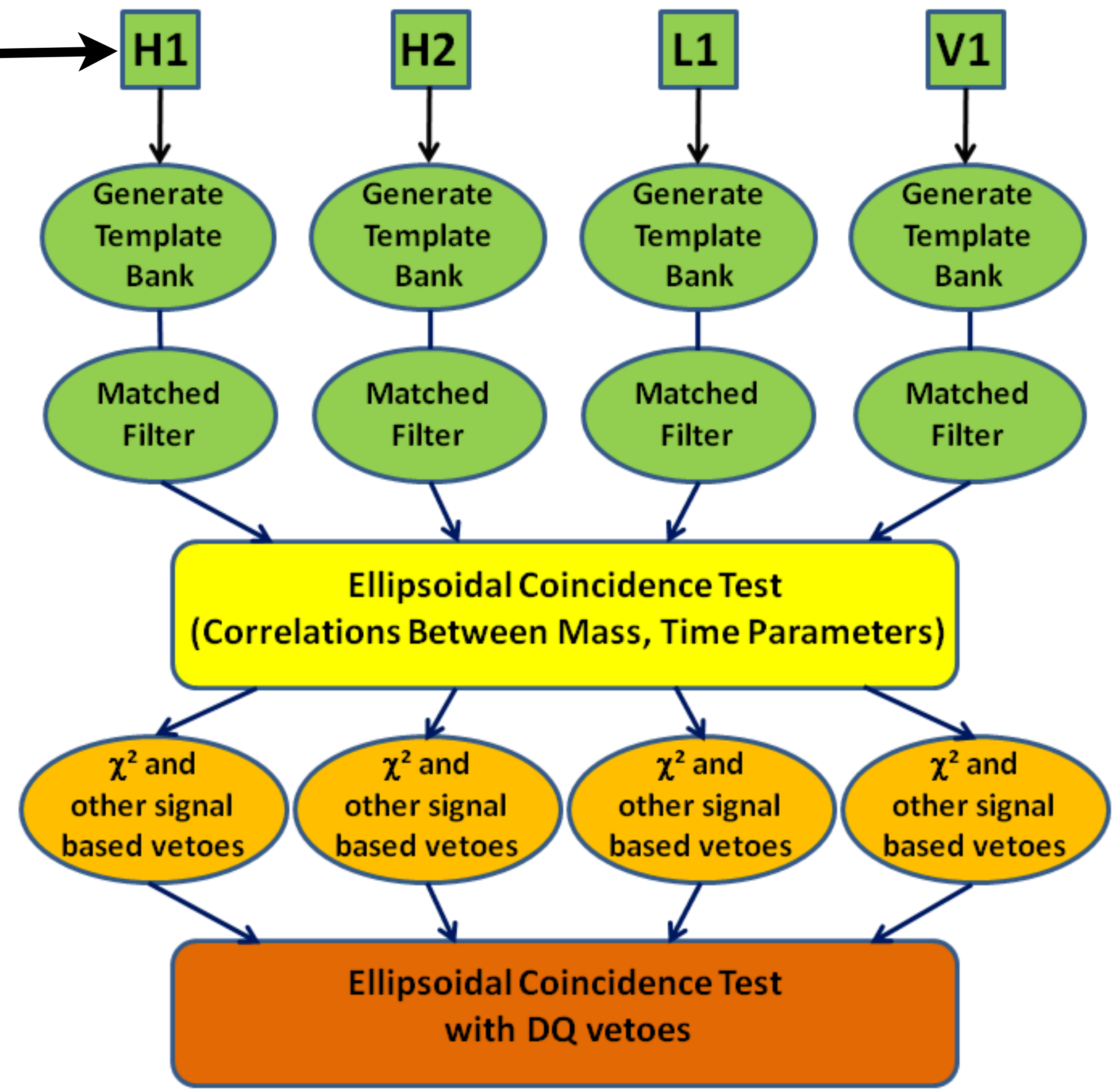
    Most recent results, first presented at APS 2009

  - Joint S5-VSR1
    - Search in data from three LIGO and Virgo detectors

    Undergoing review

The search overview

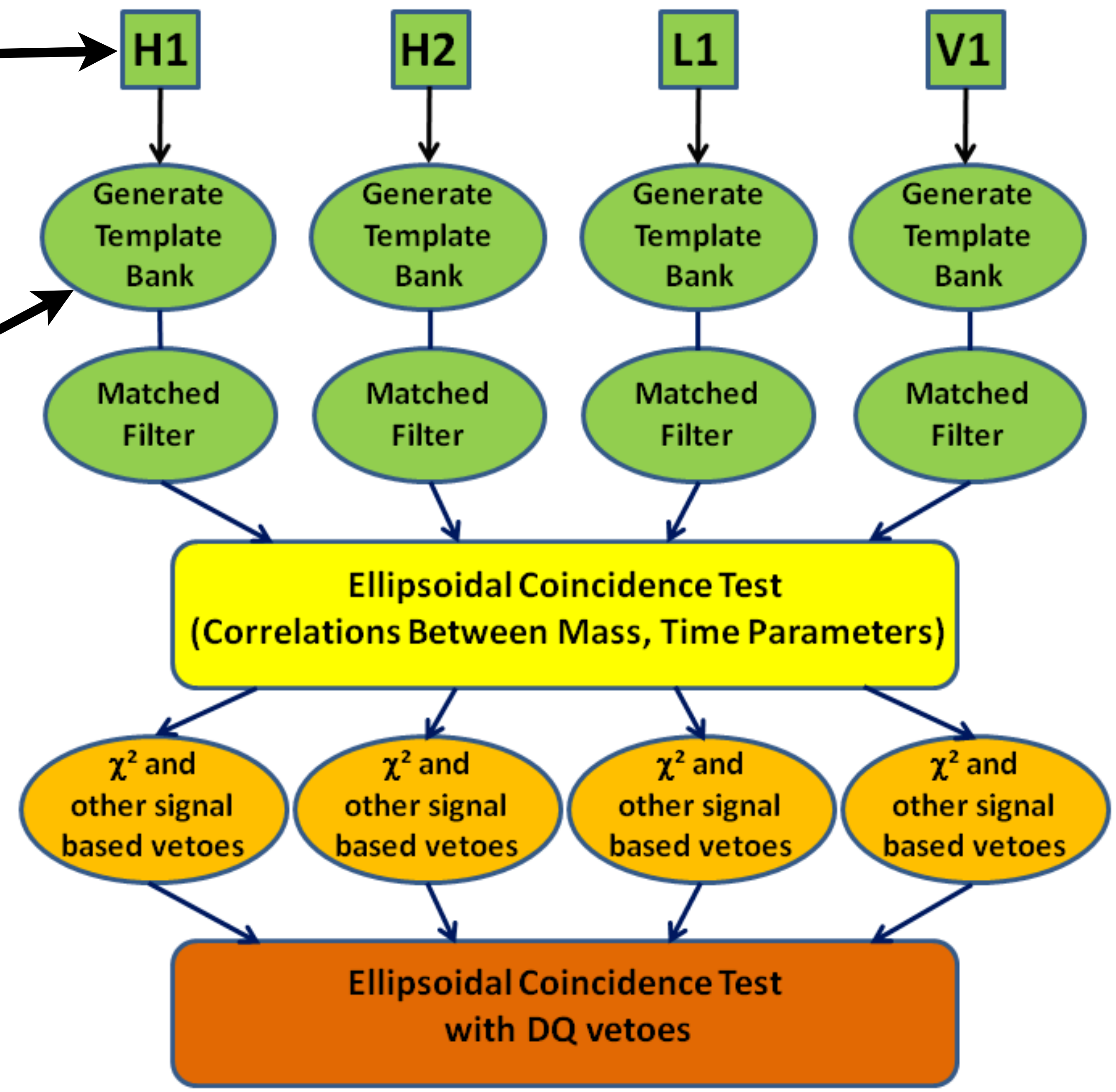
- Data from 4 interferometers



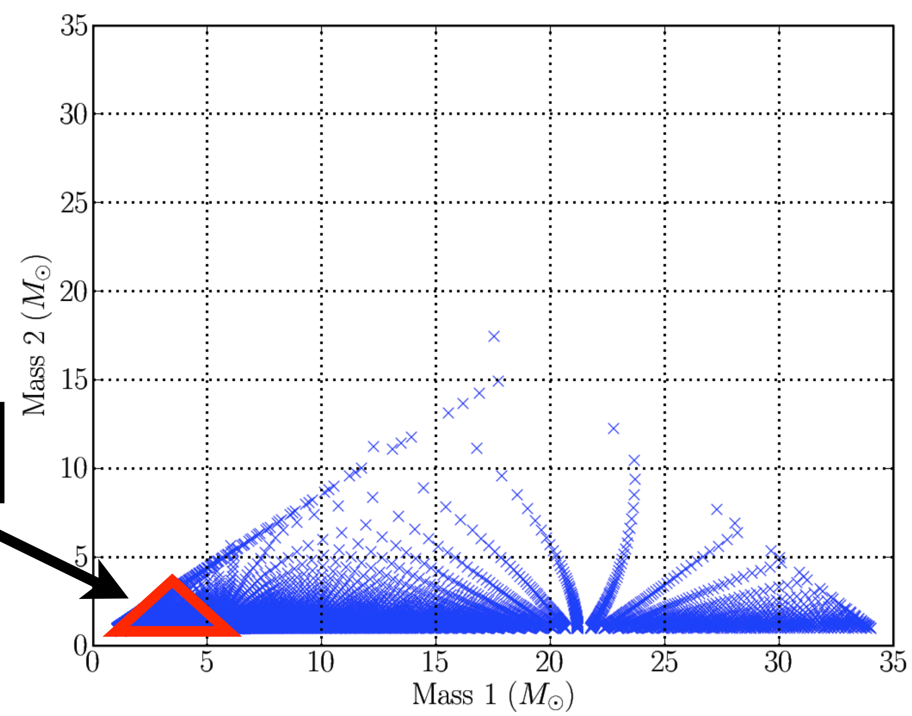
The search overview

- Data from 4 interferometers

- For each interferometer generate the template bank of 2^{nd} order Post-Newtonian SPA waveforms to cover the total mass range 2-35 $M_\odot$

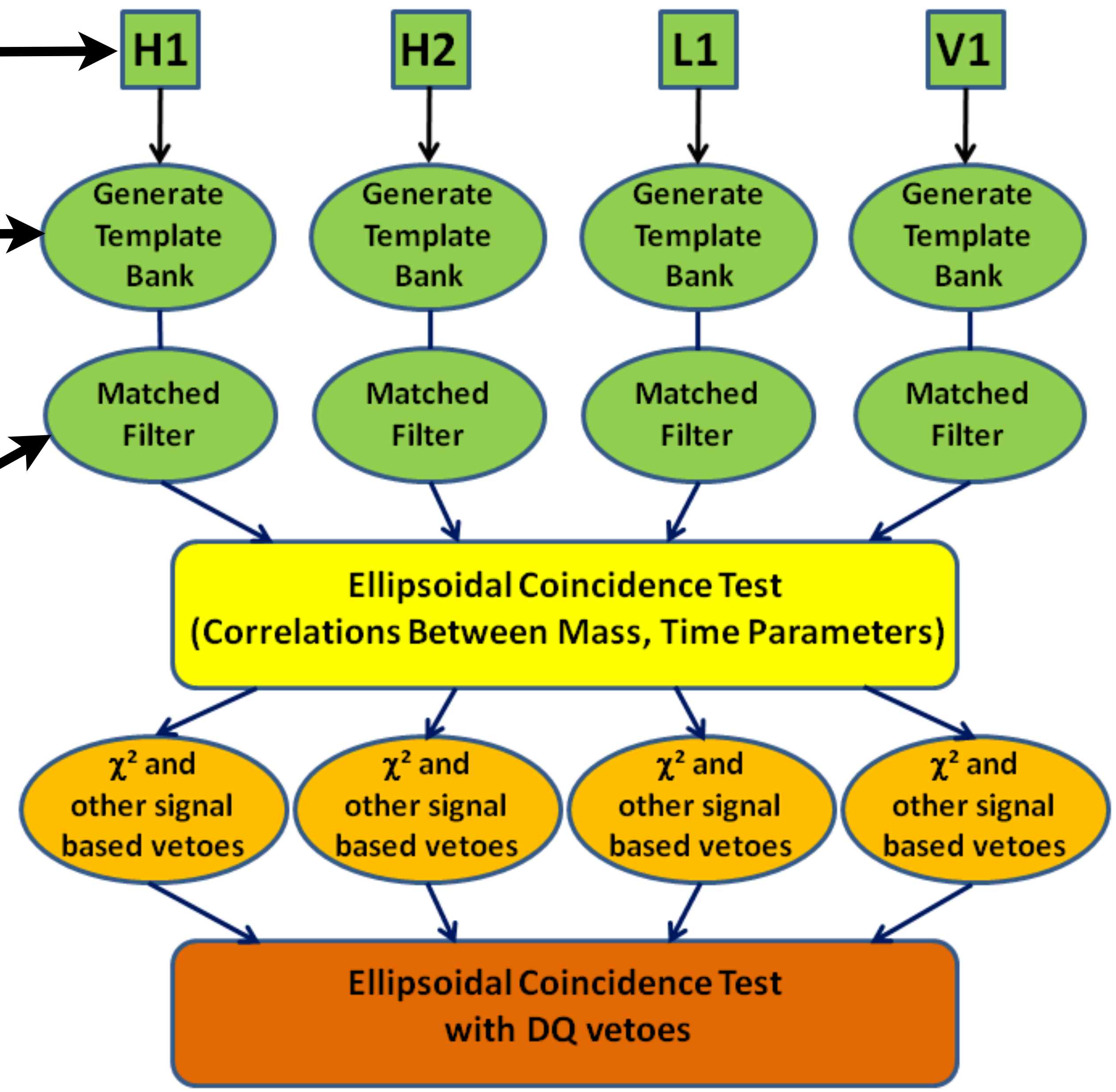


Virgo bank



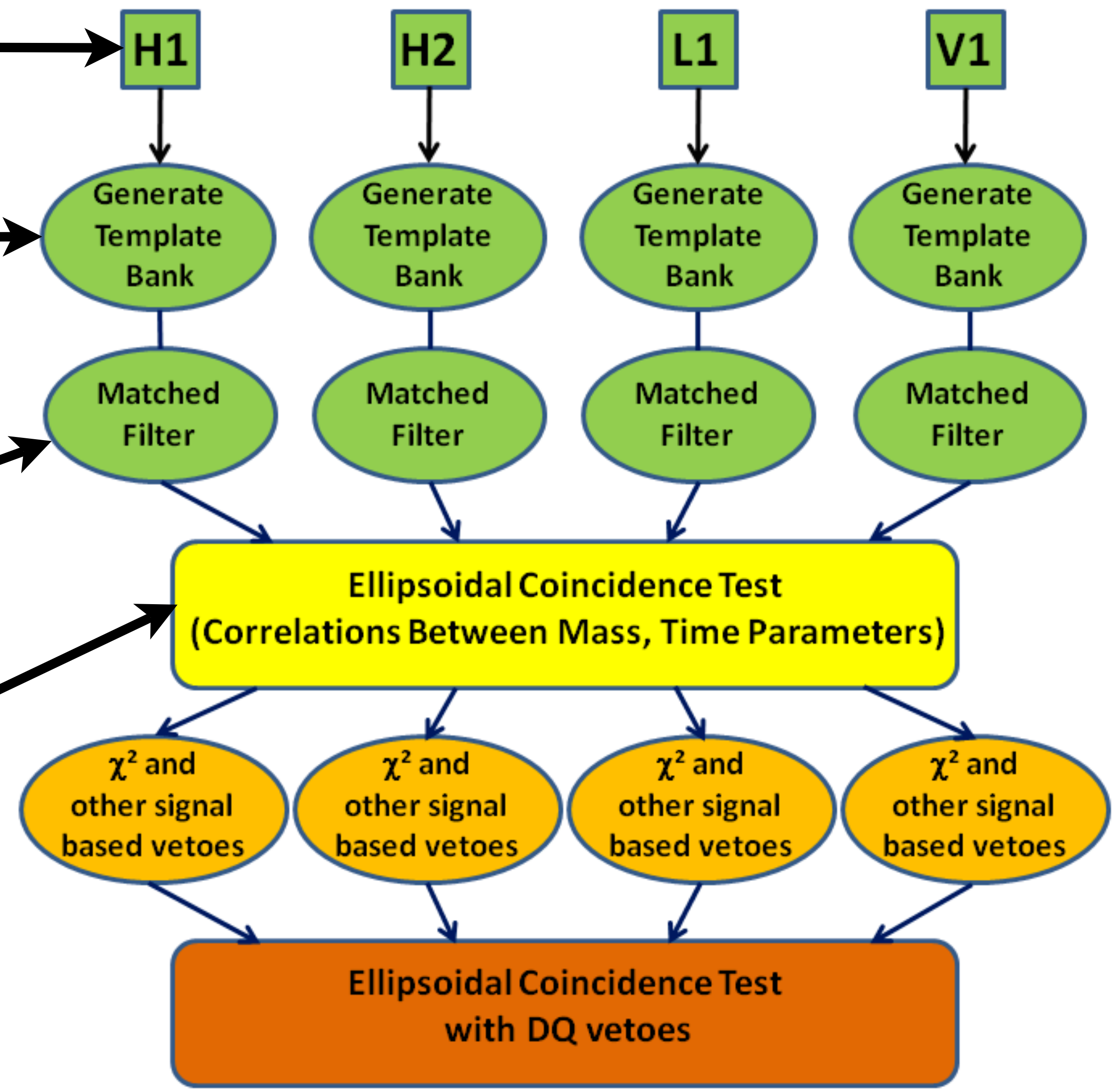
The search overview

- Data from 4 interferometers
- For each interferometer generate the template bank to cover the mass range
- Match filtering: keep triggers with Singnal-to-Noise Ratio (SNR) above a threshold



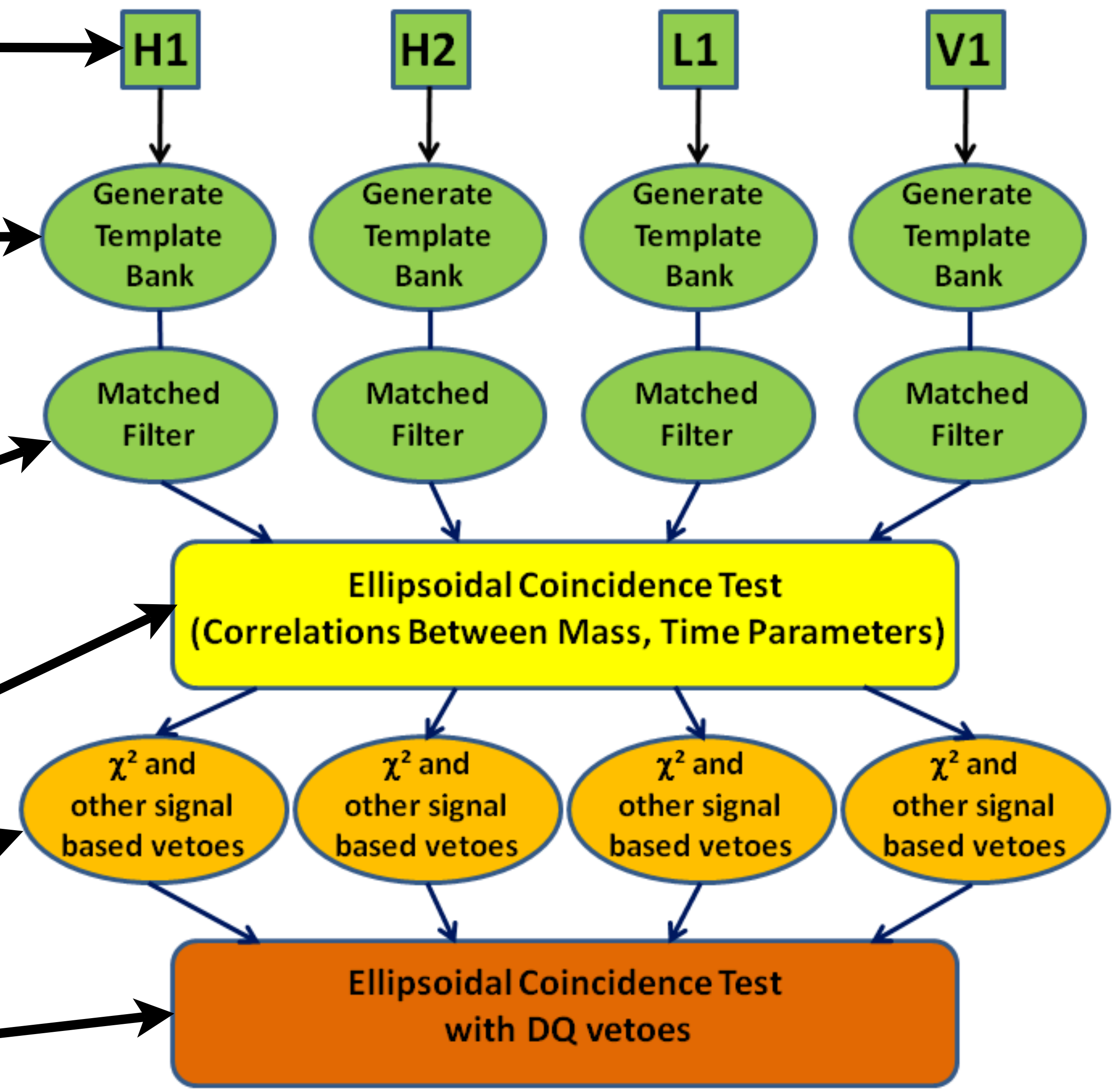
The search overview

- Data from 4 interferometers
- For each interferometer generate the template bank to cover the mass range
- Match filtering: keep triggers with Signal-to-Noise Ratio (SNR) above a threshold
- Test for coincidence in time and mass
  - Require triggers to be present in at least 2 detectors
  - Test for triple and quadruple coincidence



The search overview

- Data from 4 interferometers
- For each interferometer generate the template bank to cover the mass range
- Match filtering: keep triggers with Signal-to-Noise Ratio (SNR) above a threshold
- Test for coincidence in time and mass
- Apply vetoes
  - Signal based vetoes
  - Instrumental vetoes



Background estimation

- Background Estimation…
  - We time-slide the data from the non co-located sites with large enough time step ~10 seconds, in order to remove any correlations, and run the standard pipeline.
  - This means that any coincident events between the sites is accidental.
  - After performing 100 time-slides we have measured rates of background events for different types of triggers and detector combinations:
    - BNS (1.35, 1.35) $M_\odot$, NSBH (5.0, 1.35) $M_\odot$ and BBH (5.0, 5.0) $M_\odot$ have different background rates.
    - Different detector combinations e.g., H1L1 and H1H2L1 have different background rates.

Detection statistic

- In S5 we introduce new detection statistic:

  - We subdivide triggers found in the search into categories:
    - by mass: BNS, NSBH and BBH mass categories;
    - by combination of detectors at which a trigger with SNR above threshold was found;
    - by combination of detectors which was in science mode at the time of the event.

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  - In addition, for joint LIGO-Virgo analysis, due to very different sensitivities and large number of possible detector combinations, we introduce efficiency factors reflecting it.

  - Efficiency factors – estimate probability that a GW will trigger certain combination of detectors during the period when these (and possible other) detectors were in science mode.

Detection statistic and ranking of the candidate events.

- For S5 12–18 months, LIGO only:

$$Detection\ \ Statistic = \frac{1}{Background\ \ Rate(category)}$$

- For S5/VSR1 months, joint LIGO–Virgo:

$$Detection\ \ Statistic = \frac{Efficiency\ \ Factor(detector\ \ combination)}{Background\ \ Rate(category)}$$

- We found that new detection statistics significantly improves overall efficiency of the search.

- We quote our results in terms of Inverse False Alarm Rate, IFAR:

Detection statistic ⟹ IFAR

Results from 12-18 months of S5

- NO Detection Candidates! ☹
  - The loudest trigger in 0.25 year of data had an IFAR of 0.16 years.
  - We therefore set Bayesian rate upper limits, first individually on each month with a uniform prior before combining each month with the posterior rate limits from the S5 1st year low mass search.
  - Upper limits are a combination of how much of the Universe we were sensitive to and for how long we searched.
  - Upper limit rates are quoted in units of L_{10}^{-1} yr^{-1}. L_{10} is 10^{10} times the blue light solar luminosity.
  - The Milky Way contains ~ 1.7 L_{10}.

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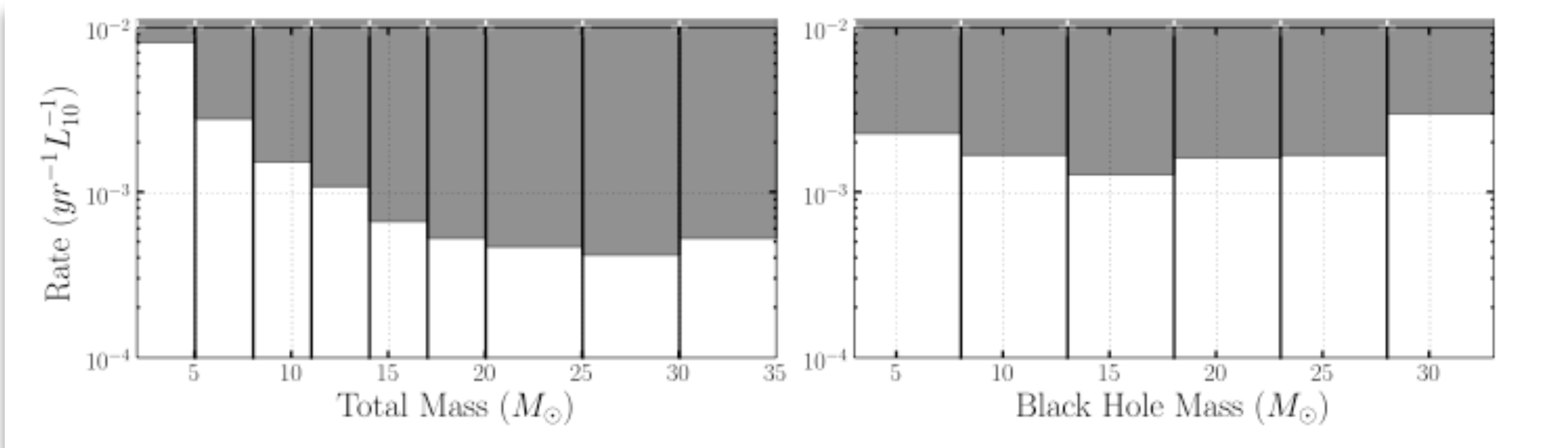
Rate upper limits (non-spinning) based on the first 18 months of S5

- BNS rate 90% confidence = $1.4 \times 10^{-2} L_{10}^{-1} yr^{-1}$.
  - Where BNS is (1.35, 1.35) $M_\odot$.
- BBH rate 90% confidence = $7.3 \times 10^{-4} L_{10}^{-1} yr^{-1}$.
  - Where BBH is (5.0, 5.0) $M_\odot$.
- BHNS rate 90% confidence = $3.6 \times 10^{-3} L_{10}^{-1} yr^{-1}$.
  - Where BHNS is (5.0, 1.35) $M_\odot$.

Upper limits on rate by total mass and by component mass



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Rate upper limits compared with astrophysical expected rates

- New limits from 12–18 months are factor of 3 lower then those from first year of S5.

Binary type	Our upper limit, 90% confidence, L_{10}^{-1} yr $^{-1}$	Astrophysical Optimistic Rates, L_{10}^{-1} yr $^{-1}$	Astrophysical most likely Rates, L_{10}^{-1} yr $^{-1}$	Comparison
BNS	1.4×10^{-2}	5×10^{-4}	5×10^{-5}	~2–3 orders
NSBH	3.6×10^{-3}	6×10^{-5}	2×10^{-6}	~2–3 orders
BBH	7.3×10^{-4}	6×10^{-5}	4×10^{-7}	~1–3 orders

Future

- 2009...
  - The results of the LIGO-Virgo S5 low mass search to be reviewed.
  - LIGO S6 and Virgo VSR2 run, with improved sensitivity.
- 2014...
  - Advanced LIGO begins operation.
  - Factor of 1000 increase in visible volume of the Universe compared to Initial LIGO!

Thanks for listening

- Any Questions… ?

LIGO-G0900543

Detection vs False Alarm probabilities curves