First Joint analysis between Gravitational Waves and High Energy Neutrinos using LIGO/Virgo-ANTARES data

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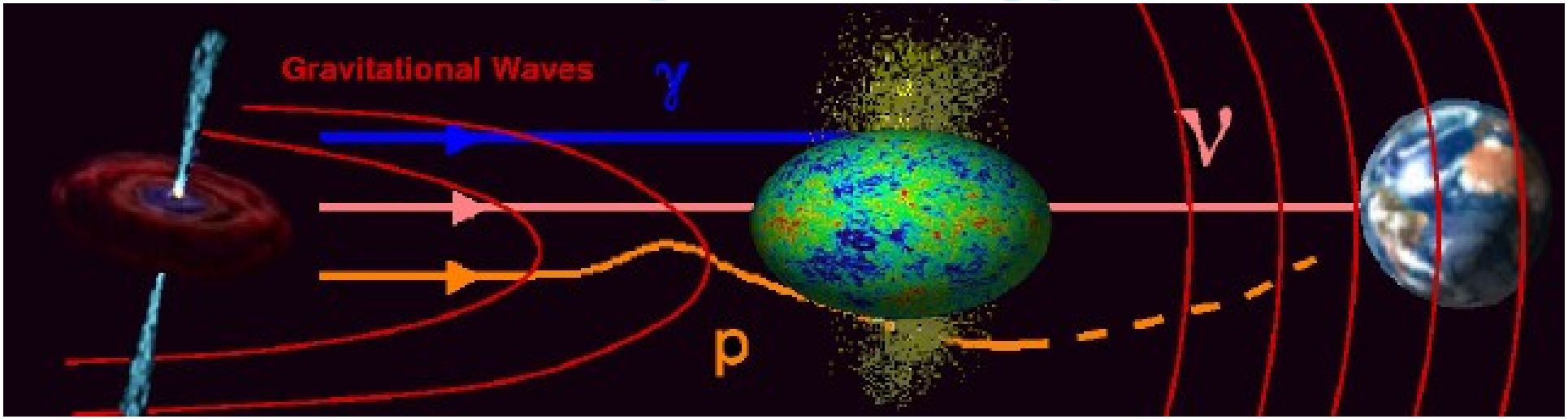
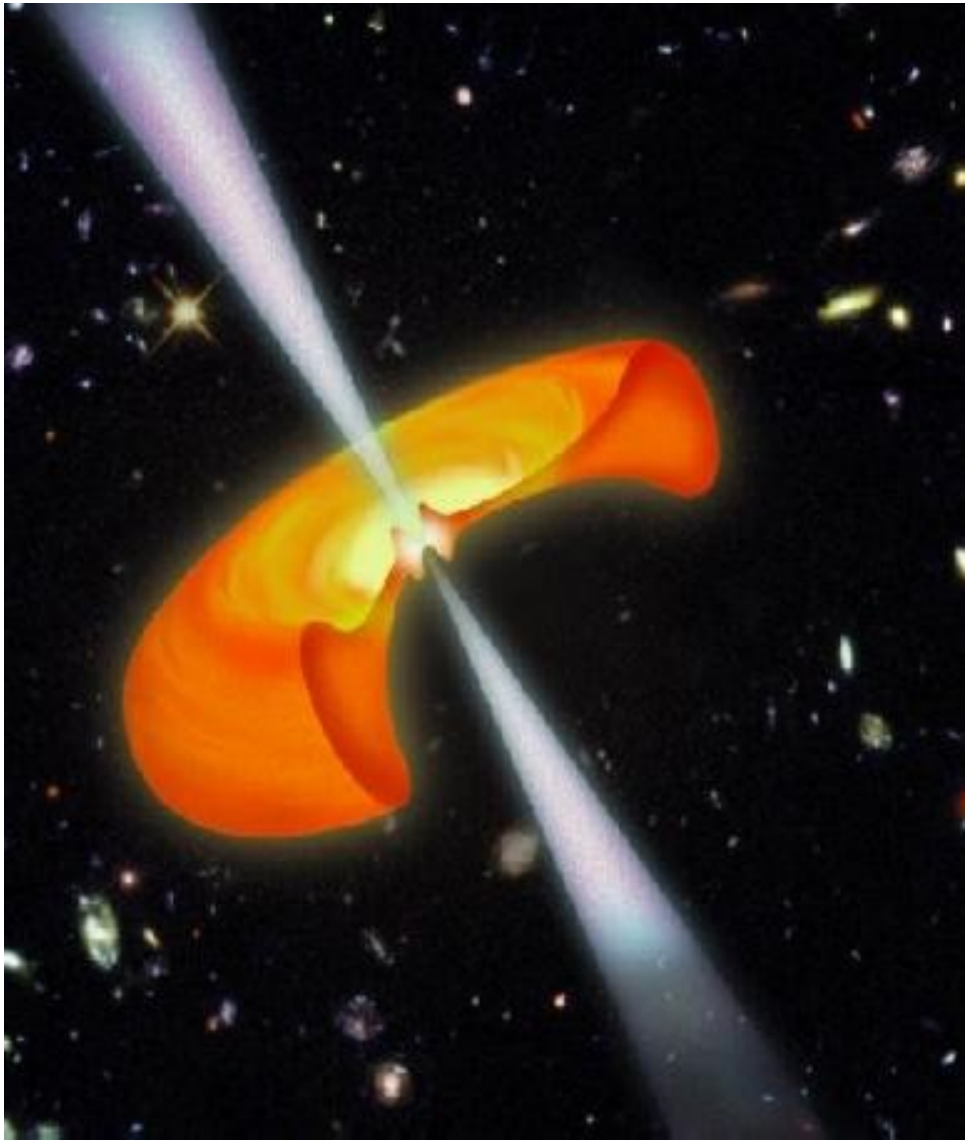
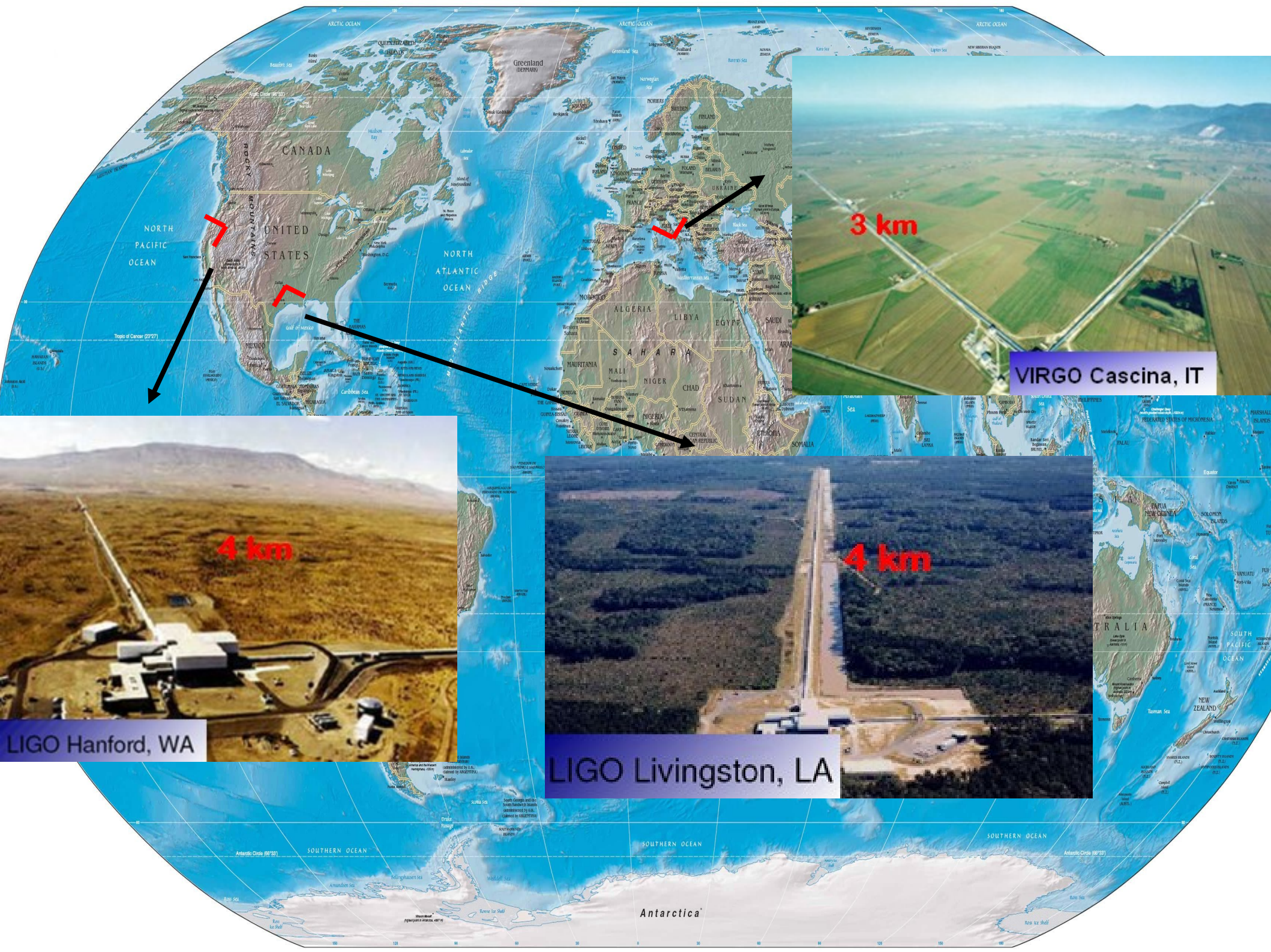


- Gravitational Waves and High Energy Neutrino can escape very dense media and travel unaffected over cosmological distances, carrying information from the innermost regions of the astrophysical engines. Such messengers could also reveal new, hidden sources that are not observed by conventional photon astronomy
- The basic idea is that the accidental occurrence of the coincidence (in time and sky location) of GW and HEN triggers is very unlikely. If such coincidence is observed, this would provide strong evidence that GWs and HENs have been observed and that they originate from a common astrophysical source.

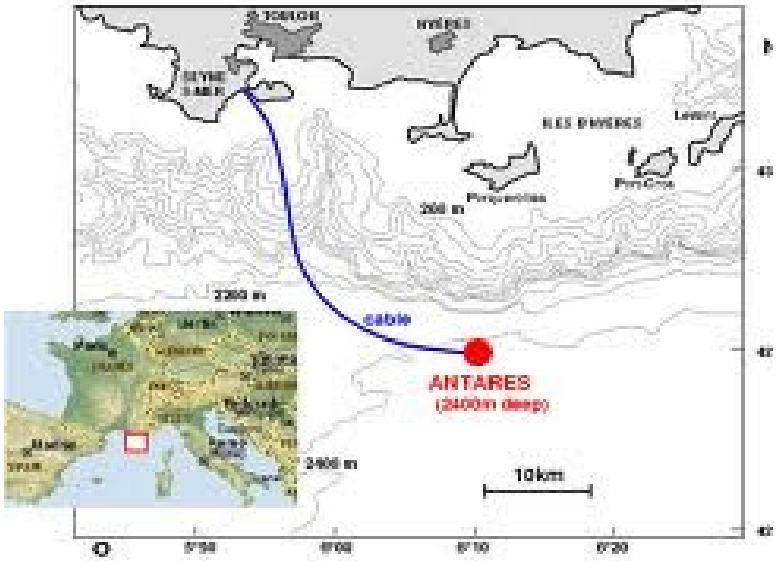
Most plausible common sources

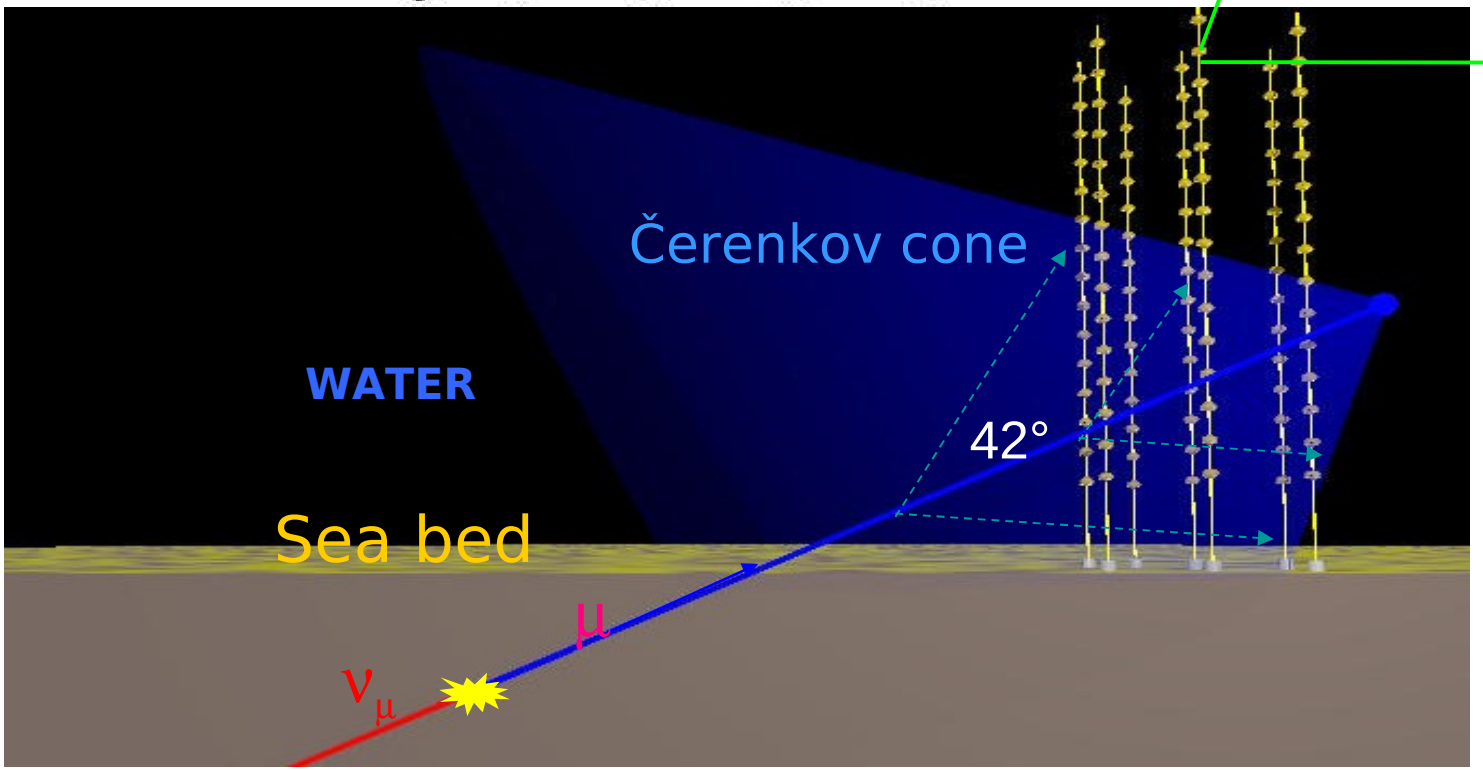


- **Long GRBs:** In the prompt and afterglow phases, High energy neutrinos (10^5-10^{10} GeV) are expected to be produced by accelerated protons in relativistic shocks (e.g., Waxman & Bahcall 1997;Vietri 1998; Waxman 2000).
- **Short GRBs:** HENs can also be emitted during binary mergers (Nakar 2007; Bloom et al. 2007; Lee & Ramirez-Ruiz 2007).
- **”Failed” GRBs:** plausibly from baryon-rich jets. Optically thick, can be hidden from conventional astronomy, neutrinos and GWs might be able to reveal their properties (Meszaros & Waxman 2001,Ando & Beacom 2005).

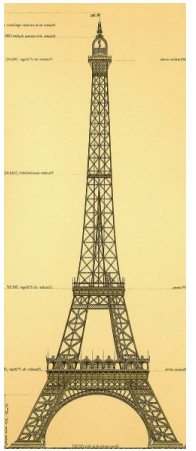

3 km
VIRGO Cascina, IT
4 km
LIGO Hanford, WA
4 km
LIGO Livingston, LA
CANADA
UNITED STATES
NORTH PACIFIC OCEAN
NORTH ATLANTIC OCEAN
Greenland
SOUTHERN OCEAN
Antarctica

ANTARES Neutrino Telescope





~450 m



Gravitational Wave Bursts

GW bursts are defined loosely as any transient signal for which we do not rely on a specific theoretical model. Search for GW bursts typically focusses on detecting generic waveform with duration range 1-100 ms.

- **"Untriggered"** searches scan all available data, they look for simultaneous jumps of energy in all detectors in some time-frequency region, with consistent measurement of amplitude or correlation between the detectors.

- **"Triggered"** searches scan a small amount of data around the time of an astronomical event (GRB, neutrinos), by cross-correlating data from pairs of detectors. These searches exploit knowledge of the time and direction to the astronomical event to improve the sensitivity of the search.

GW Bursts Detection Algorithm

- **Coherent network method:**

  - X Pipeline is a matlab-based software package for performing coherent searches for gravitational-wave bursts in data multiple detectors, weighted by relative sensitivity to the sky location of the neutrino.

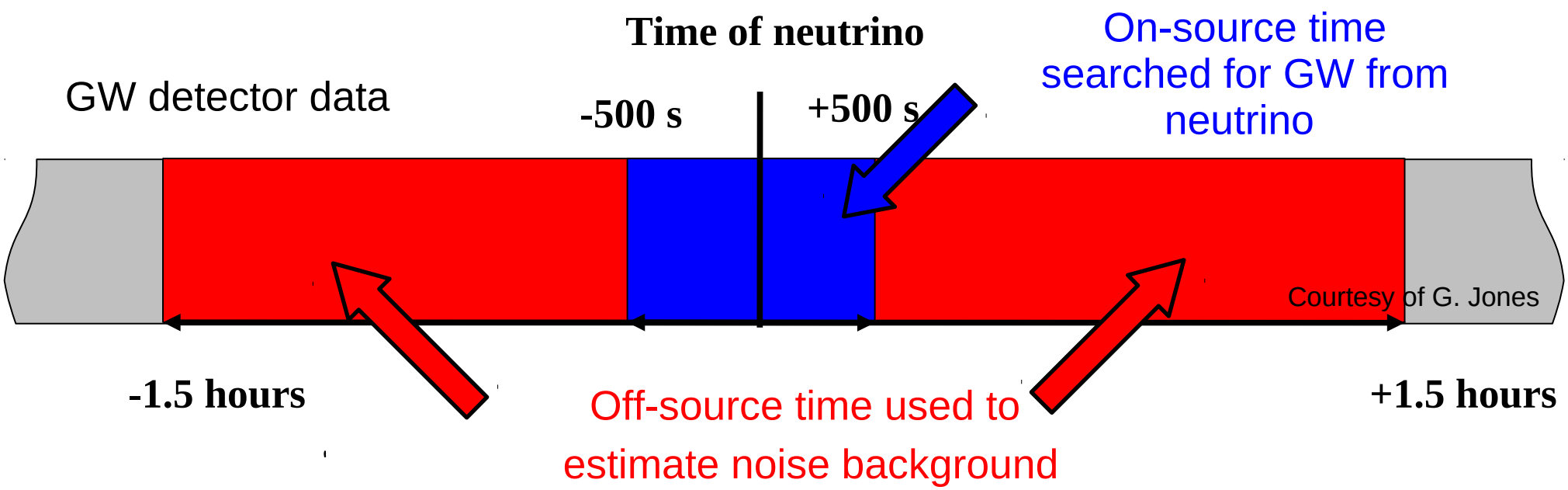
  - It constructs linear combinations of data streams: those that maximize the signal to noise ratio (SNR) of any GW signal present. Search time-frequency map of that data for excess energy.

  - Then, the energies in the streams are compared to attempt to discriminate between true Gravitational Wave Bursts and background noise fluctuations.

References: astro-ph.0908.3824v1
https://trac.ligo.caltech.edu/xpipeline/

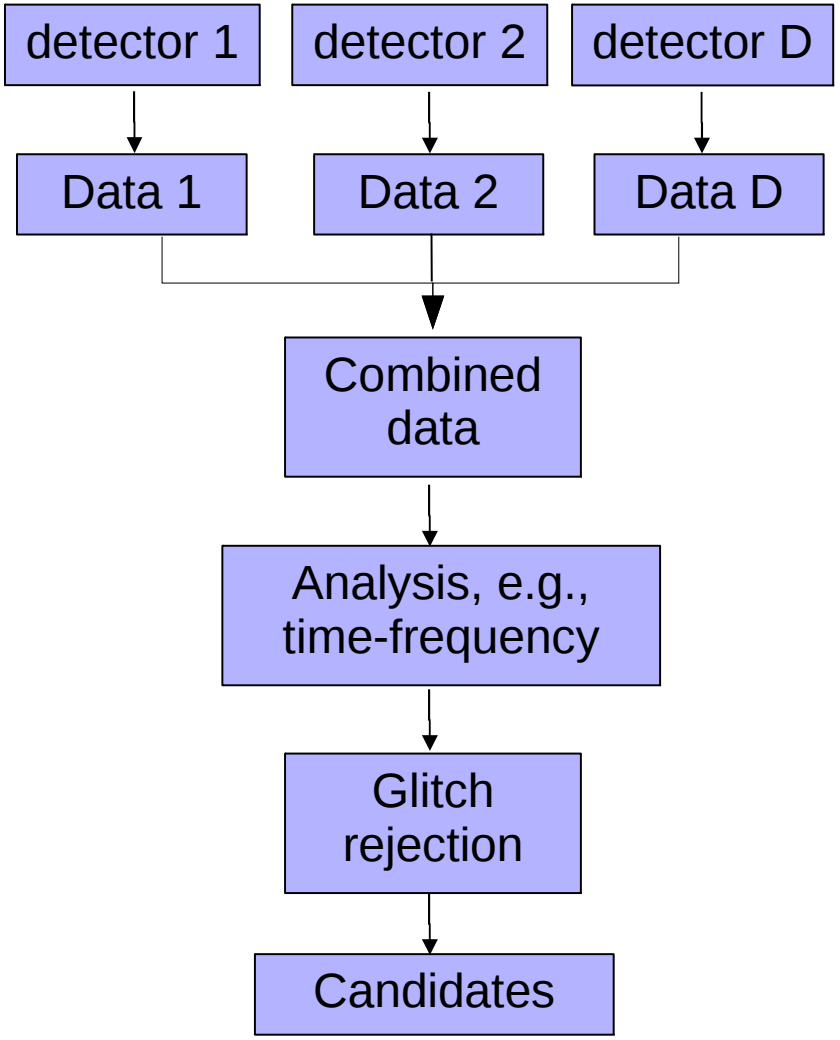
X-Pipeline search

- The data is divided into two sets:
  - On-source: [-500, +500] s around each neutrino trigger (arXiv:1101.4669).
  - Off-source: all other data within +/- 1.5 hr of the neutrino, divided into blocks of the same length as the on-source period + time slides.
- The on-source data is searched for large excess energy events.
  - The significance of each event is estimated by comparing to typical values in the off-source data.



Coherent Analysis

Coherent analysis combines data **before** generating triggers meaning more info can be extracted. Automatically takes into account varying detector sensitivity and measures similarity in data



Blind non-biased analysis:

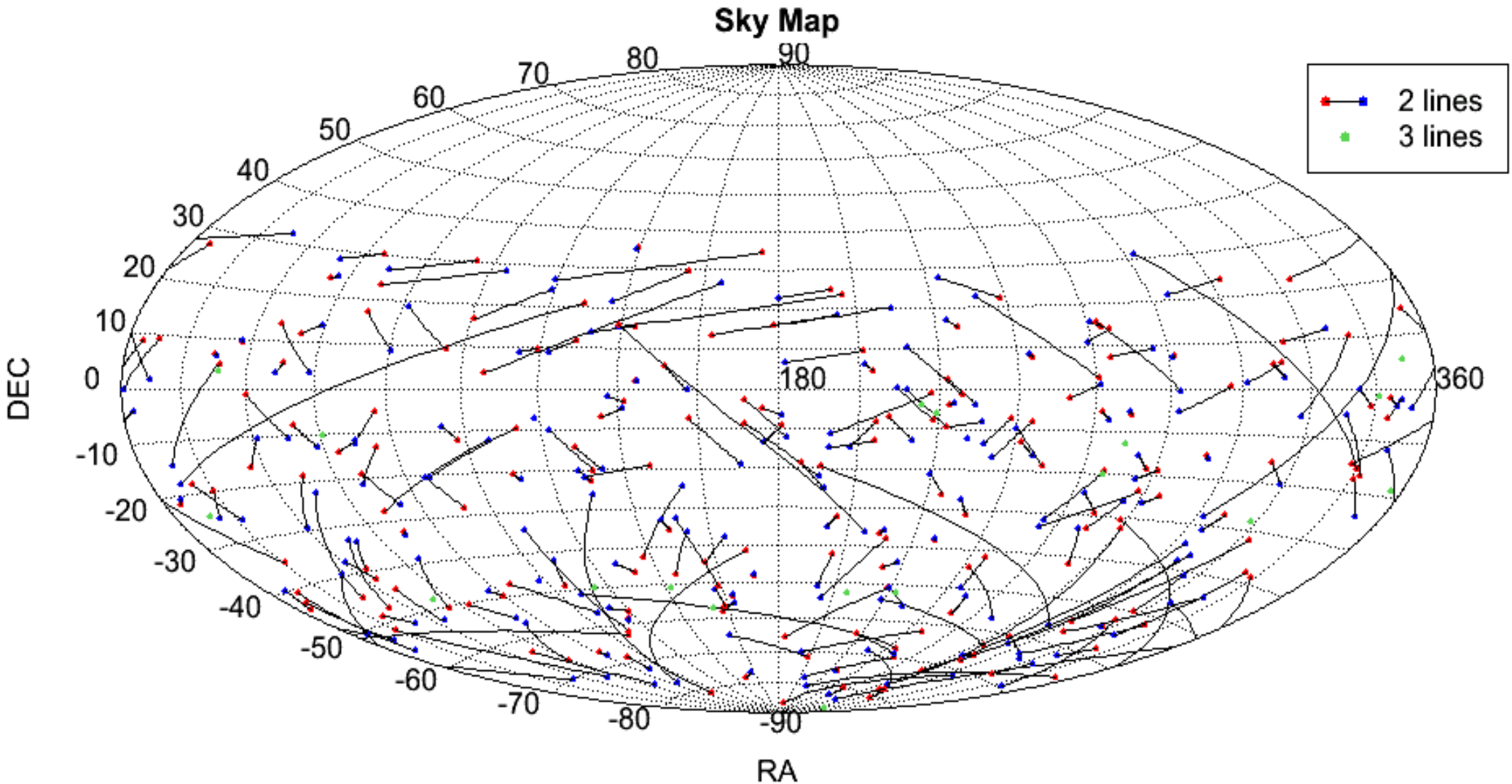
Closed-box analysis: Tune our search parameters on off-source.

Open-box analysis: Search for GW in on-source with optimal parameters.

Sky Map of ANTARES trigger positions

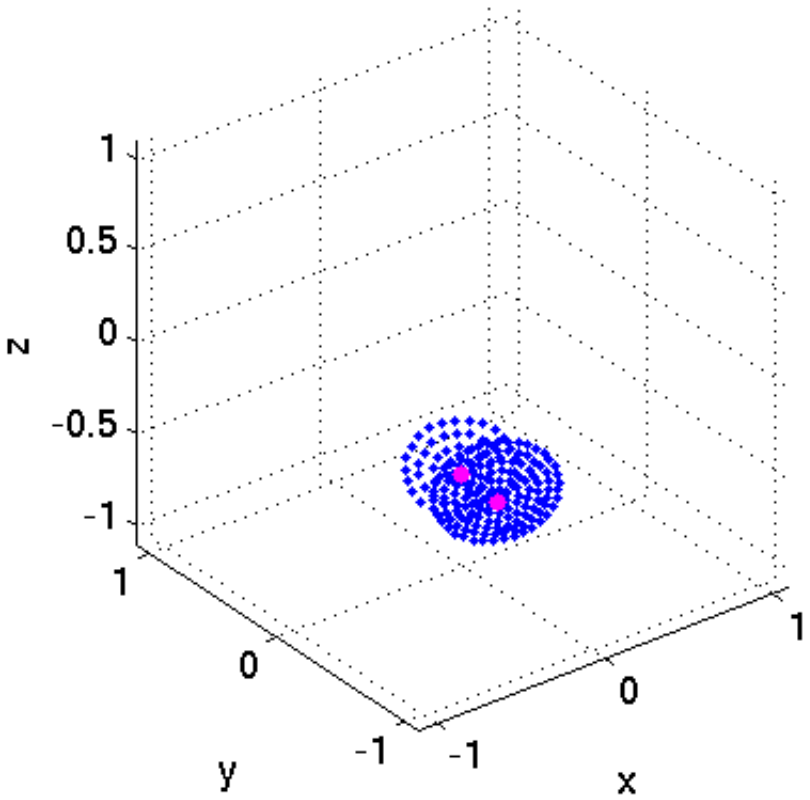
ANTARES provided 216 independent neutrino triggers (from Feb. to Sept. 2007):

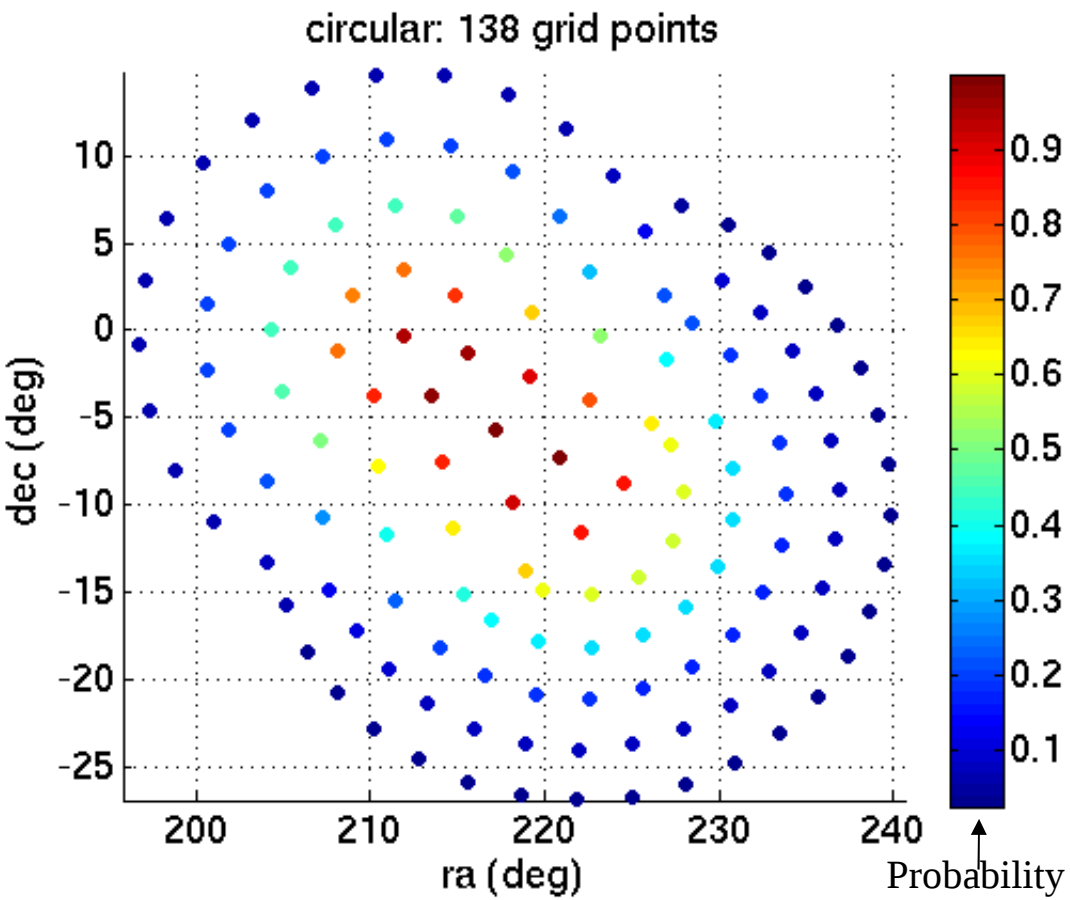
- 18 events reconstructed with 3 lines and more.
- 198 events reconstructed with two lines, in which case the origin of the neutrino is not uniquely identified and there are 2 possible locations (LIGO–T1100197-v2)



Searching for one point and its mirror image at once: Example

ra1 = '221.99' ; dec1 = '-9.38'; [deg]
ra 2= '211.85'; dec2 = '-0.36'; [deg]
gps = '864109778';
sigma_deg = '10~10';

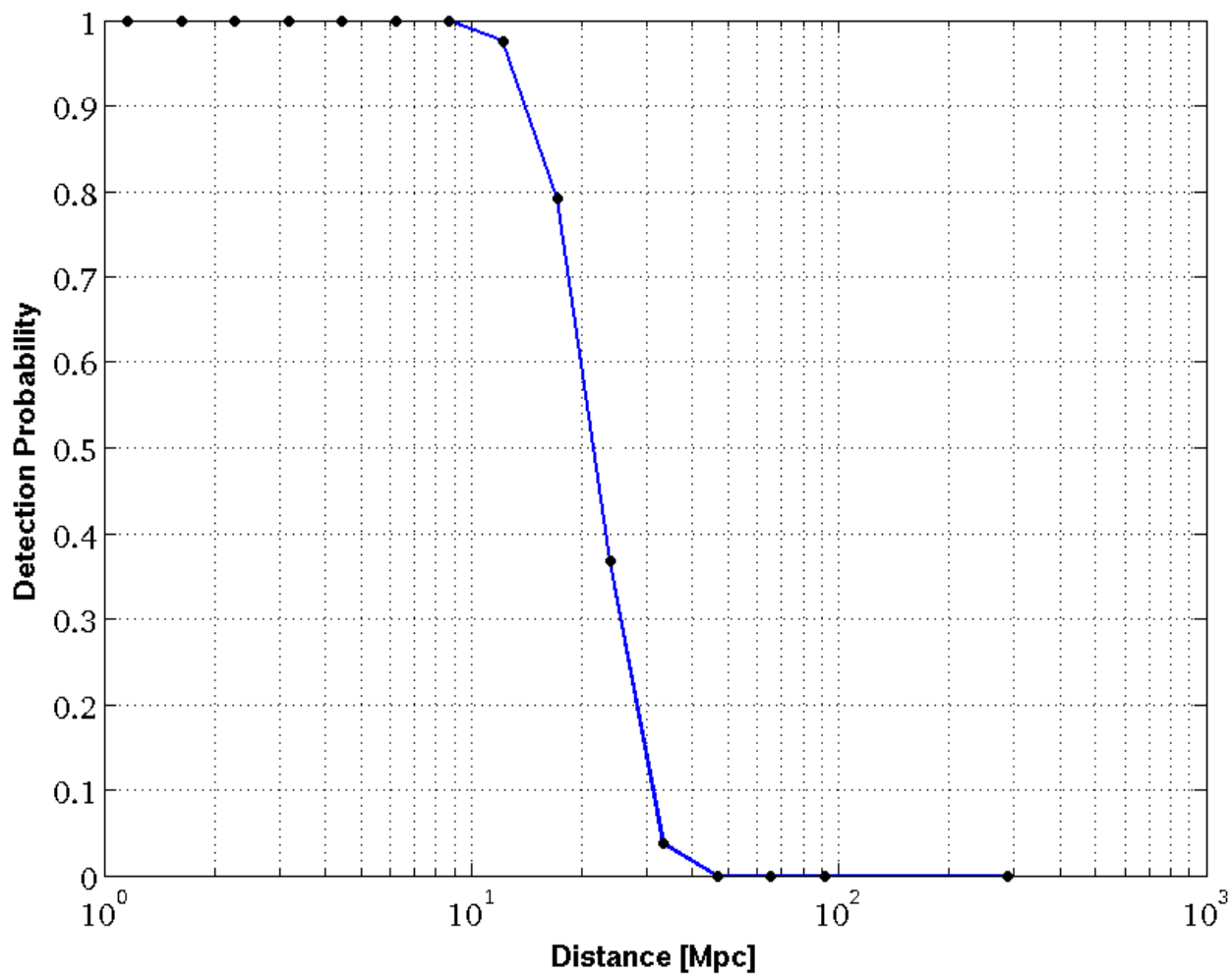


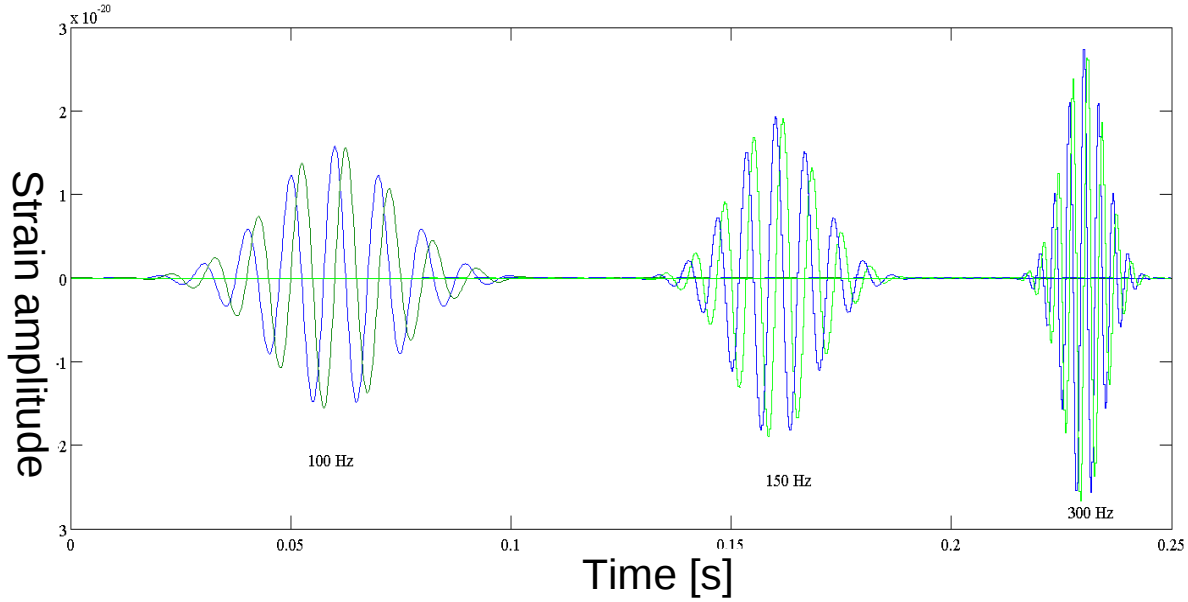


Given the estimated locations and errors in sky location measurement, the code generates a list of sky positions which we should search over to keep time-delay errors into account.

Example of sine-Gaussian 150 Hz injection

Fraction of simulated Gravitational Waves signals detected at a false-alarm probability of 1%.

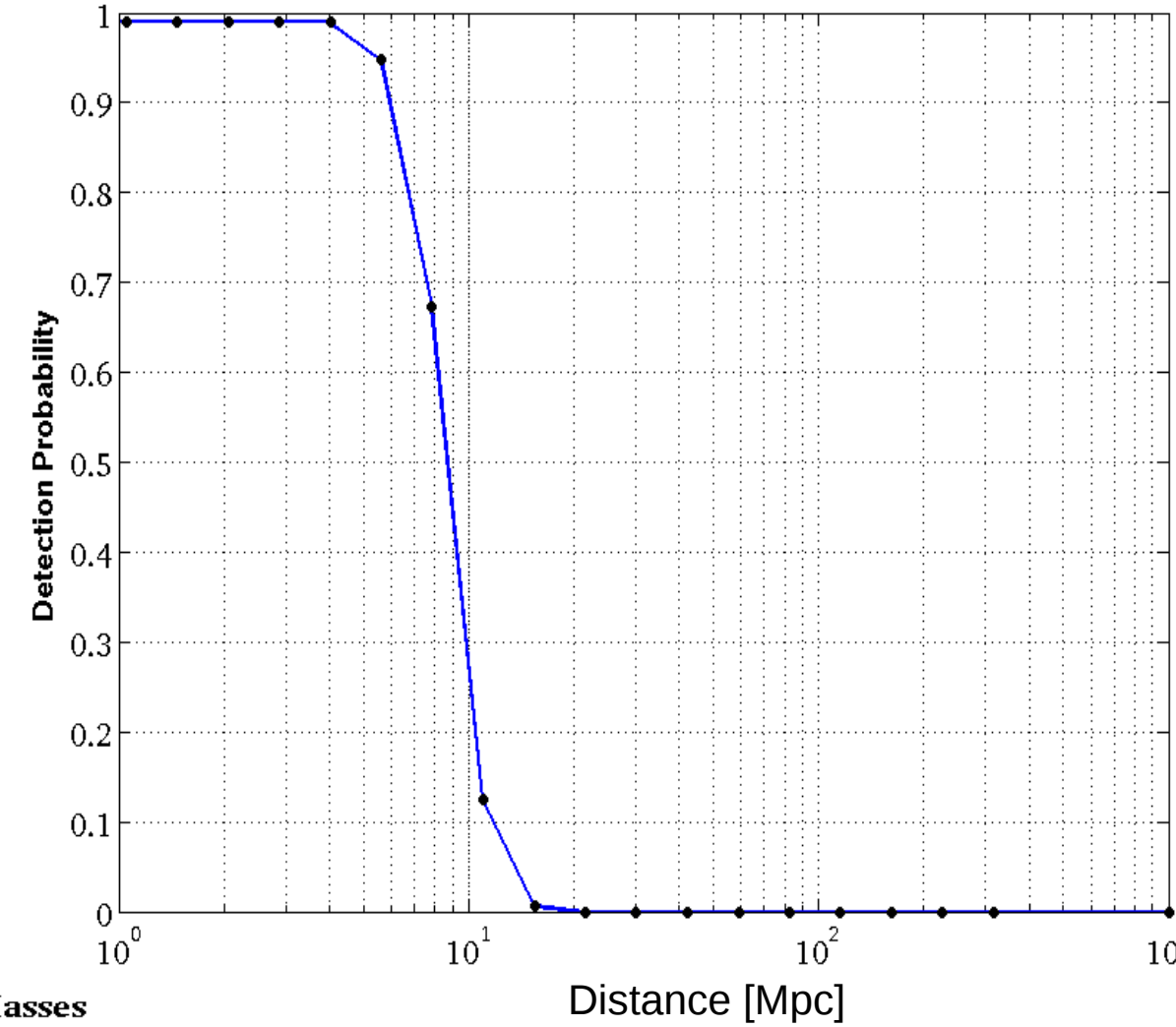


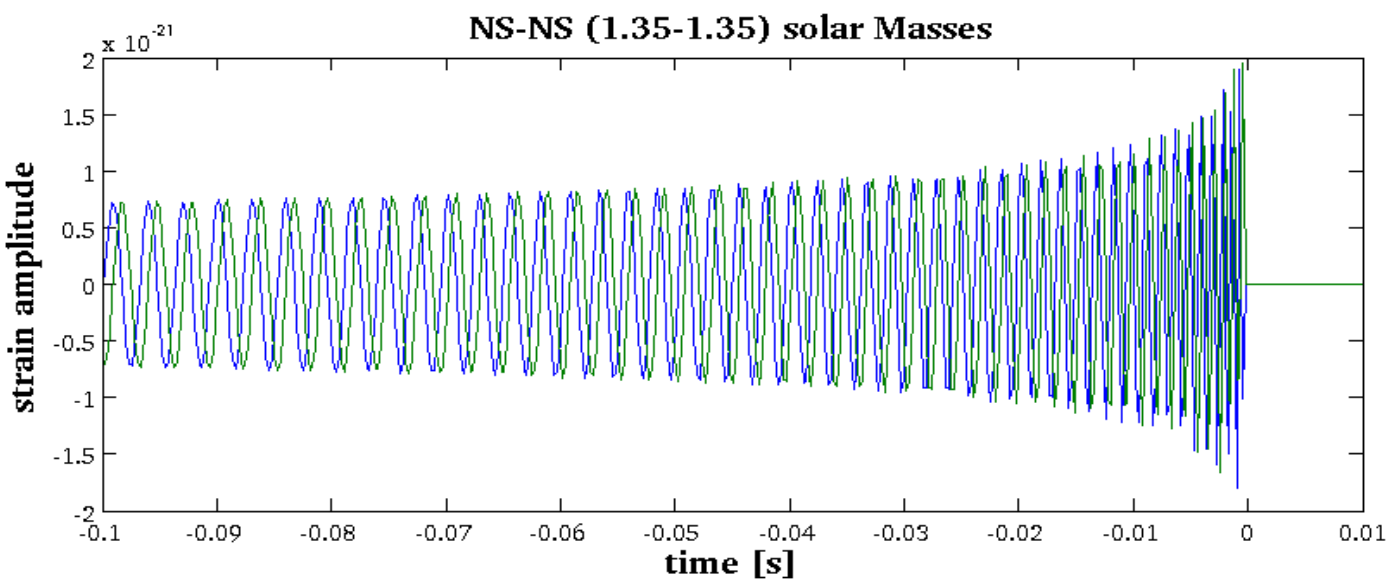


To convert injected signal amplitude into distance we assume that an energy $E_{GW} = 10^{-2} M_{\odot} c^2$ is emitted.

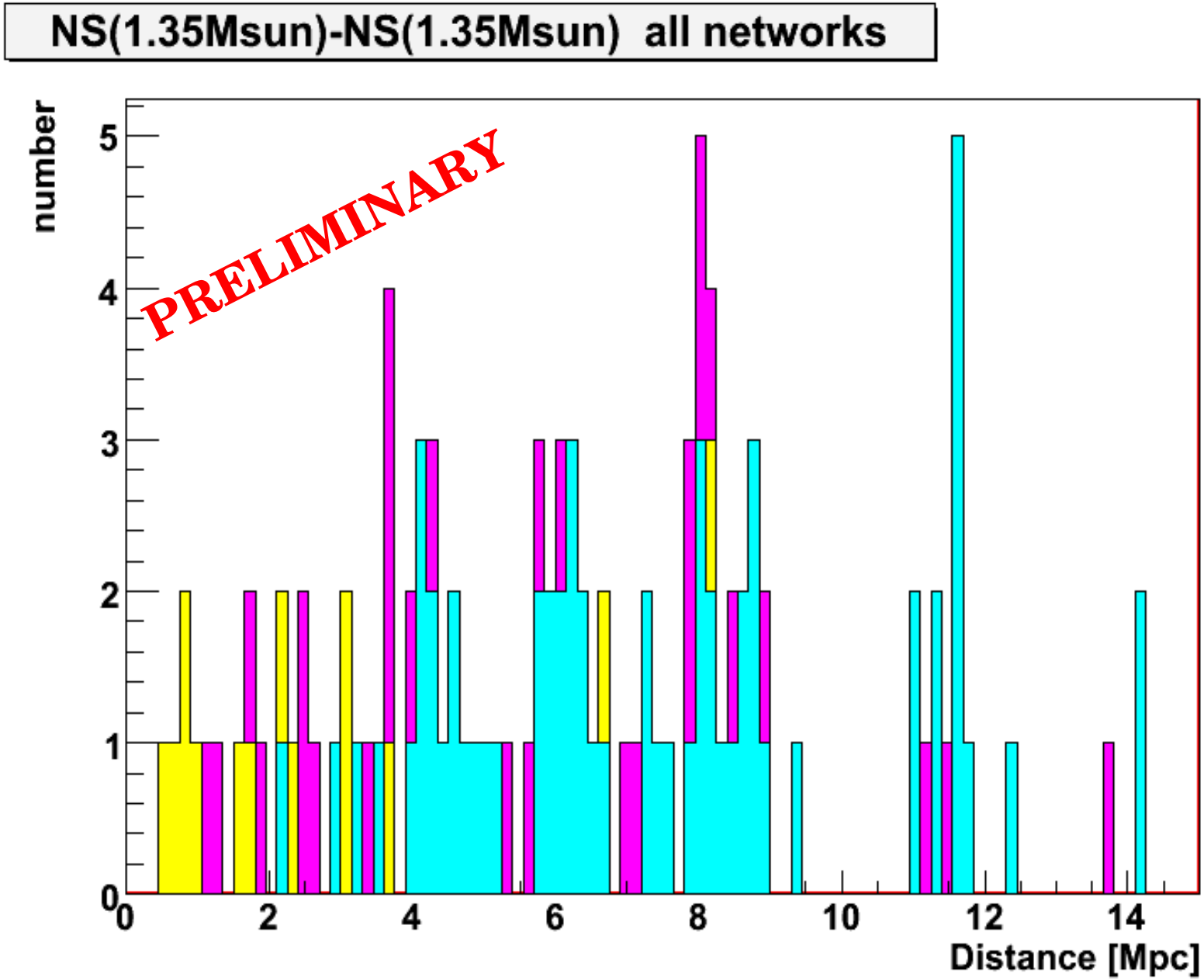
Example of NS-NS Injection

Fraction of simulated Gravitational Waves signals detected at a false-alarm probability of 1%.





NS-NS: Histogram of distance

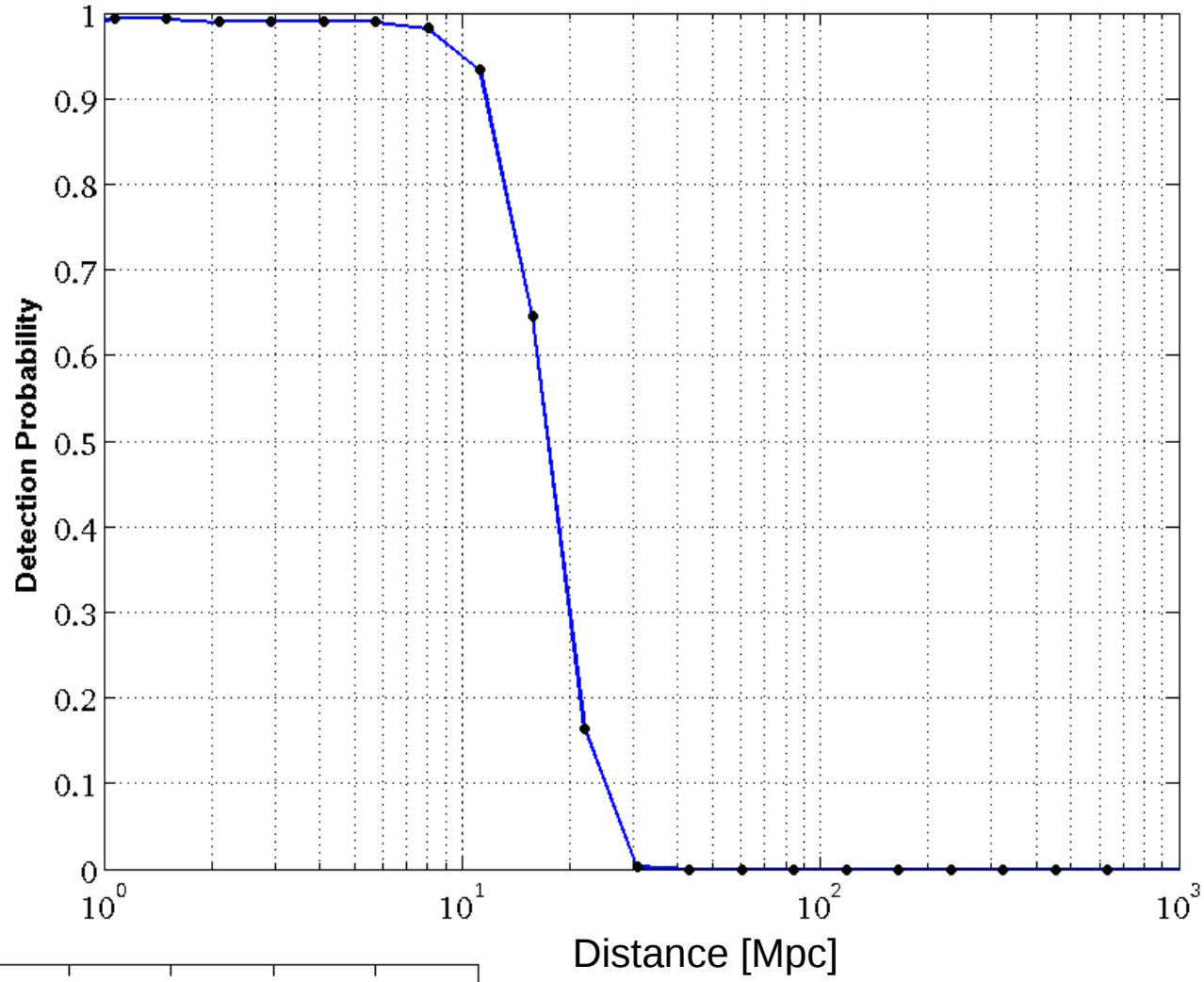


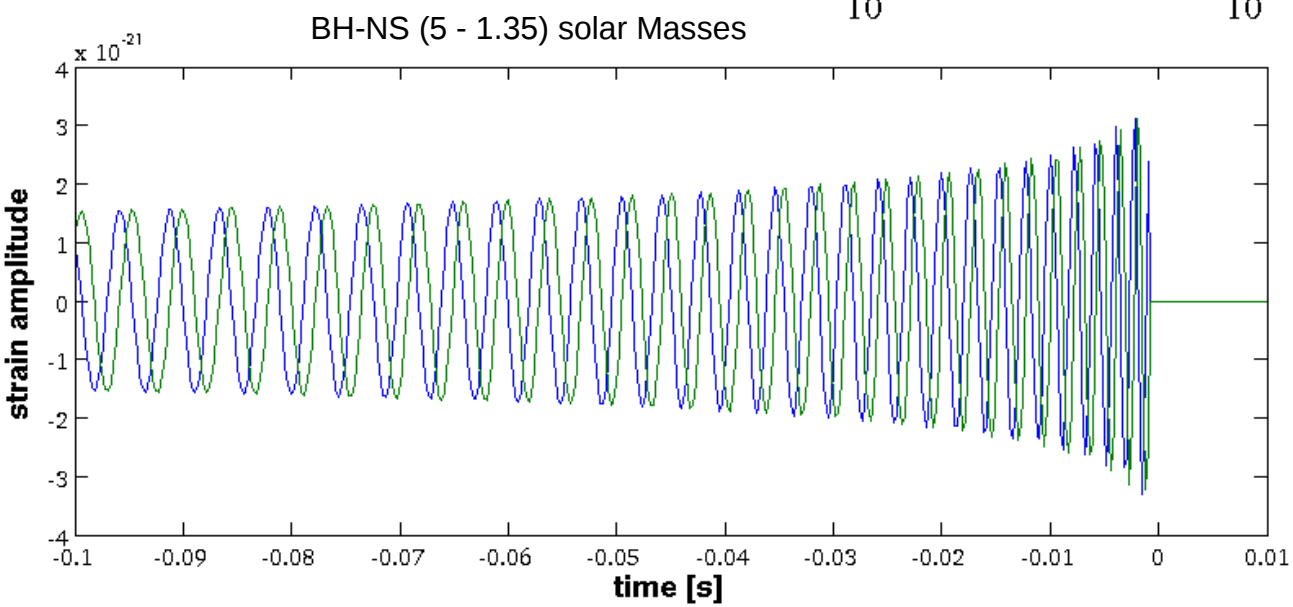
CLOSED-BOX RESULTS

- 2 detectors in network: mean = 4.4 Mpc
- 3 detectors in network: mean = 6.0 Mpc
- 4 detectors in network: mean = 7.6 Mpc

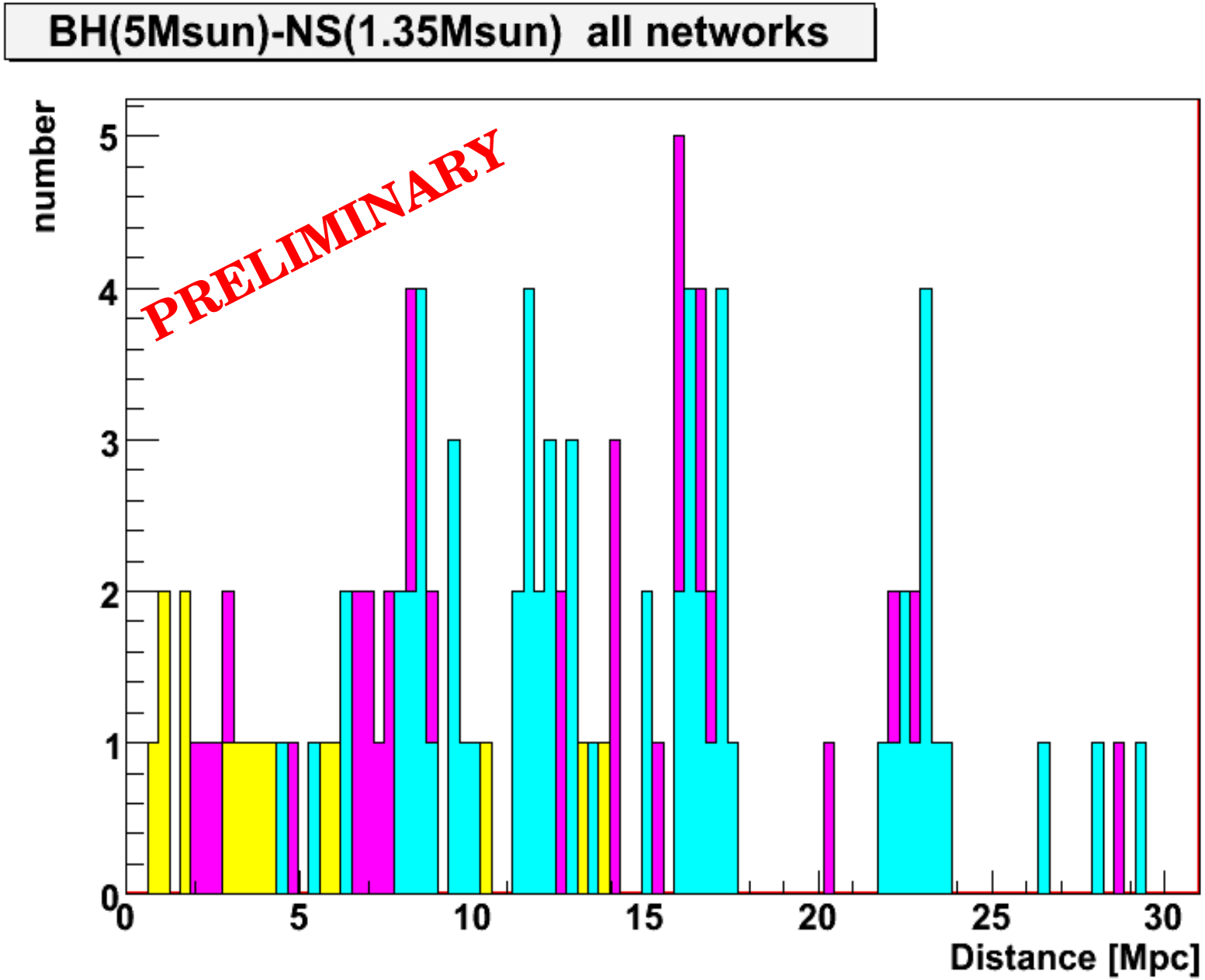
Example of BH-NS Injection

Fraction of simulated Gravitational Waves signals detected at a false-alarm probability of 1%.





BH-NS: Histogram of distance



CLOSED-BOX RESULTS

- 2 detectors in network: mean = 8.5 Mpc
- 3 detectors in network: mean = 11.7 Mpc
- 4 detectors in network: mean = 14.7Mpc

Outlook

- This is the first joint analysis between Gravitational Waves and High Energy Neutrinos using LIGO, Virgo and ANTARES data.

- Internal review is ongoing from both the gravitational site and the neutrino one.

Future GW-HEN plans:

Joint analysis with ANTARES using 2008-2010 data

Joint analysis with IceCube on 2009- 2010 data

Thanks for listening!