



Towards the first coherent multi-ifo search for NS binaries in LIGO

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Talk Plan

- What is a coherent multi-detector inspiral search?
 - » What is the motivation for it?
 - » What are the expectations of it *vis a vis* a single detector search?
- The LIGO Science Run #2, and the case for a coherent inspiral search
- Coherent search studies on the S2 “Playground” data
 - » Software injections
 - » Hardware injections
 - » Comparisons with single detector search results

Motivation for a coherent search

- Is the optimal search strategy (in Gaussian noise)
- Allows one to draw a single figure-of-merit on data from multiple detectors
- Is a veto in itself (in a “ coincidence” sense)
 - » Sets a coincidence time-window
 - » Vetos candidates that lack consistent parameter information across a network of detectors
- *Vis a vis* a single detector search:
 - » Should give you somewhat better SNR (by $\sim\sqrt{\#}$ of detectors)
 - » Information on a larger set of source parameters
 - » A better detection efficiency or a tighter upper limit

A Coherent Multi-detector statistic

- Strain at a single detector, A :

$$\begin{aligned}
 s^A(t) &= F_+^A(\phi, \theta, \psi) h_+(t - \tau^A; \mathbf{l}, \vartheta^\alpha) + F_\times^A(\phi, \theta, \psi) h_\times(t - \tau^A; \mathbf{l}, \vartheta^\alpha) \\
 &= \Re \left[\left(E_A^* S^A \right) e^{i\delta_c} \right]
 \end{aligned}$$

where the E 's are functions of F 's and \mathbf{l} .

- The strains from M detectors form a vector:

$$\mathbf{s} = \left(s^1, s^2, \dots, s^M \right)$$

- And the detection statistic is:

$$\ln \Lambda = \sum_{A=1}^M \left\langle s^A, x^A \right\rangle_{(A)} = \left\langle h_+(t; \mathbf{l}, \vartheta^\alpha), X_+ \right\rangle + \left\langle h_\times(t; \mathbf{l}, \vartheta^\alpha), X_\times \right\rangle$$

A Coherent Multi-detector statistic (*contd.*)

- Maximizing Λ over $(\kappa, \delta_c, \psi, \iota)$ gives:
 - For two aligned detectors:

$$\Lambda(\tau) = \frac{1}{\sqrt{2}} \left| C_1(t) + C_2(t; \tau_{(2)}) \right|$$

where

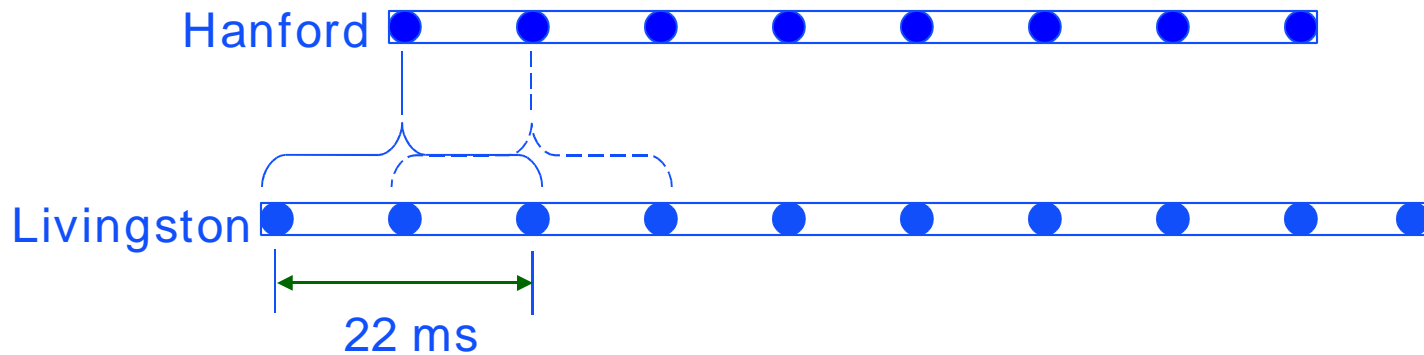
$$C_A(t; \tau_{(A)}) = \left\langle S^A(t), x^A(t; \tau_{(A)}) \right\rangle_{(A)}$$

- And for two non-aligned detectors:

$$\Lambda(t) = \sqrt{|C_1(t)|^2 + |C_2(t; \tau_{(2)})|^2}$$

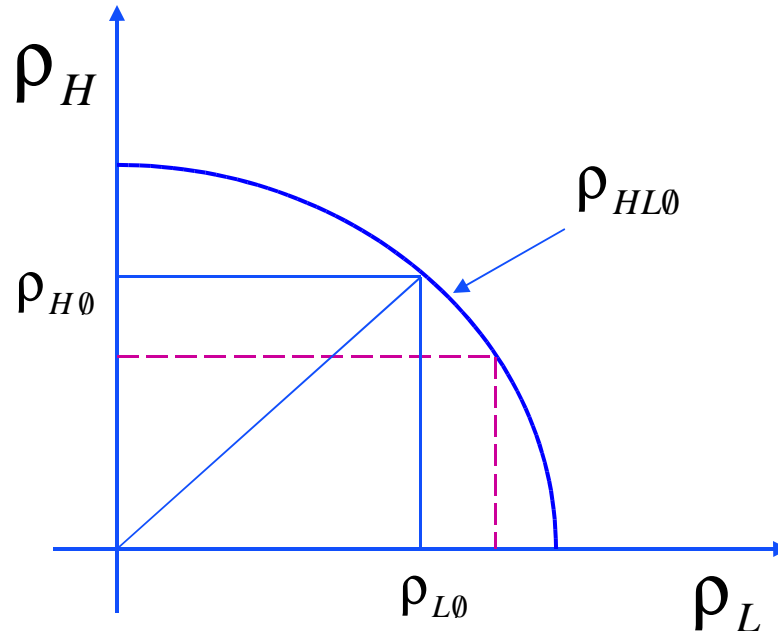
Allowing for time delay

$$\Lambda(t) = \sqrt{|C_1(t)|^2 + |C_2(t; \tau_{(2)})|^2}$$



The Coherent SNR

$$\Lambda(t) = \sqrt{|C_H(t)|^2 + |C_L(t; \tau_{(L)})|^2} = \sqrt{\rho_H^2(t) + \rho_L^2(t; \tau_{(L)})}$$

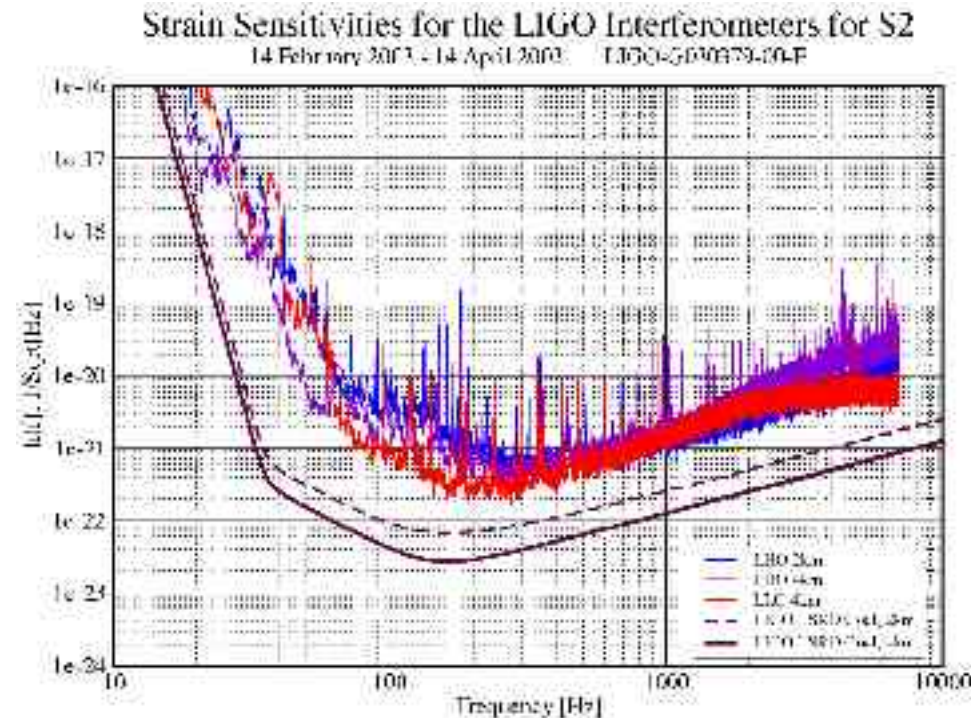


LIGO Science Run #2: Case for a coherent search

Comparable sensitivities:

Run-avg. sensitivity to optimally oriented $\{1.4, 1.4\}$ Msun NS binary at SNR = 8 in playground:

Detector	Range (Mpc)
LLO 4k (L1)	1.8
LHO 4k (H1)	0.9
LHO 2k (H2)	0.6



Studies on S2 Software Injections

- 2 sets of sources (1.4,1.4)Msun were injected into the playground

End Times (734146000+)	703	803	903
Eff. Dist. (Mpc)	0.06	0.06	0.06
Eff. Dist. (Mpc)	0.6	0.6	0.6

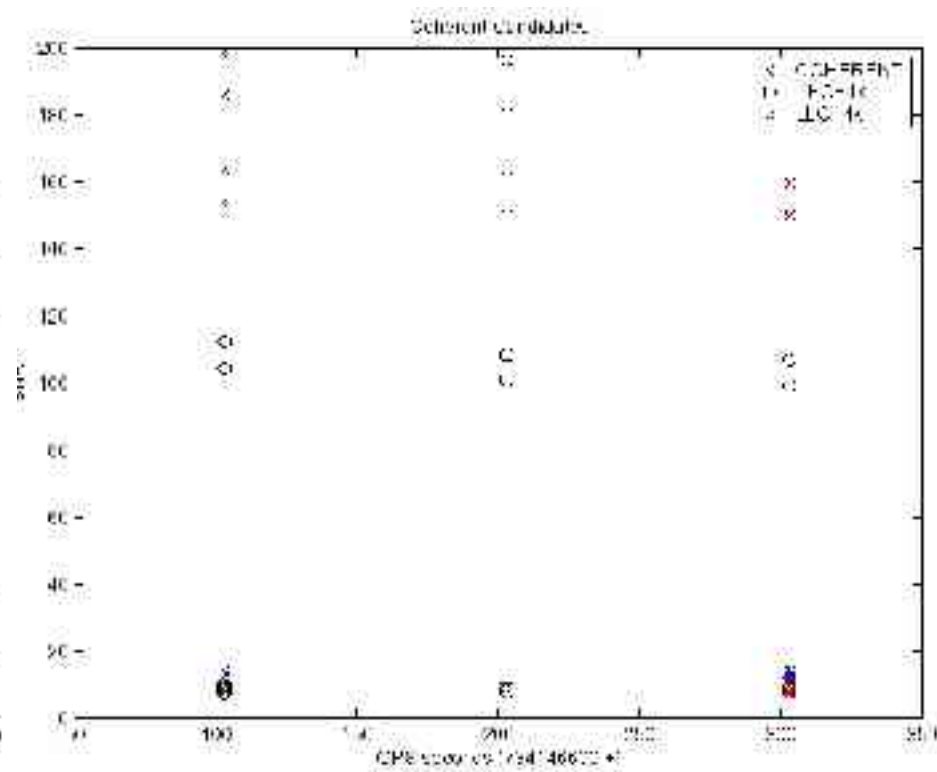
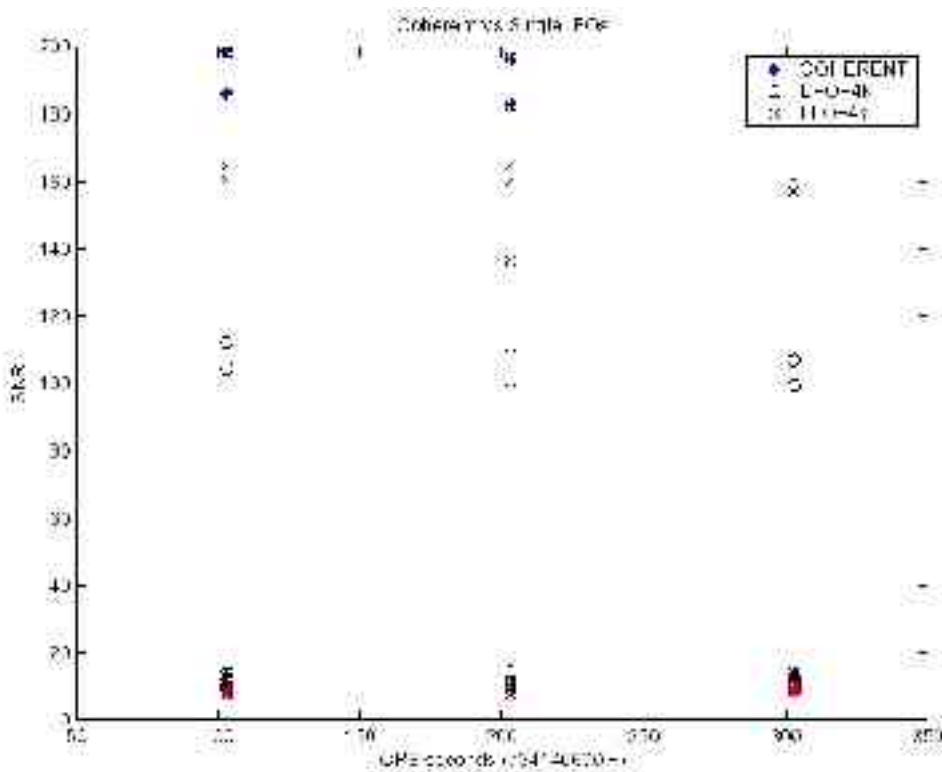
- We examined these injections with the following thresholds:

	H1	L1	Coherent H1-L1		
	MW (M33)	MW (M33)	H1	L1	H1-L1
SNR >	7.7 (7.0)	7.7 (7.0)	6.5	6.5	7.7 (10)
Chi-sq <	30.0	30.0	40.0	40.0	NONE

SW Injections: Milky Way SNRs

Coherent vs Single IFOs

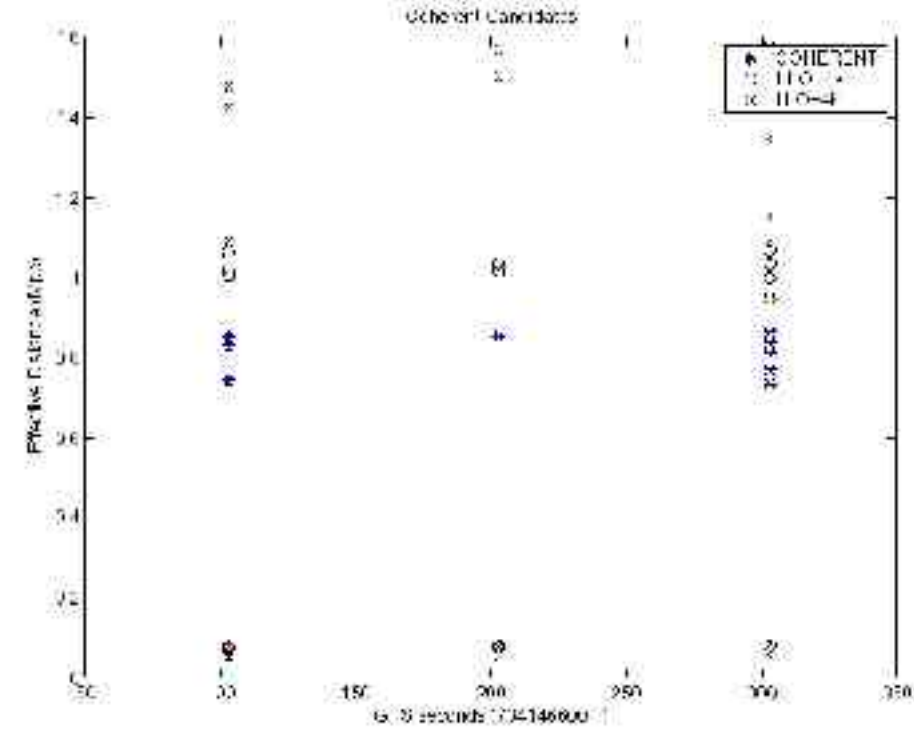
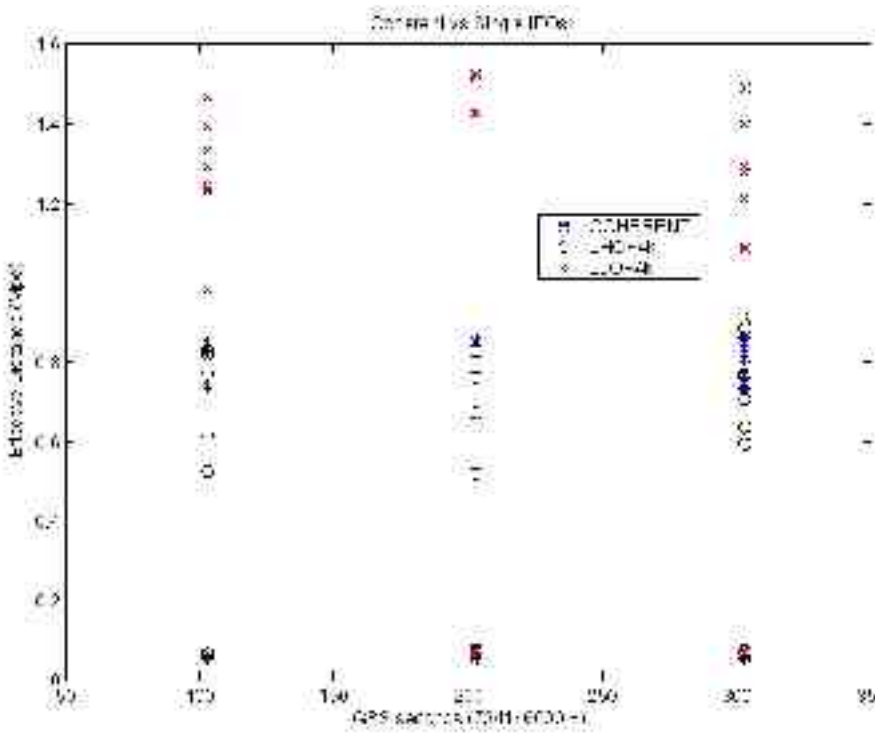
Coherent candidates only



SW Injections: Milky Way Effective Distances

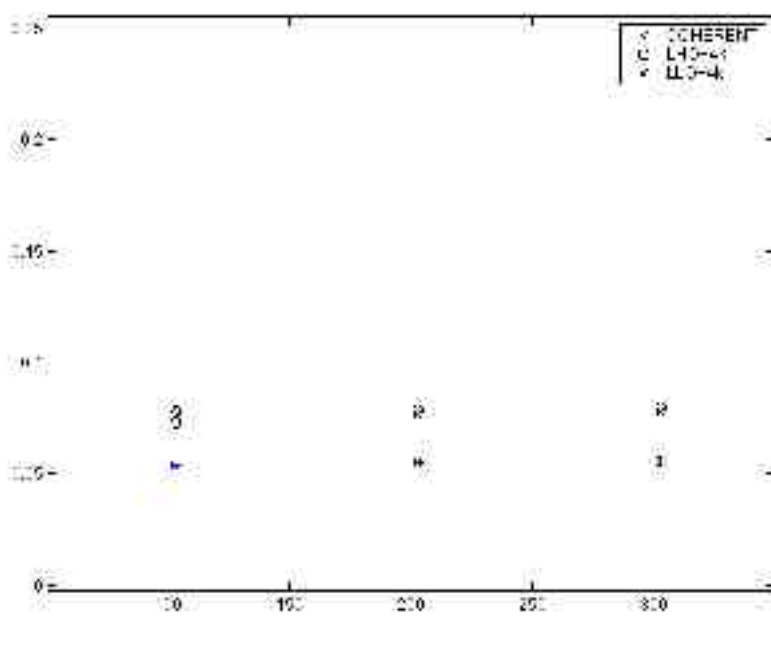
Coherent vs Single IFOs

Coherent candidates only



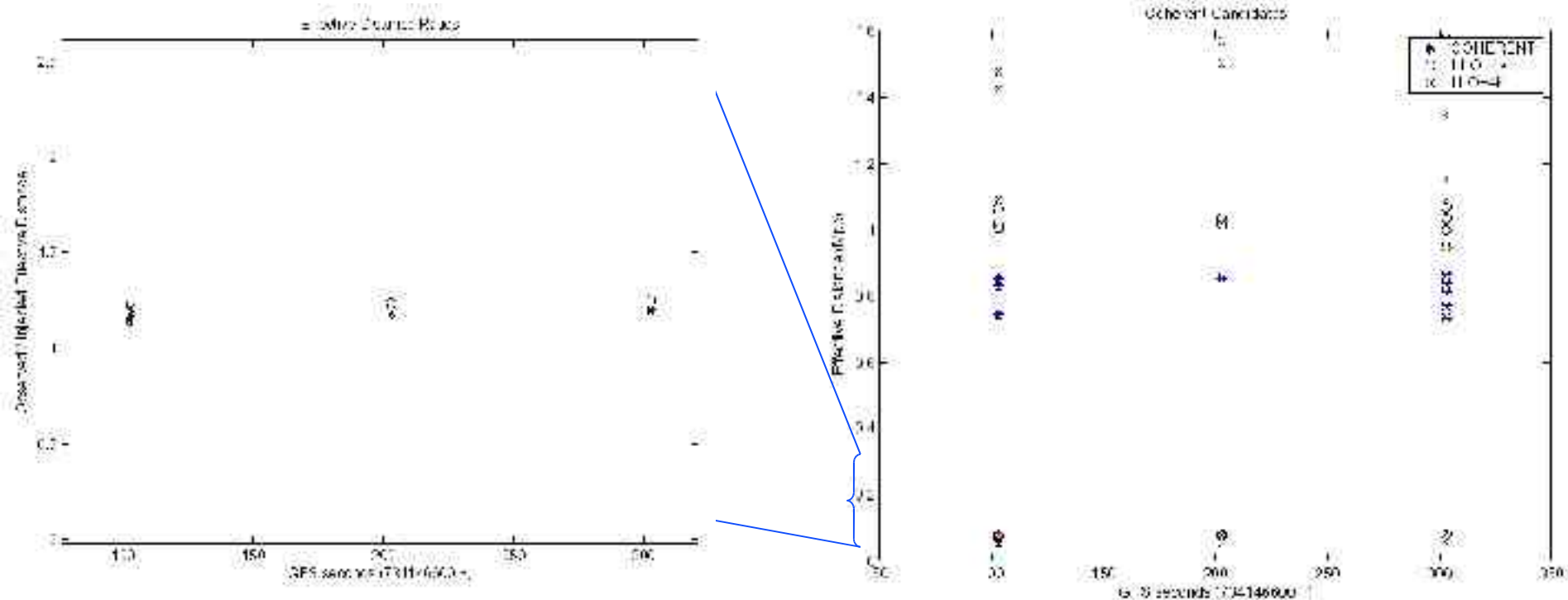
SW Injections: Milky Way Observed effective distances

Coherent candidates only

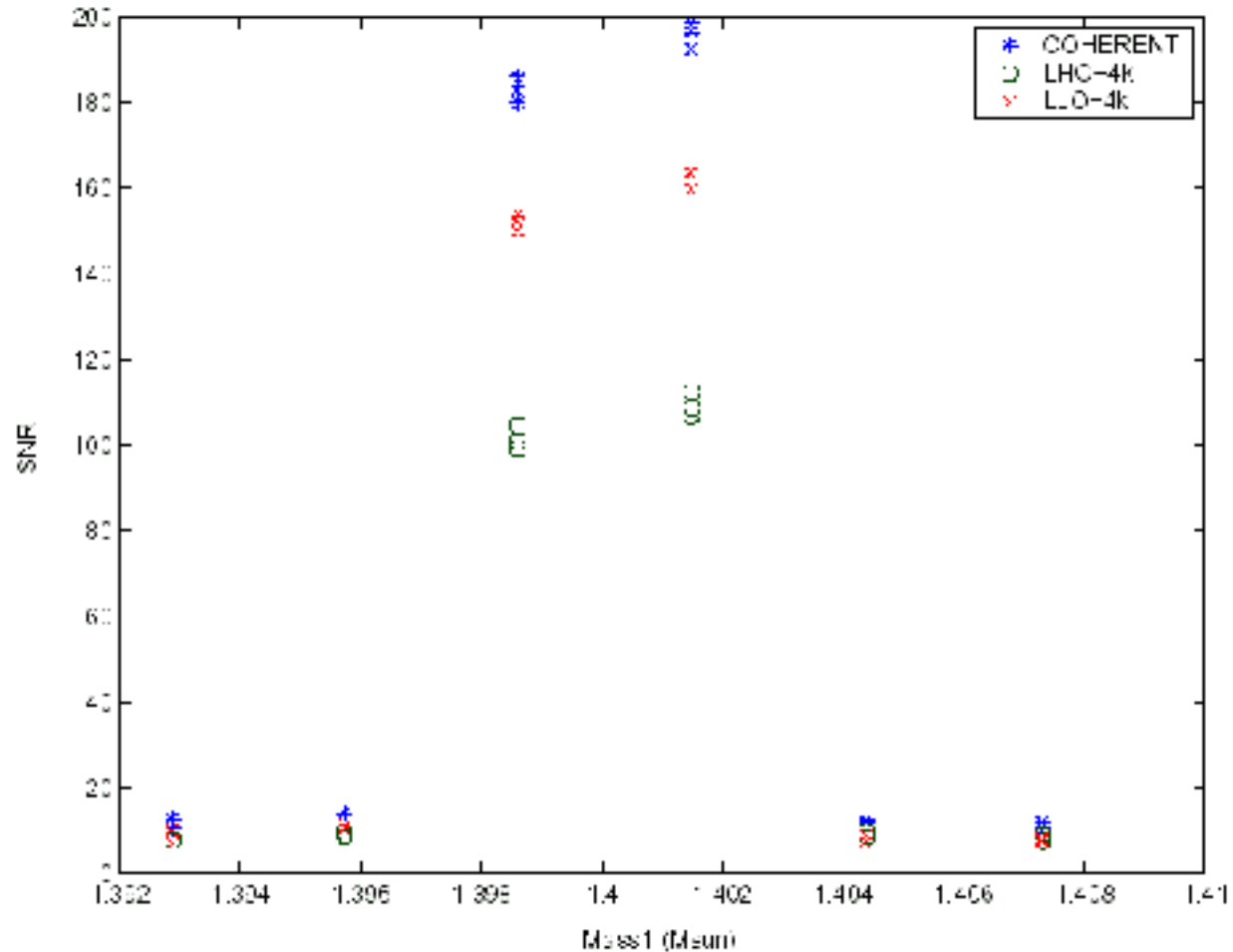


SW Injections: Milky Way Observed / Injected eff_dist

Coherent candidates only

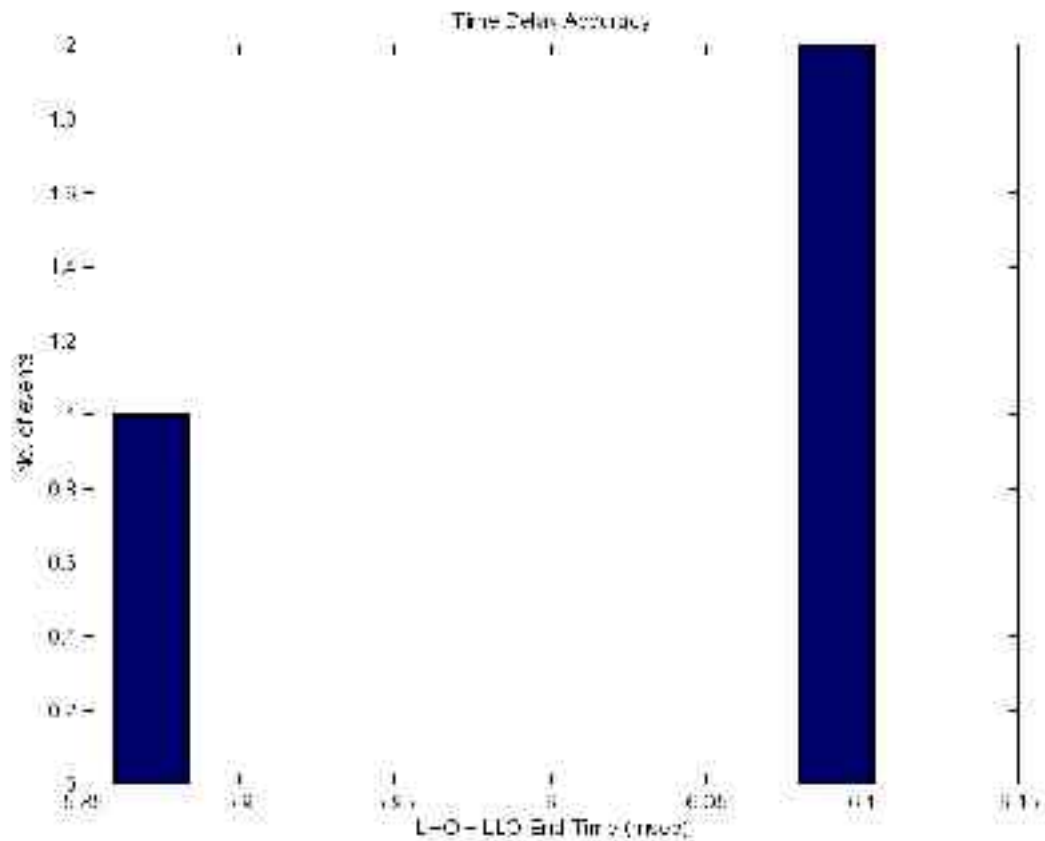


SW Injections: Milky Way SNR vs Mass



SW Injections: Milky Way Time Delay accuracy

LHO End Time - LLO End Time

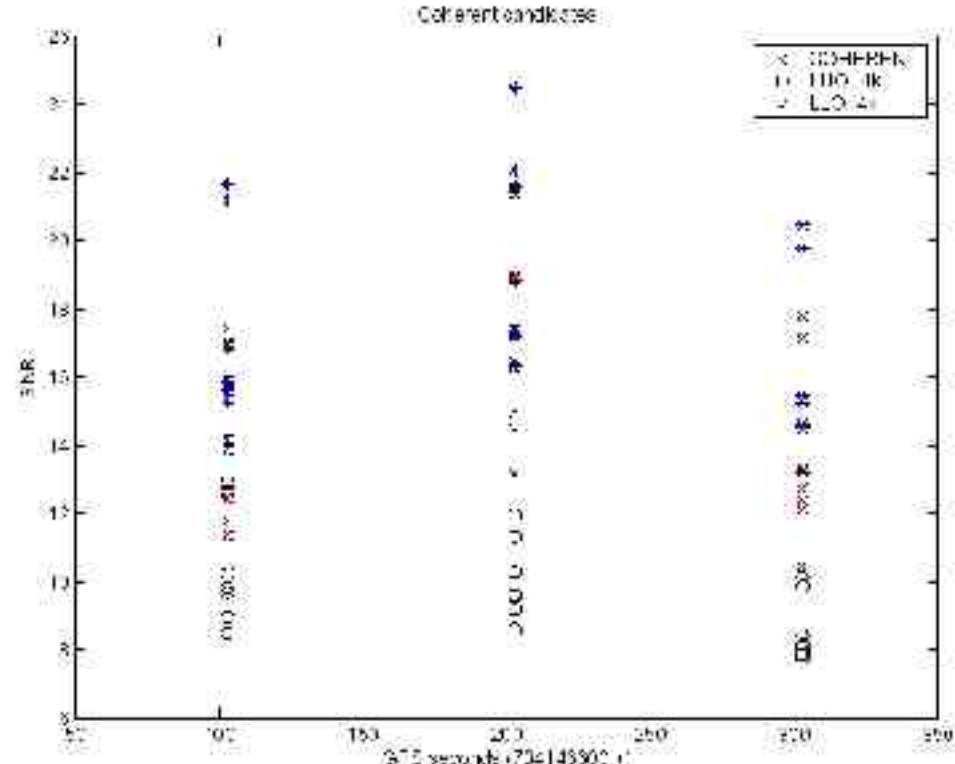
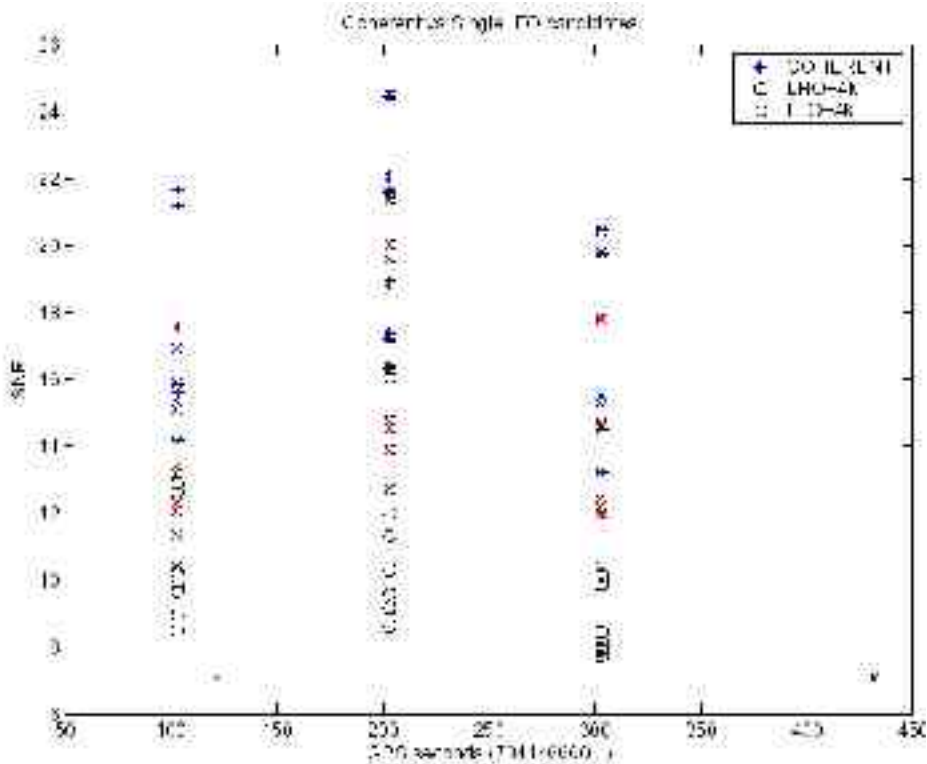




SW Injections: “Andromeda” SNRs

Coherent vs Single IFOs

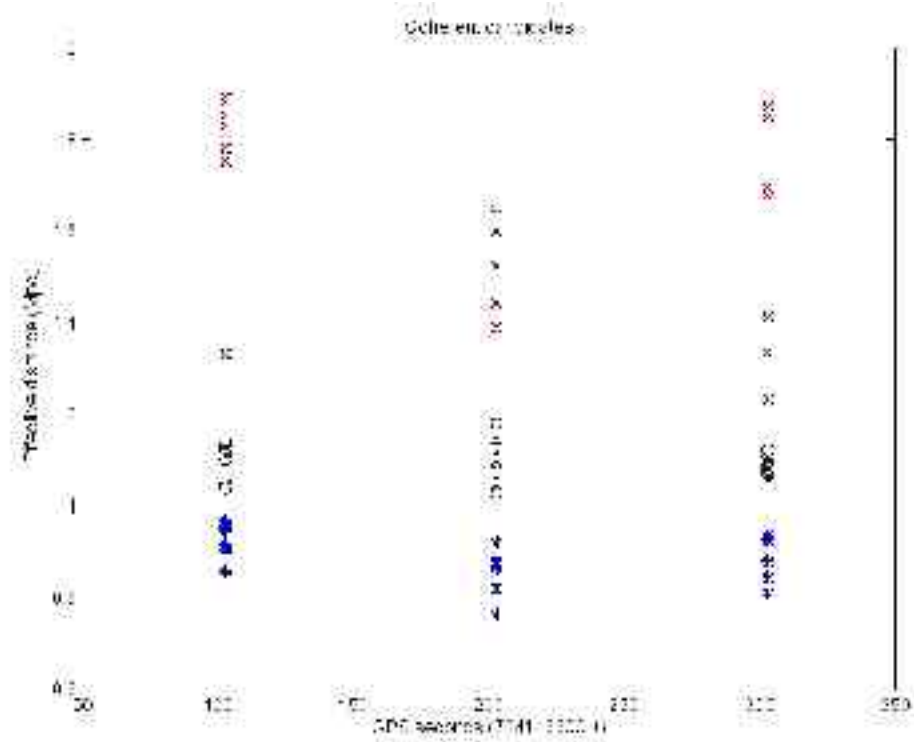
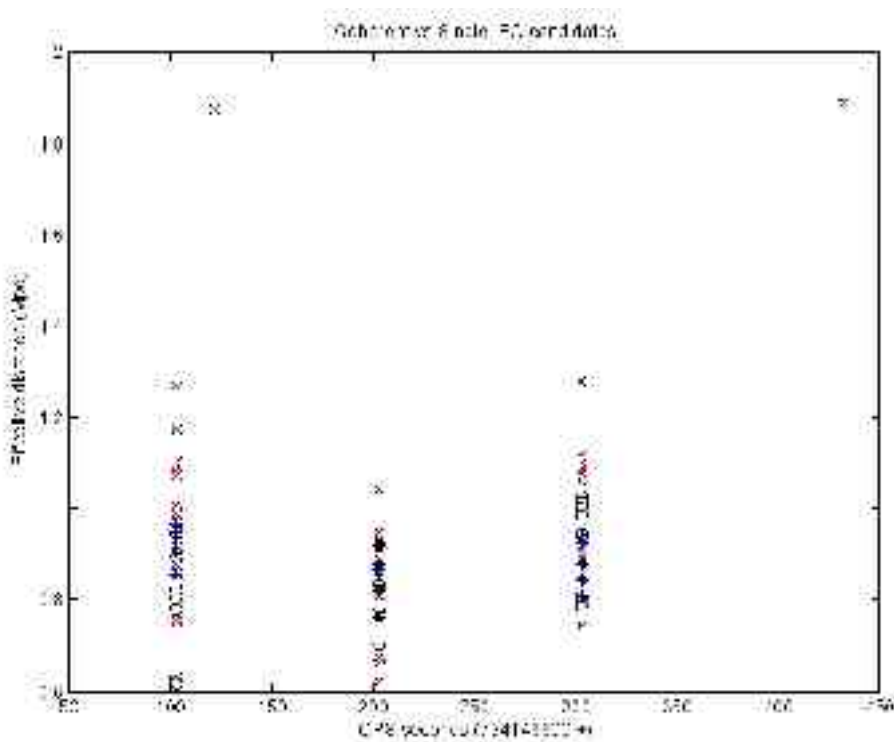
Coherent candidates only



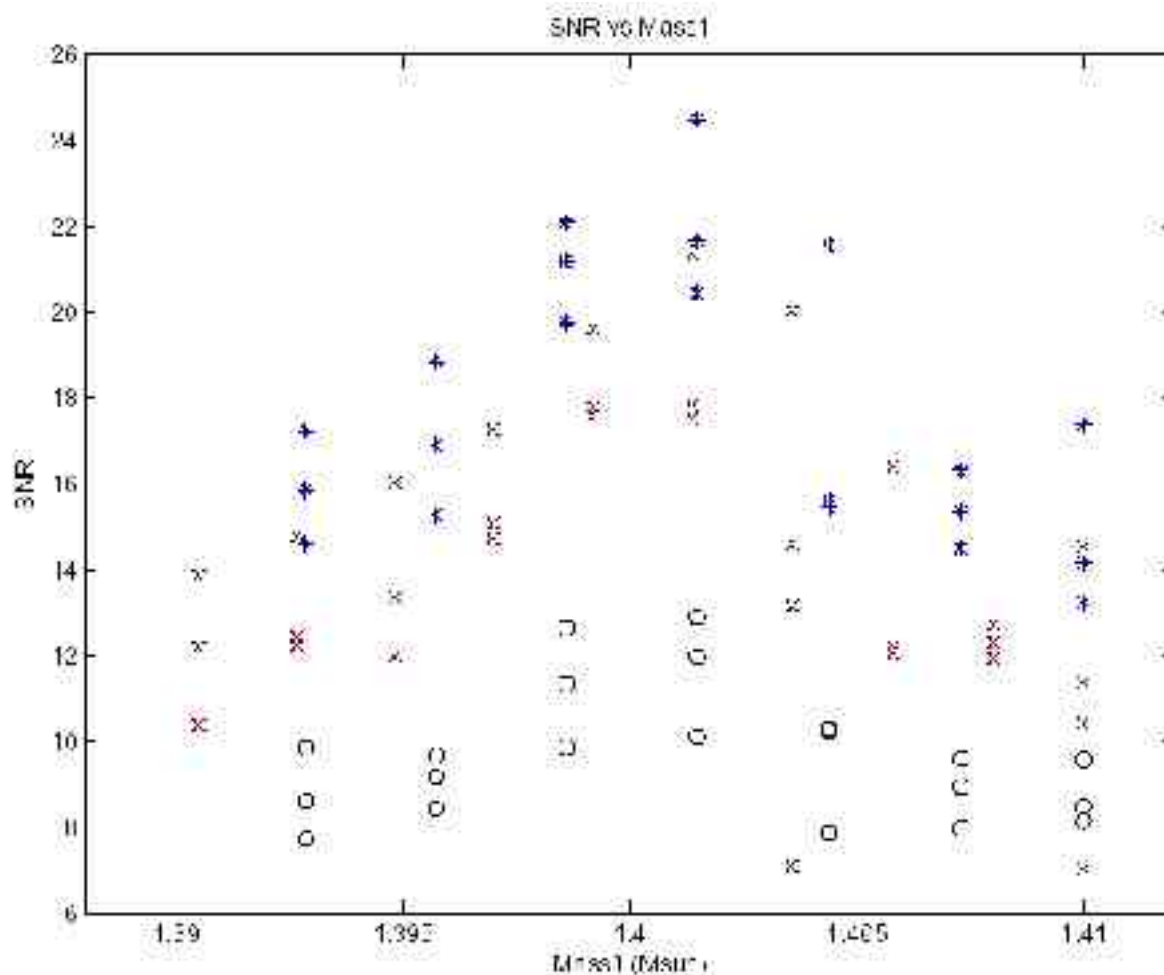
SW Injections: “Andromeda” Effective Distances

Coherent vs Single IFOs

Coherent candidates only

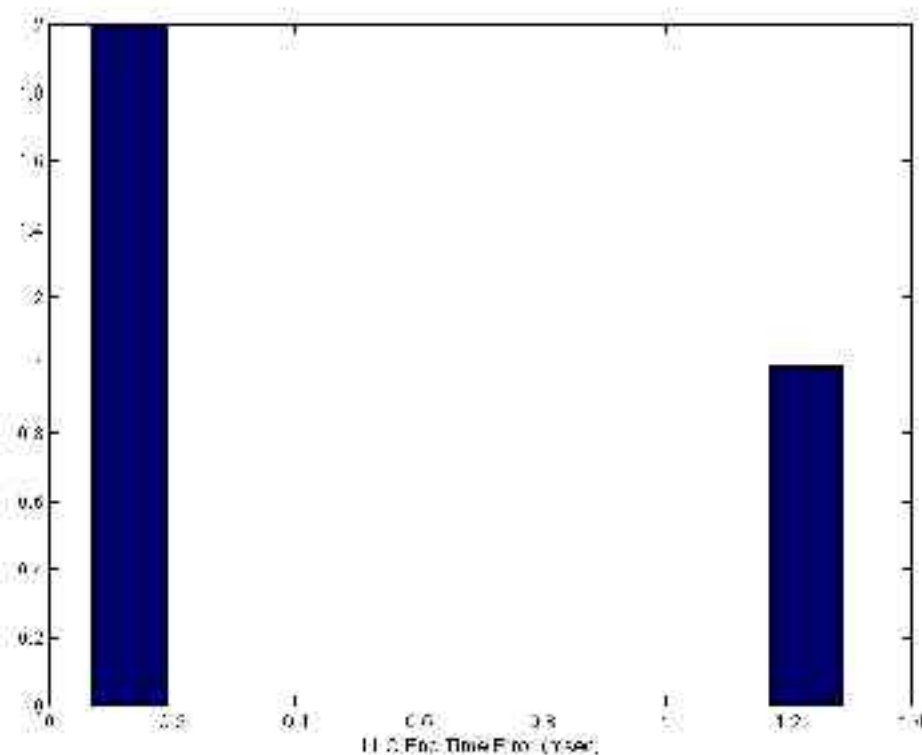


SW Injections: “Andromeda” SNR vs Mass

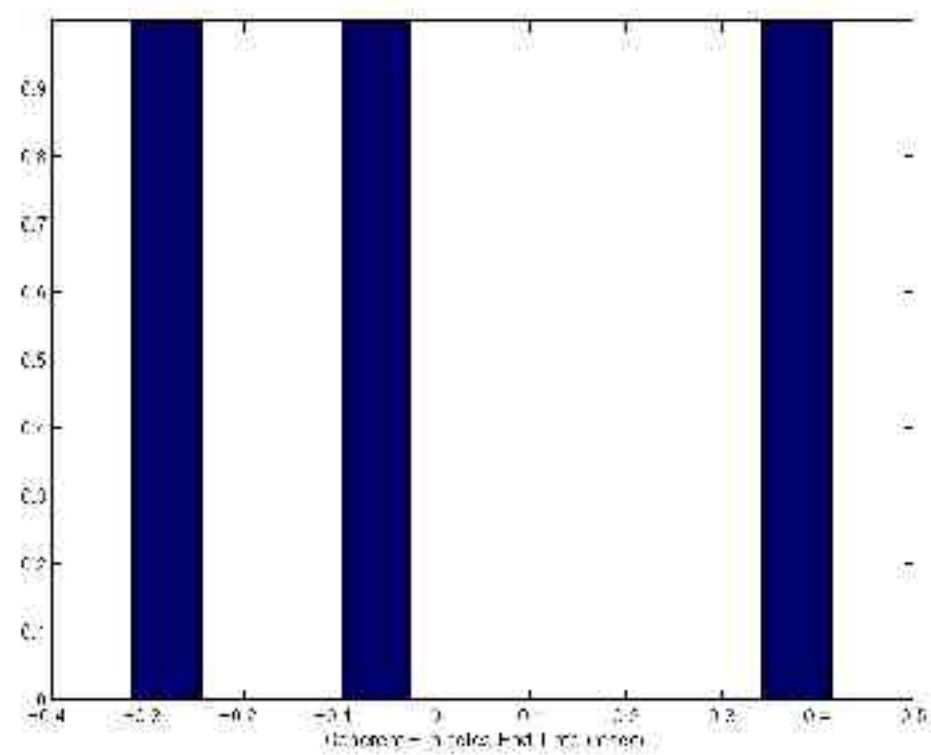


SW Injections: “Andromeda” End Time accuracy

LLO-only End Time error



Coherent cand. End Time error





Studies on S2 Hardware Injections

- A set of 7 HW injections were done on April 10th, towards the end of S2, at the following GPS times (in seconds):

Times 733988000+	8116	8416	8716	9016	9316	9616	9916
Strengths (Mpc)	5	2.5	1.25	0.62	0.31	0.15	0.075

- We examined these Hardware injections with both the coherent search pipeline and the single-detector pipelines.

Studies on Hardware Injections (contd.)

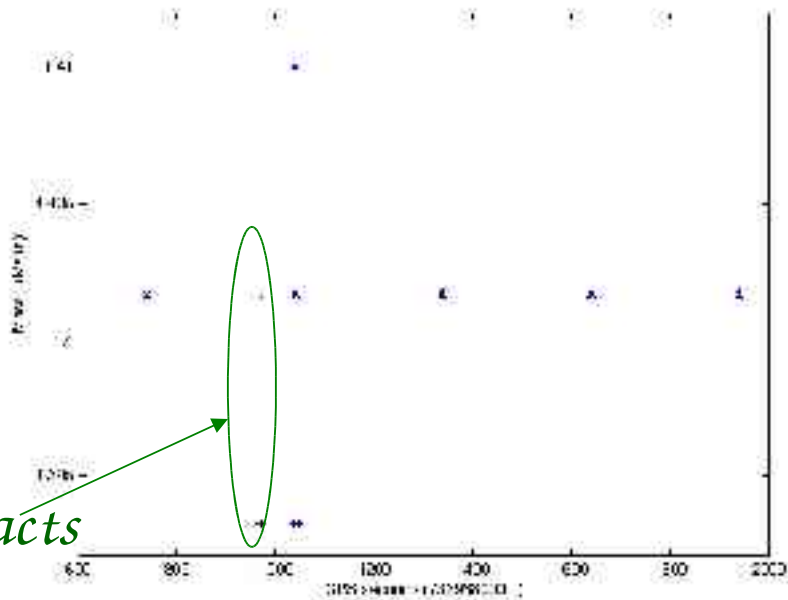
- The thresholds chosen for the various searches were:

	H2	H1	L1	Coherent H1-L1		
				H1	L1	H1-L1
SNR	8.0	8.0	8.0	6.5	6.5	8.0
Chi-sq	10.0	10.0	30.0	20.0	40.0	NONE

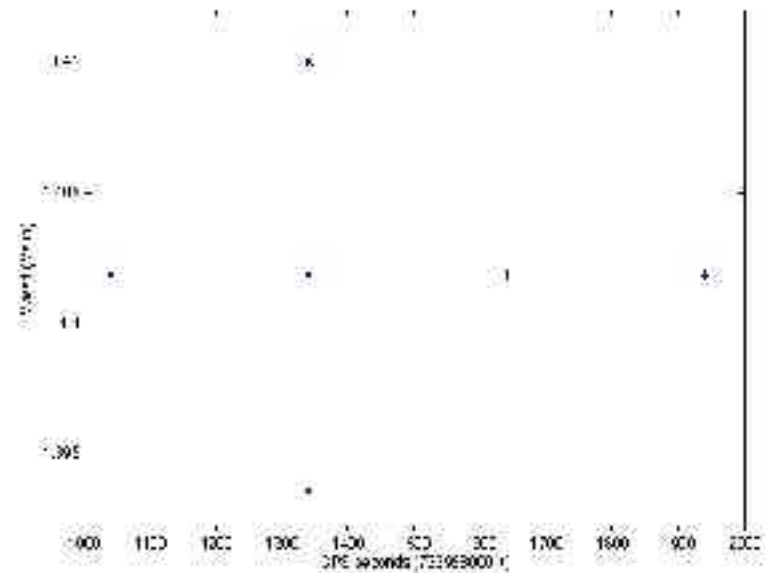
- The search was done on data re-sampled at 4096 Hz.

Hardware Injections: Chirp' s end time

Injection start 733988000+	8116	8416	8716	9016	9316	9616	9916
Obs. End Times (sec)	Not seen	Not seen	8741	9041	9341	9641	9941



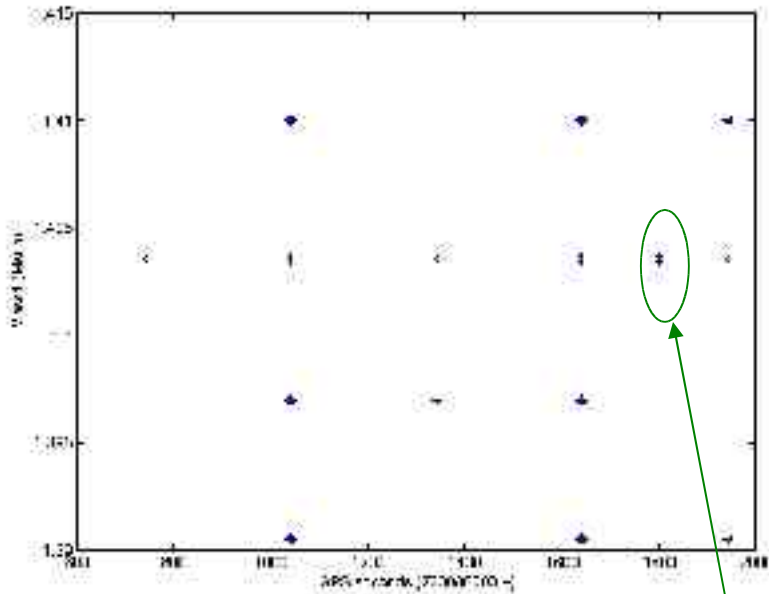
H1 only



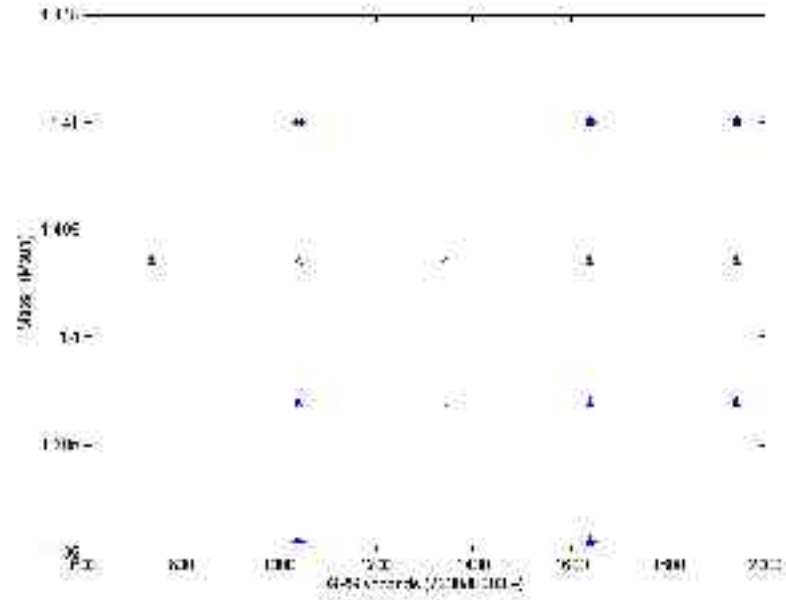
H2 only

Hardware Injections: Chirp' s end time (contd.)

L1 only



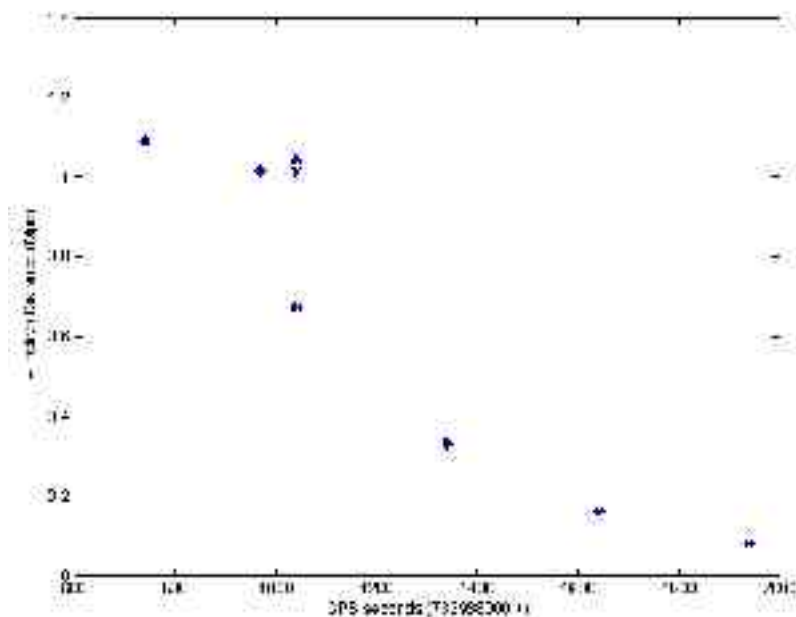
Coherent H1-L1



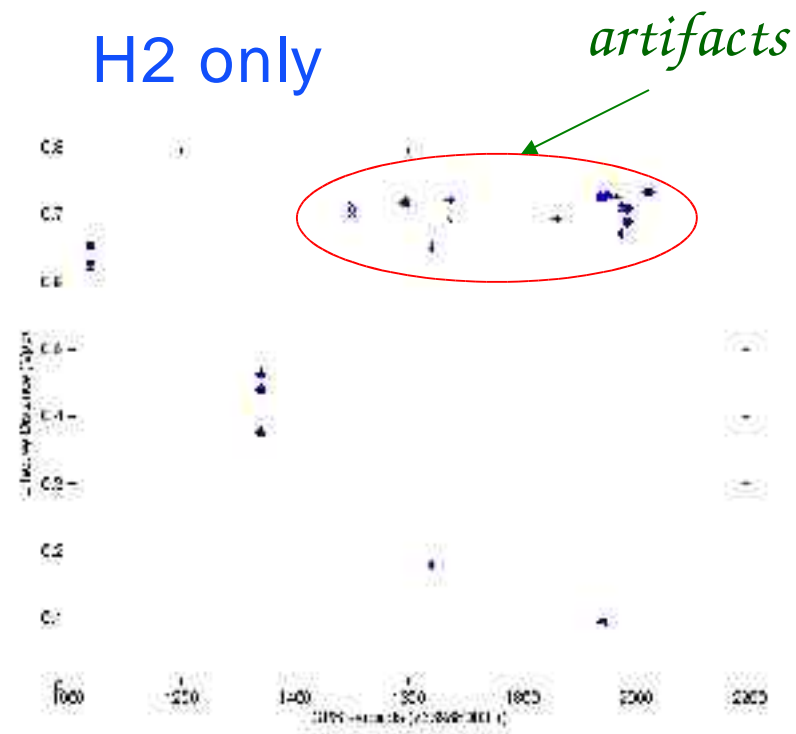
artifact

HW Injections: Effective Distances

H1 only

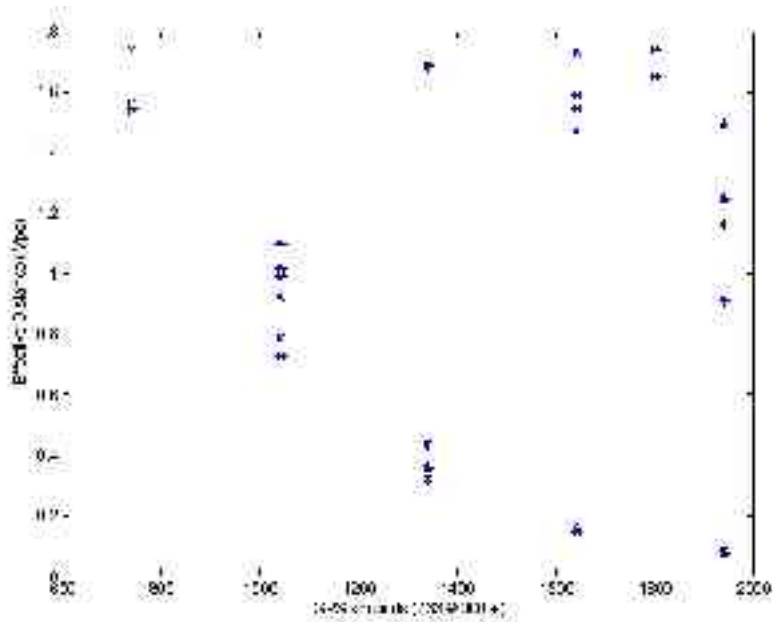


H2 only

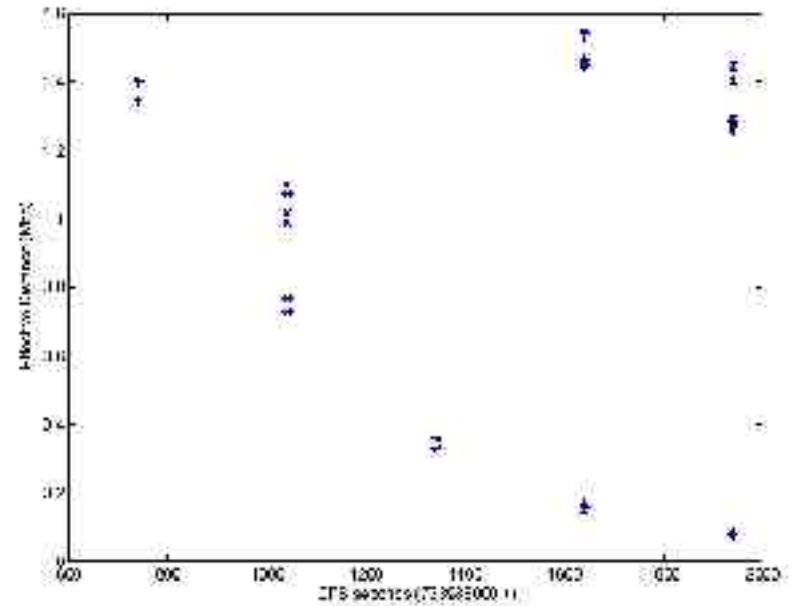


HW Injections: Effective Distances (contd.)

L1 only



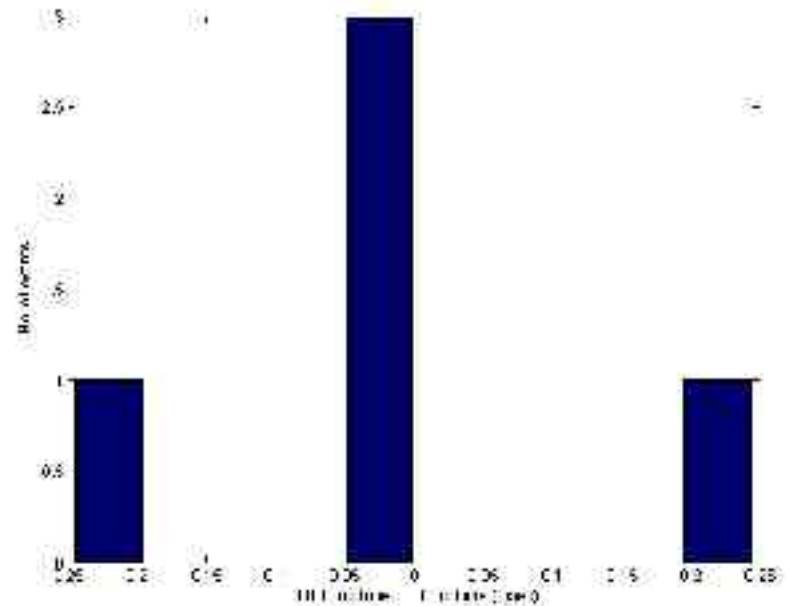
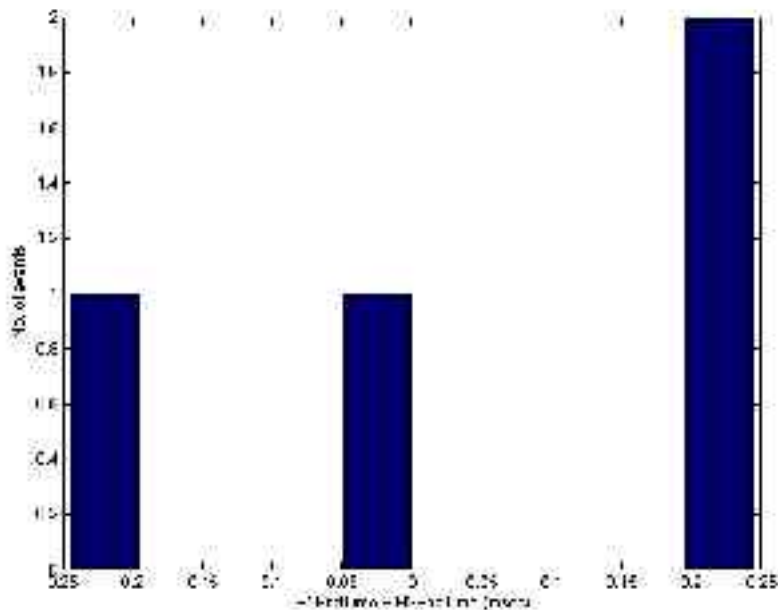
Coherent H1-L1



Coincident HW Injections: Time delays

(H1 only) – (H2 only)

CoherentH1L1 – (L1 only)



Summary

1. The SW / HW injection plots show that:
 - » All *effective distances* found within 15-20% of injected value
 - » All of the detected injections in the **Coherent H1-L1** search were within a time-point of the corresponding events in **L1**.
 - » All 4 of the detected HW injections in **H2** were within a time-point of the corresponding events in **H1**

2. Note that in a coherent H1-L1 search, even with a looser chi-square threshold (~twice as large as in the single-detector searches), but with the same SNR threshold, all (and only) the injected events are detected
 - Does this imply that the detection efficiency (on the playground data) of a coherent H1-L1 search is better than an H1 (only) search and an L1 (only) search?

3. Errors in observed (ψ, ι) needs to be studied