Very Low Latency Search for Low Mass Compact Binary Coalescences in the Upcoming LIGO S6 and Virgo VSR2 Data

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CBC searches during S6/VSR2

- Baseline searches organized in weekly runs
  - All sky and externally triggered searches covering full parameter range
    - » Low mass search
    - » High mass search
    - » Ringdown search
    - » GRB-triggered searches
  - Include full consistency tests of triggers and follow-ups of candidates
  - Reference analyses for publications of detections or upper limits

Next science runs of LIGO (S6) and Virgo (VSR2) to begin soon

- Very low latency search
  - Low mass range
  - Higher threshold analysis
  - More limited consistency tests
  - Focus on triple coincidences for multi-detector analysis

↑ This talk

Why a very low latency search ?

- Extract single detector triggers for real time detector characterization
  - ◆ Monitoring of trigger rate and data quality

- Online multi-detector search
  - ◆ Quickly identify and localize in the sky interesting triple coincident candidates that deserve an electromagnetic follow-up

Why electromagnetic follow-ups ?

- NS-NS or NS-BH mergers are plausible progenitors of short, hard gamma ray bursts
  - A GRB + GW coincident observation could
    - Confirm this hypothesis
    - Give great confidence in GW detection
    - Bring additional information about the source
      - Accurate sky position, host galaxy, redshift…
  - Searches triggered by short, hard GRBs are part of LIGO-Virgo analyses, but…
  - GRBs are believed to result from collimated outflows
    - Beaming factor reduces chance of observation
    - Many GRBs can be observed only through their afterglows (*orphan afterglows*)
    - Afterglow ~15 times more likely to be observed
    - Worth triggering afterglow search on GW trigger
      - Timescale of afterglows – hours – compatible with this approach

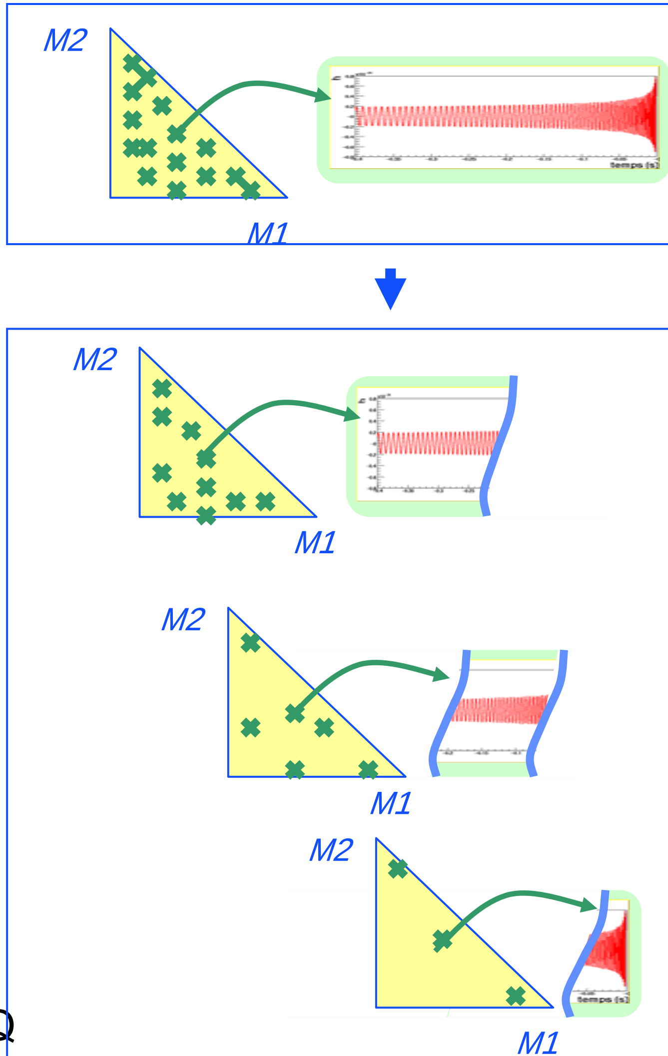
Which follow-up instruments ?

- Getting dedicated observation time from other instruments requires establishing external collaborations
- Target of opportunity observations with Swift
  - Approved
  - Look for afterglows in X-ray, UV and optical wavelengths
  - Could also be triggered by interesting candidates from low latency burst search
    - » Long GRBs, SGR flares
  - Expect ~3 requests during latter half of Swift Cycle 5
  - Most likely to be due to detector noise, could plausibly contain a true signal
  - One of the triggering candidates could be a test
    - » “Blind” hardware injections to probe detection process
- Wide-field optical follow-ups
  - Under discussion
  - Look for electromagnetic counterparts using array of wide-field optical telescopes

The MBTA pipeline

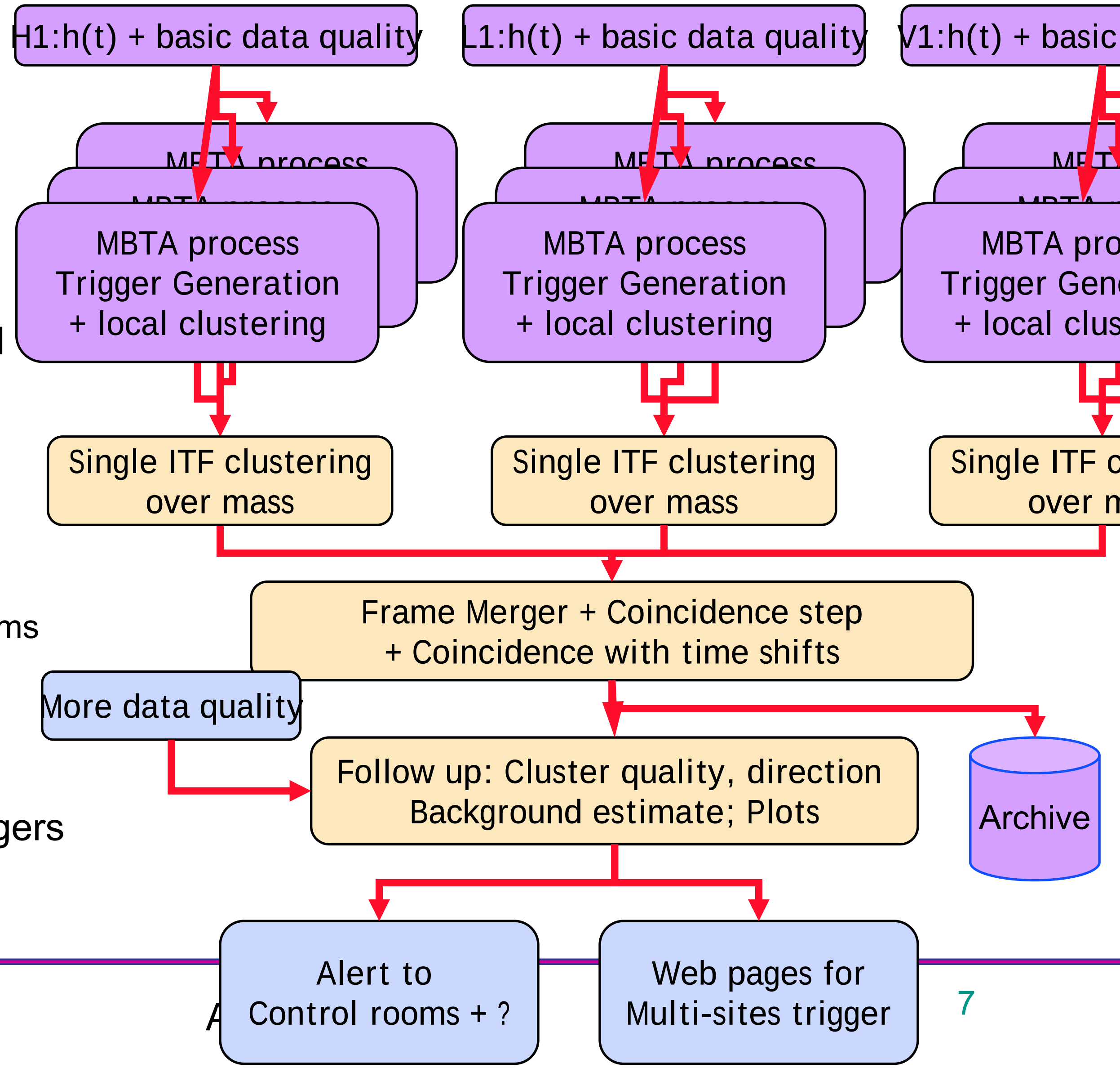
Multi-band template analysis

- Efficient implementation of matched filtering over a bank of templates
  - » Computes matched filtering integral over two frequency bands
  - » Coherently adds SNR from low and high frequency bands
- Cover mass range from 1 to 34 $M_\odot$,
  - » 2 $M_\odot$ < total mass < 35 $M_\odot$
- 2^{nd} order post-Newtonian, time-domain templates
- Limited but computationally inexpensive consistency test
  - » 2 band χ^2
- Adaptive mechanisms to follow detector non-stationnarities
- No files involved in the data transfer between processes
  - » Use TCP-IP based protocol developed for Virgo DAQ

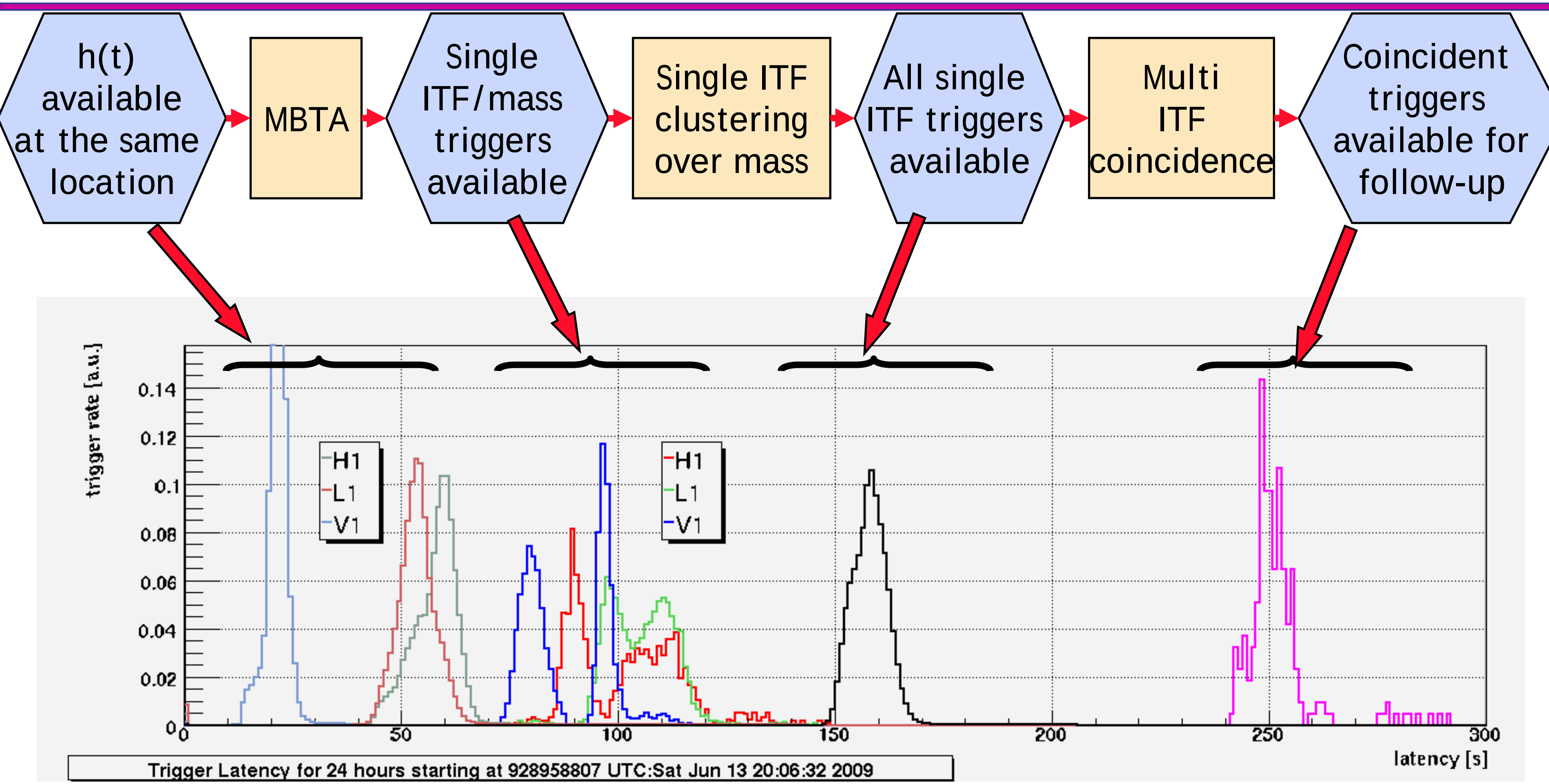


Online implementation

- Bring all data @ Virgo
- Processing split by:
  - ITF & Mass range
- Single ITF clustering
  - Cluster triggers separated by less than ~0.1 second
- Multi-ITF clustering
  - Based on time
    - » HL time window: ~20 ms
    - » H/L-V time window: ~40 ms
  - Clustering can apply time shifts for background estimation
  - Provide 1, 2 or 3 sites triggers



Latency



- Preliminary: observed values during WSR13/E14 engineering run

Data quality, vetoes, follow-ups

- Assessing the quality of the data at the time of potential candidates with low latency is the most challenging aspect
  - With the experience of S5/VSR1, we believe this can be done successfully in S6/VSR2, at least after some learning period
  - Data quality flags and vetoes are produced online and can be used by the very low latency analyses
- Before an alert is sent to the outside world, some basic follow-up of the candidate should be done
  - Procedure can be automated to some extent
    - » Requirements to be defined
  - Validation should be done by scientist on shift

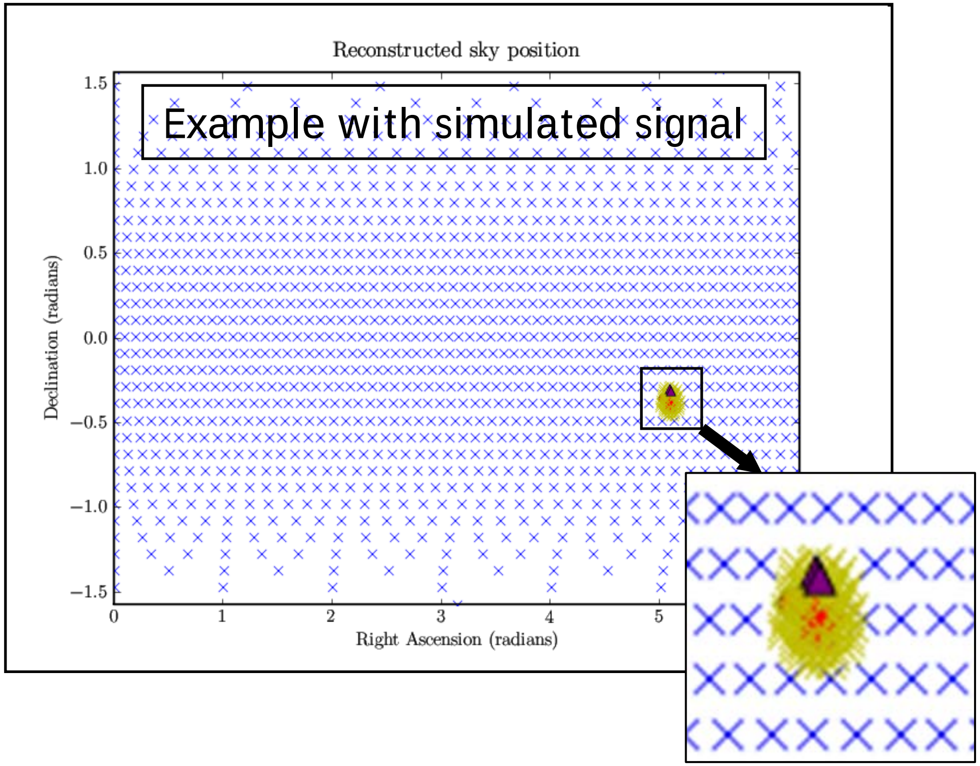
Assessing significance of candidates

- How to estimate the false alarm rate of interesting candidates?
  - From single detector observed trigger rates
    - Assuming single ITF trigger rate = 0.1 Hz
    - Coincidence windows
      - Hanford - Livingston: ± 20ms Hanford/Livingston - Virgo: ± 40ms
    - Expect ~1.5 events/hour for H1L1 coincidences, ~3 events/hour for H1V1 or L1V1
    - Expect ~8 events/month for H1L1V1 triple coincidences
    - Triple coincidence rate low, but double coincidences can be used to check how well the background can be estimated from trigger rates
  - From coincidence rates observed with time offsets
    - Accumulate background estimates based on past hours/days
- Tune threshold so as to get ~1 trigger/month to be considered for *possible* follow-up by Swift
  - Monitor over first months of run before requesting real follow-ups
  - Threshold could be lower for optical follow-ups

Sky localization

- Use triangulation based on time of flight between H1, L1, V1 detectors to locate the source on the sky
  - For better accuracy, use time when signal crosses some reference frequency ~150 Hz instead of end time
  - Use effective distance measured at each detector to help lifting the symmetry ambiguity
  - Expect modest pointing accuracy
    - » ~ several degrees for signals at detection threshold

Scan the sky and identify those points the signal is most likely to come from



➔ See talk by Antony Searle

➔ See poster by Larry Price

Conclusion

- Very low latency searches may be a key point in making a joint GW + electromagnetic observation
  - Allow to trigger search for EM counterpart on GW candidates
- Compact coalescing binaries involving a neutron star are potentially observable also as GRBs and/or their afterglows
  - GRB triggered searches for GW nicely complemented by GW triggered searches for GRBs / afterglows
- Likely to pay off with advanced detectors
  - Unlikely but plausible with enhanced detectors
  - S6/VSR2 is the time to get ready and setup procedures