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

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#  Very low latency CBC searches

- During science run S6 of LIGO and VSR2 of Virgo from July '09
- Very low latency search (this talk)
  - NOT baseline search used for publications of detections or upper limits
  - Low mass range : from 1 to 34 $M_\odot$,
    - 2 $M_\odot$ < total mass < 35 $M_\odot$
  - Higher threshold analysis
  - More limited consistency tests
  - Focus on triple coincidences for multi-detector analysis



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

      ➜ see talk by F. Robinet
  - 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 ?

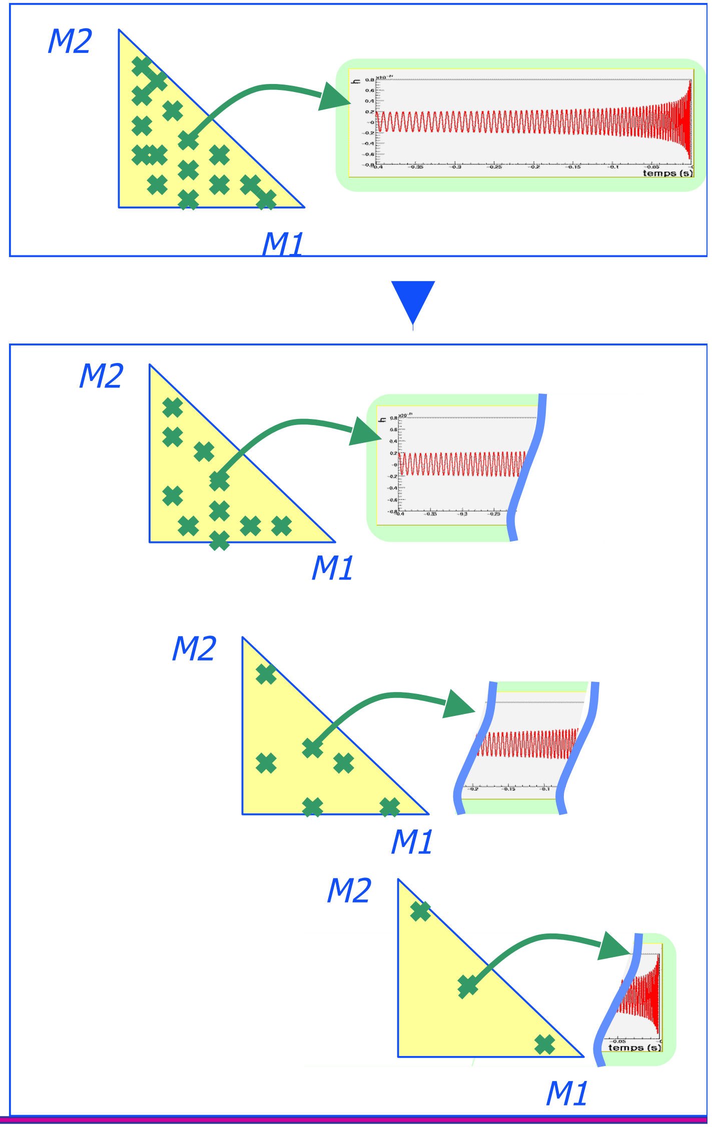
- NS-NS or NS-BH mergers are plausible progenitors of short, hard gamma ray bursts
- A GRB + GW coincident observation could
  - Confirm this hypothesis
  - Give great confidence in GW detection
  - Bring additional information about the source
    - Accurate sky position, host galaxy, redshift…
- Searches 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 could 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

# Follow-up instruments

- External collaborations established with other instruments
- Target of opportunity observations with Swift
  (CBC point of view)
  - Look for afterglows in X-ray, UV and optical domains
  - Expect ~3 requests during Swift Cycle 6 (starting April 2010)
  - 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 followups
  - Look for electromagnetic counterpart using array of wide-field optical telescopes
  - Examples : TAROT, QUEST, Pi of the Sky

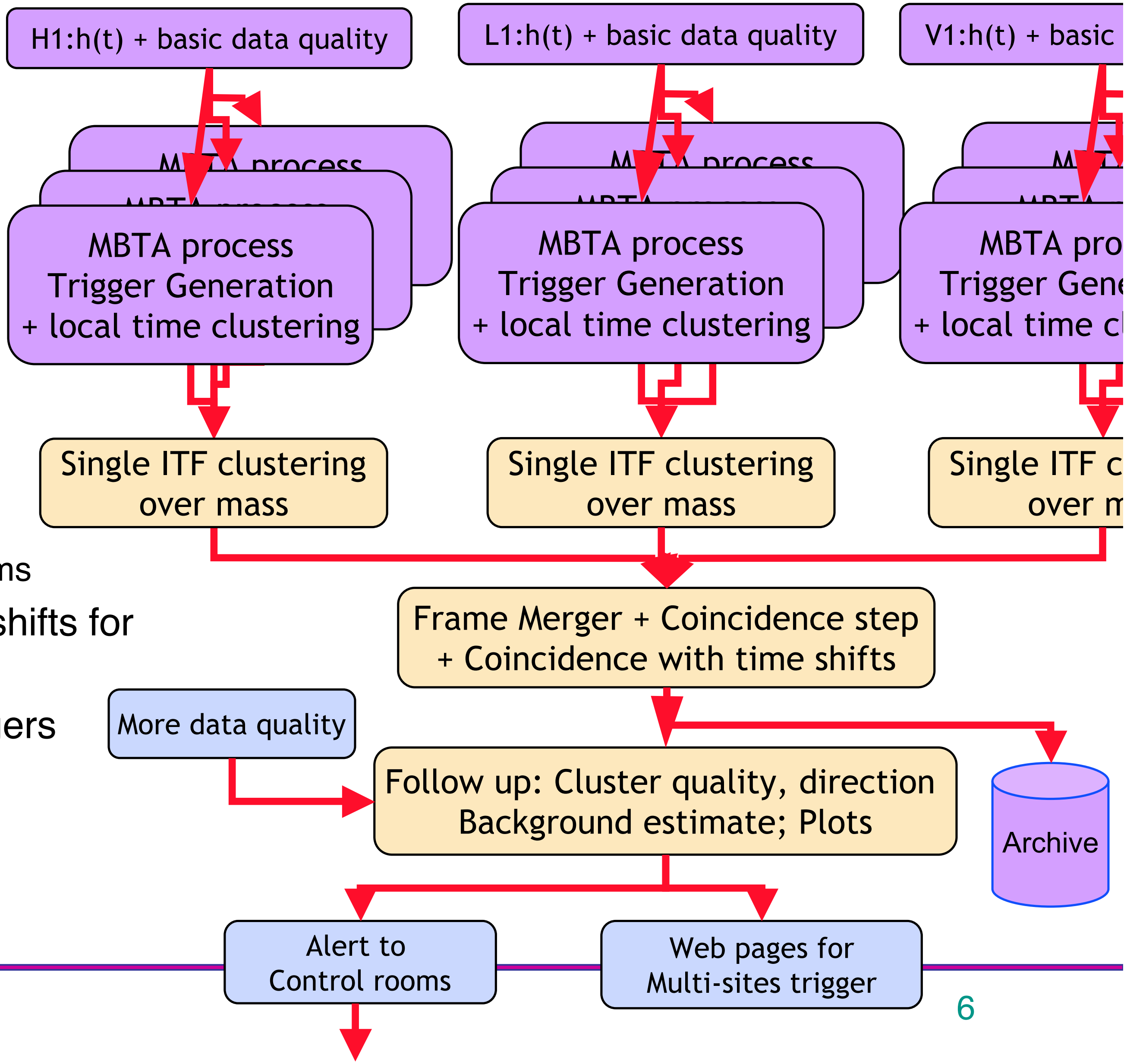
# The MBTA pipeline

- 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
  - 2nd order post-Newtonian, time-domain templates
  - Adaptive mechanisms to follow detector non-stationnarities
  - Speed, speed, speed…
    - » Limited but computationally inexpensive consistency test
      - – 2 band $\chi^2$
    - » 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
- The triggers journey continues…



# A trigger's journey

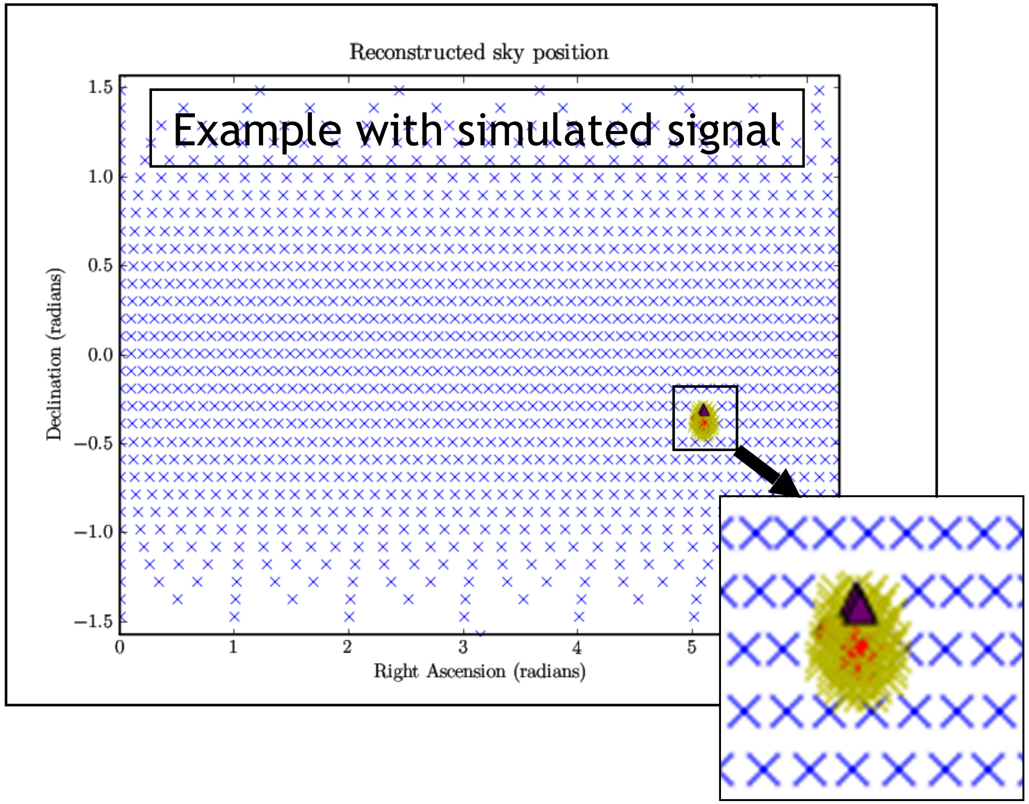
- After generation of a coincident trigger
- Sent to a database ( "GraceDB" )
  - Record candidate event
  - Record information about followup
  - Connected to an alert system (not yet enabled)
- Activation of a sky localization procedure
- Data Quality
  - Data quality flags and vetoes are produced 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 will be done
    - Procedure can be automated to some extent
    - Validation should be done by scientist on shift

# Sky localization



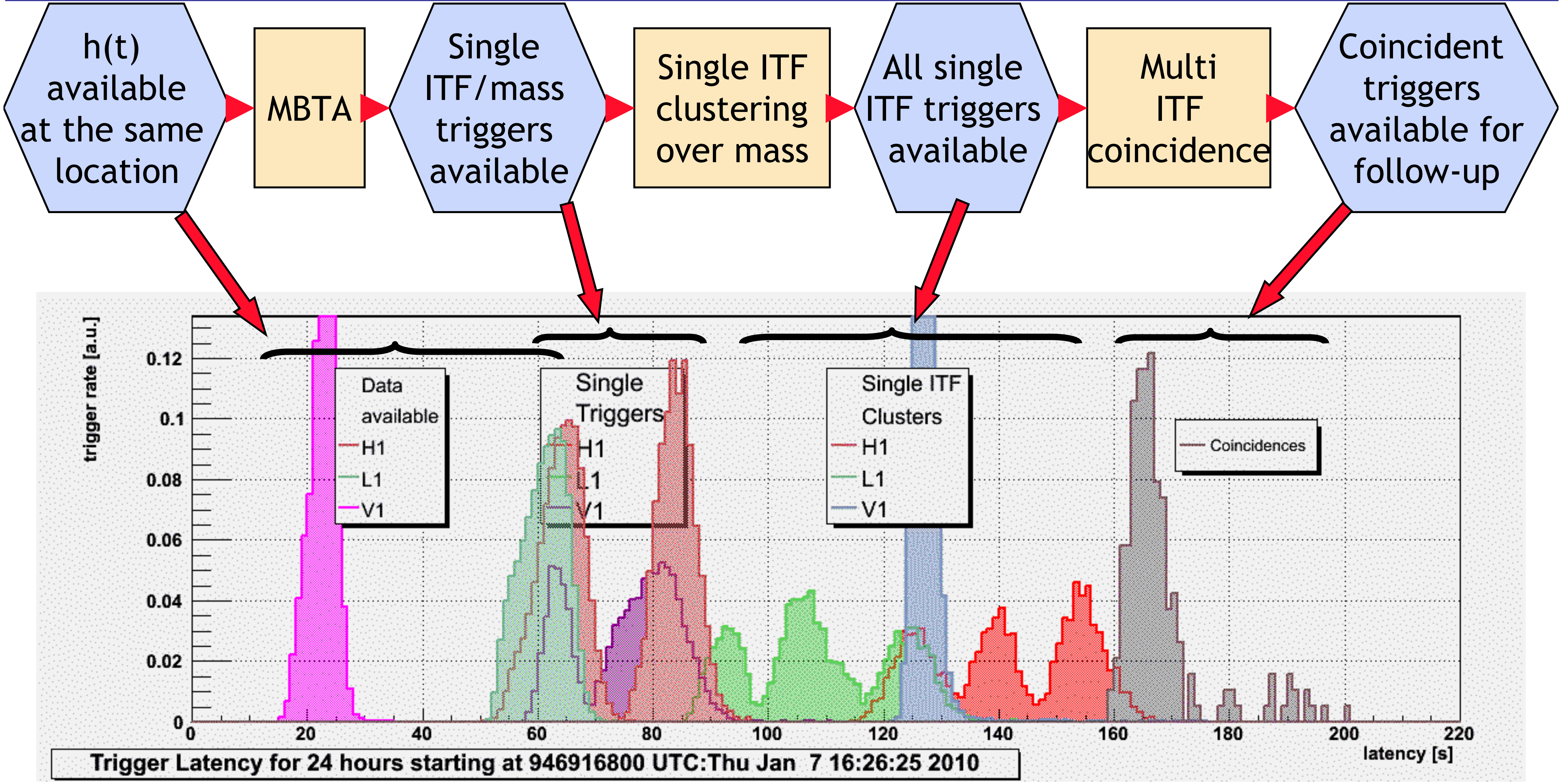
- Use triangulation based on time of flight between H1, L1, V1 detectors to locate the source on the sky
  - For better accuracy, use time when signal crosses some reference frequency ~150 Hz instead of end time
  - Use effective distance measured at each detector to help lifting the symmetry ambiguity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




Use hardware injections to assess performance of sky localization

# Latency

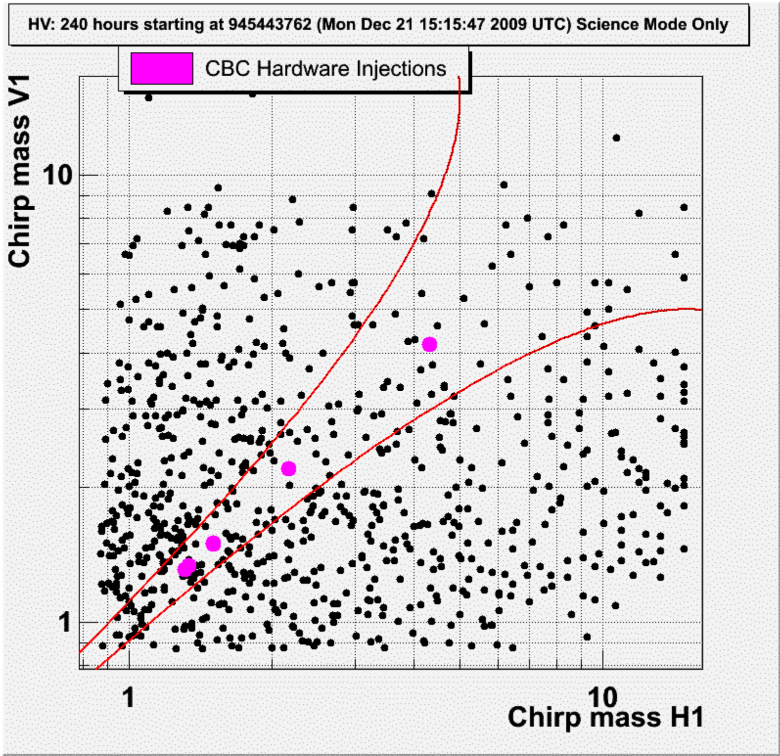



Latency from data to coincident triggers : < 3 min

# Controlling the trigger rate

- Goal : Tune threshold for ~1 trigger/month to be considered for *possible* follow-up by Swift

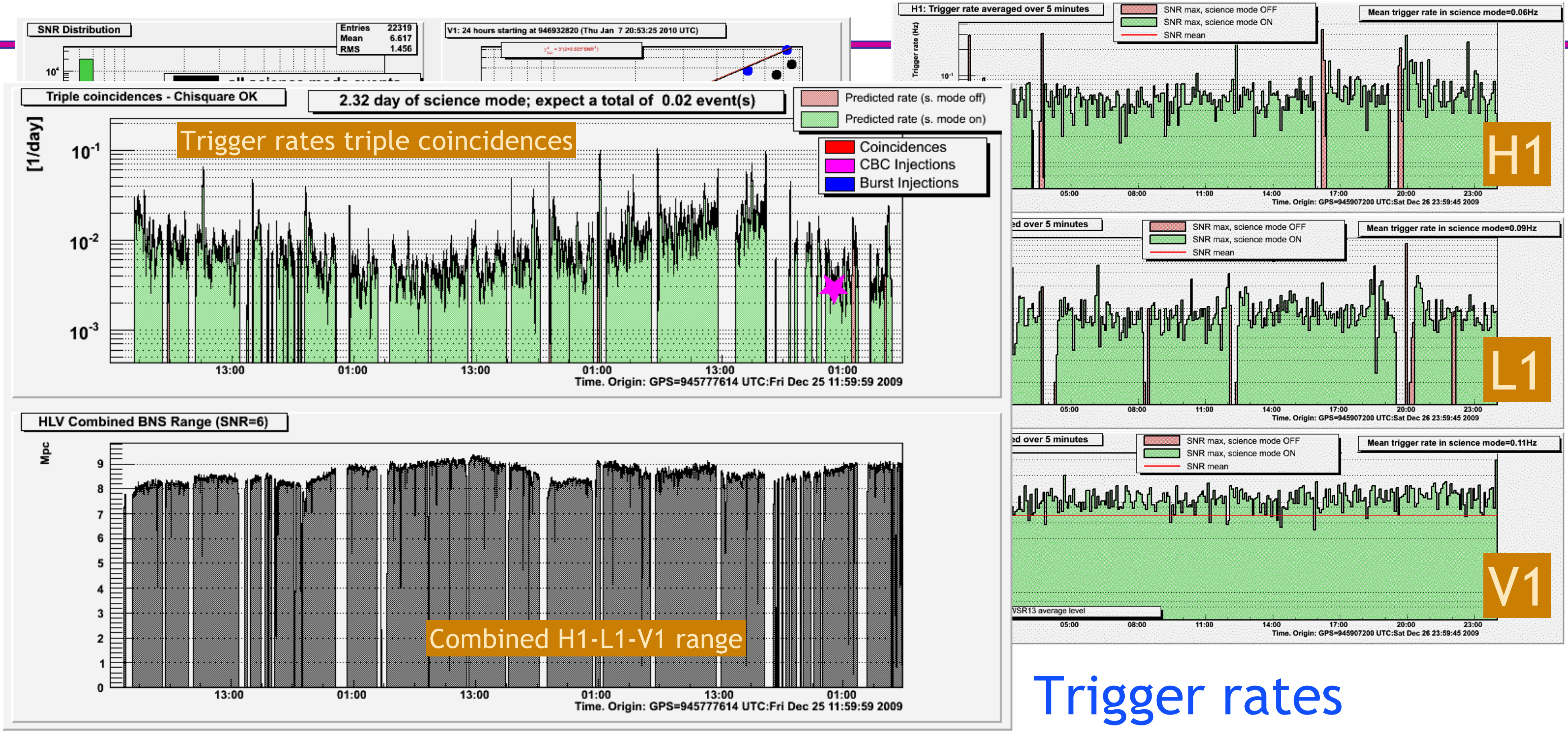
- Cuts on Time Of Flight and Chirp Mass
  - Efficiency and performance checked with software injections
  - Single detector trigger time resolution = $\frac{5\text{ ms}}{SNR}$
  - Coincidence windows
    - » Hanford - Livingston: ± 20ms
      Hanford/Livingston - Virgo: ± 40ms




- Estimation of the trigger rates
  - Assuming single ITF trigger rate = 0.1 Hz
  - Expect/observe
    - » ~1.5 events/hour for H1L1 coincidences,
    - » ~3 events/hour for H1V1 or L1V1
  - When applying chirp mass cuts
    - » Expect/observe less than 1 H1L1V1 triple coincident event/month

- Triple coincidence rate low, but double coincidences can be used to check how well the background can be estimated from trigger rates

# Figures of merit




Trigger rates

| | H1 | L1 | V1 | HL | HLV |
|---|---|---|---|---|---|
| MBTA duty cycle (first two months) | 94% | 96% | 97% | 93% | 92% |

# Conclusion

- Compact coalescing binaries involving a neutron star are potentially observable also as GRBs and/or their afterglows
- 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
- A very low latency pipeline (MBTA) was running during S6/VSR2 runs
  - Latency < 3 min until availability of trigger
  - Duty cycle of the pipeline for three detector coincidences > 90 % over the full run
  - Expect/observe less than 1 triple coincident event/month
- Trigger submission for E.M follow-up will be enabled after Virgo data taking resume.