An End-to-End Test of the Sensitivity of IceCube to the Neutrino Burst from a Core-Collapse Supernova

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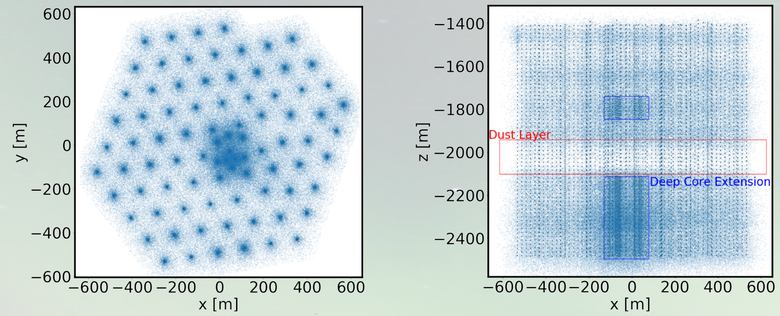
1. Motivation

The next galactic Core Collapse Supernova (CCSN) presents the opportunity to make a groundbreaking multi-messenger measurement. The neutrinos emitted by such an event will probe both fundamental neutrino physics and astrophysics. These neutrinos also trigger electromagnetic (EM) and gravitational wave (GW) followups, providing probes of..

- Stellar core structure
- Stellar core equation of state
- Neutrino mass hierarchy
- Beyond Standard Model physics [1]
- (GW) The absolute mass of the neutrino [2].
- (EM) First multiwavelength observations of the onset of the explosion.



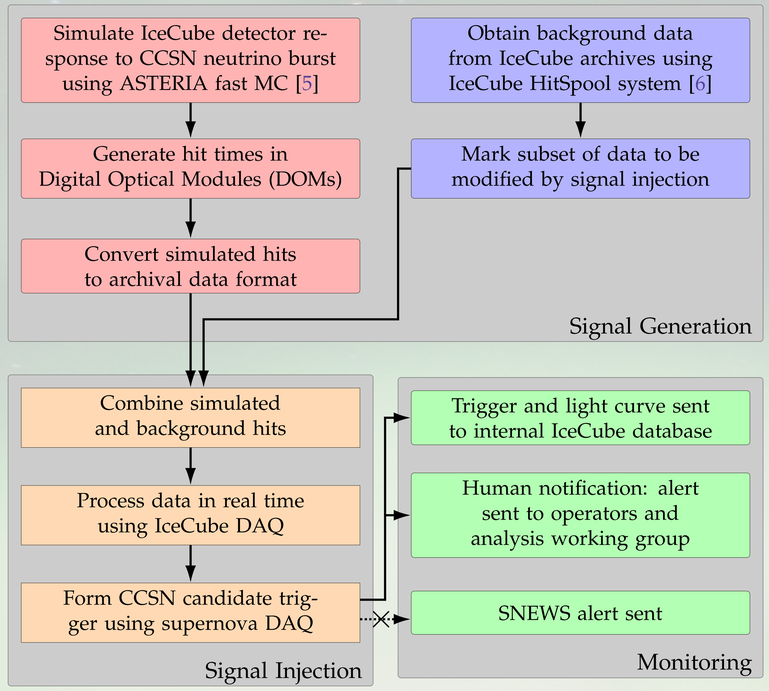
Top and side view of 3.4×10^5 *simulated hits in IceCube supernova* $\overline{\nu}_e$ *interaction vertices registered by IceCube DOMs. [3]*

IceCube monitors the Galaxy for CCSNe with $> 99\%$ uptime and can measure the neutrino lightcurve with sub-nanosecond precision. With sensitivity to galactic CCSN at a level $> 10\sigma$ [4], IceCube is critical to galactic CCSN detection. **In this contribution, we discuss tests of IceCube's supernova trigger formation and the collaboration's handling of alerts to ensure they are ready to observe the next Galactic CCSN.**

4. Lessons Learned

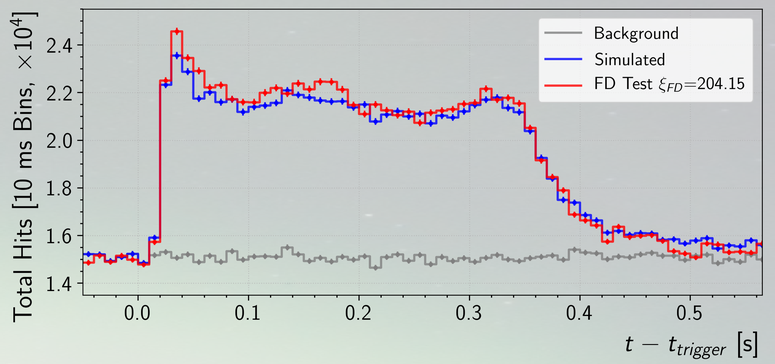
The first signal injection "Fire Drill" test was successful; this open, offline test produced a trigger ($\xi_{FD} = 204.15$) that is in agreement with expectation ($\xi = 193.36 \pm 13.91$). Also, this test identified technical issues that could have hindered data preservation and offline analyses in the case of a real alert.

2. Signal Injection Method



3. Signal Injection Results

An end-to-end test of IceCube's trigger formation and alert distribution was performed. A simulated CCSN signal was injected into archival data and was used to form a trigger with significance $\gg 10\sigma$ via the supernova triggering system (SNDAQ).



IceCube response to a 13 $M_\odot$ *progenitor [8] at 10 kpc assuming normal mass ordering and adiabatic MSW effects [9].*

$$\xi = \frac{\Delta\mu}{\sigma_{\Delta\mu}}, \qquad \mathcal{L}(\Delta\mu) = \prod_{i=1}^{N_{DOM}} \frac{1}{\sqrt{2\pi}\,\langle\sigma_i\rangle} \exp\left(-\frac{(R_i - (\langle R_i\rangle + \varepsilon_i \cdot \Delta\mu))^2}{2\,\langle\sigma_i\rangle^2}\right)$$

CCSN triggers are evaluated using a test statistic ξ, the ratio of the most likely collective rate increase $\Delta\mu$ and its estimated uncertainty $\sigma_{\Delta\mu}$. These are obtained by maximizing $\mathcal{L}(\Delta\mu)$ with DOM i hit rate R_i, estimated hit rate variance $\langle\sigma_i\rangle^2$, relative DOM efficiency ε_i, and $N_{DOM} = 5160$ [4, 6].

5. Next Steps (IceCube)

The next step will test the human elements of alert handling; the detector operators and collaboration working groups. Online testing may be used to examine edge cases and develop procedures to avoid failure states, e.g.,

- How will the collaboration respond to a high significance alert?
- Will CCSN signals close to the detection threshold be caught?
- Can the SN-WG promptly obtain measurements from a CCSN signal?

Signal injection data challenges have demonstrable utility. This functionality will be integrated into software for IceCube-Gen2 [7].

6. Next Steps (SNEWS 2.0)

Coordinating simulated alerts with the SuperNova Early Warning System (SNEWS 2.0)[10], which includes other neutrino experiments and optical astronomers (professional and amateur). Questions to explore:

- How do other neutrino detectors (and IceCube) respond to an external SNEWS alert without an internal coincident signal?
- Given coordinates in the sky, can astronomers identify the transient?

Upcoming "Fire Drill" tests will be integrated with IceCube's monitoring systems, and will use the SNEWS test alert server as an endpoint.

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National Science Foundation
Office of Polar Programs

ICRC2021
PoS 1085

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