Updates to IceCube realtime alert system for muon tracks

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The IceCube Collaboration has recently updated the reconstruction algorithms used to determine the arrival direction of astrophysical neutrino candidate events that produce a muon track in the detector. The goal of this update, which applies only to the "follow-up" reconstruction (see 1), is to improve the angular resolution of muon track alerts and the statistical coverage of their directional uncertainties. This should in turn improve the sensitivity of searches for coincident electromagnetic counterparts, and enable better statistical tests of spatial correlation with high-energy neutrino events. The update went into effect with alert IceCube-240929A (GCN Circular 37625) and will be applied to all subsequent alerts.

The new reconstruction approach results in an overall reduction of the uncertainty regions for alert events, as shown in Fig. 1. The solid angle covered by the 50% (90%) uncertainty regions based on the new reconstruction procedure decreases by a median factor of 5.14 (4.45) when compared to the same uncertainty regions for alert events in the IceCube Event Catalog of Alert Tracks (IceCat-1, [1]). The median solid angles covered by the 50% and 90% uncertainty regions are now 0.36 deg^2 and 1.26 deg^2, respectively. A distribution of opening angles between the new reconstruction and those published in IceCat-1 is shown in Fig. 2, with a median angular offset of 0.27° between both reconstructions for all alert events.

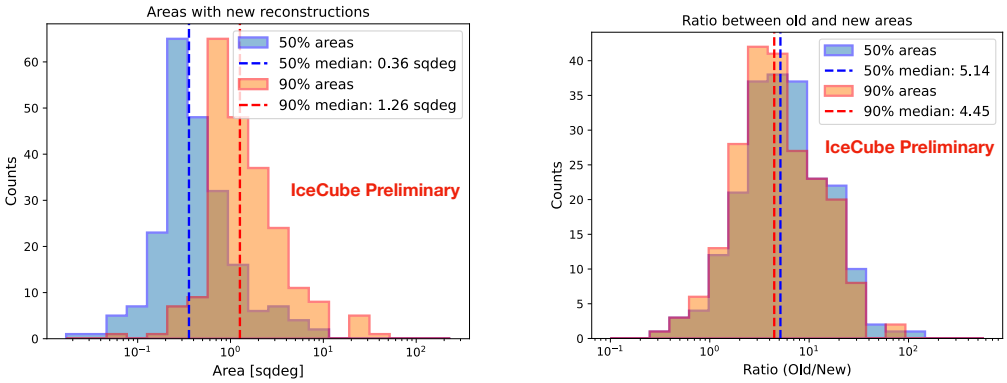

Figure 1: *Left:* Distribution of solid angles (in squared degrees) covered by the 50% (blue) and 90% (orange) uncertainty regions for the updated alert reconstructions applied to 221 IceCat-1 events. *Right:* Ratio of solid angles for the 50% and 90% uncertainty regions for 221 events published in IceCat-1 with respect to the updated reconstruction approach.

1 Description of the updates

The events in consideration for this update are those distributed as "Astrotrack" alerts and classified as "Gold" or "Bronze", depending on the probability of the event being astrophysical in origin. Gold and Bronze events have average astrophysical probabilities of 50% and 30%, respectively. See here for more details regarding the Gold and Bronze alert streams.

Astrotrack events are selected by the IceCube realtime alert system (see details regarding the realtime event selection in [2]) and openly circulated to the community via GCN as Notices and Circulars via a two-step process:

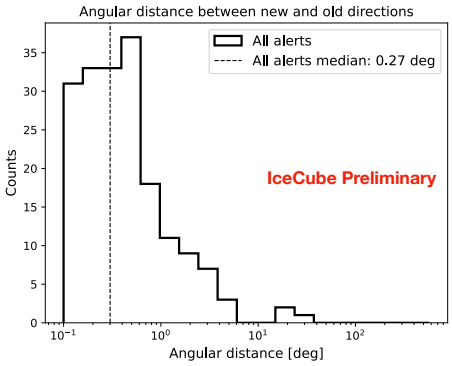

Figure 2: Distribution of opening angles between the reconstructions published and those from the updated reconstruction approach for 221 events in IceCat-1 [1].

1. A prompt GCN Notice (Revision 0) is first broadcasted shortly after the identification of an astrophysical neutrino candidate at the South Pole. This first notice is automatically issued (i.e. no human in the loop). The notice contains, among other information, the best-fit position of the event in equatorial coordinates, as well as 50% and 90% uncertainty radii. This prompt alert position is based on the SplineMPE reconstruction algorithm [3], which is also used in IceCube searches for astrophysical neutrino sources (e.g. [4]) as well as other realtime searches and in public data releases [5]. **This step remains unchanged in the current update**.

2. A follow-up reconstruction, which is more computationally intensive, is then performed and circulated in a new revision of the alert (Revisions 1 and higher), with an updated position and uncertainty radii. This is accompanied by a GCN Circular (e.g. GCN Circular #37723 for IceCube-241006A) which includes a directional error box for the event as well as the position of nearby gamma-ray sources of interest, if any. Prior to the update, this reconstruction was performed using an older version of the Millipede reconstruction algorithm [6]. **The current update applies to this step alone.**

Recent improvements in the follow-up reconstruction algorithm, for both SplineMPE and Millipede [7, 8], have significantly enhanced both reconstructions, yielding muon track positions with improved angular resolution and better statistical properties of the angular uncertainties associated with the best-fit position. This is a result of a better understanding of light propagation in the ice [9, 10, 11], the implementation of new minimization procedures in the directional fitting process, as well as updates to the infrastructure required to perform follow-up reconstructions [12, 13].

Based on these recent developments, IceCube has decided to update the follow-up reconstruction step, using the updated SplineMPE reconstruction for events with low energy deposition in the detector, and the updated Millipede for high-energy deposition events, or tracks starting within the detector volume. This hybrid approach maximizes the angular precision of the alerts in their respective energy deposition regimes while still providing good statistical coverage for the reported position uncertainties.

Upcoming updates to the realtime system will be announced via GCN Circulars, and additional information will be available in the IceCube Realtime website: https://roc.icecube.wisc.edu/. Additional details will be included in future conference proceedings and a follow-up peer-reviewed publication. We also anticipate a revision to the IceCat-1 alert catalog using the updated reconstruction approach.

Comments, suggestions and questions from the community are encouraged and welcomed. The point of contact for the IceCube Realtime system is roc@icecube.wisc.edu.

References

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