RAPID RESPONSE TO EXTRAORDINARY EVENTS WITH THE ICECUBE EXPERIMENT

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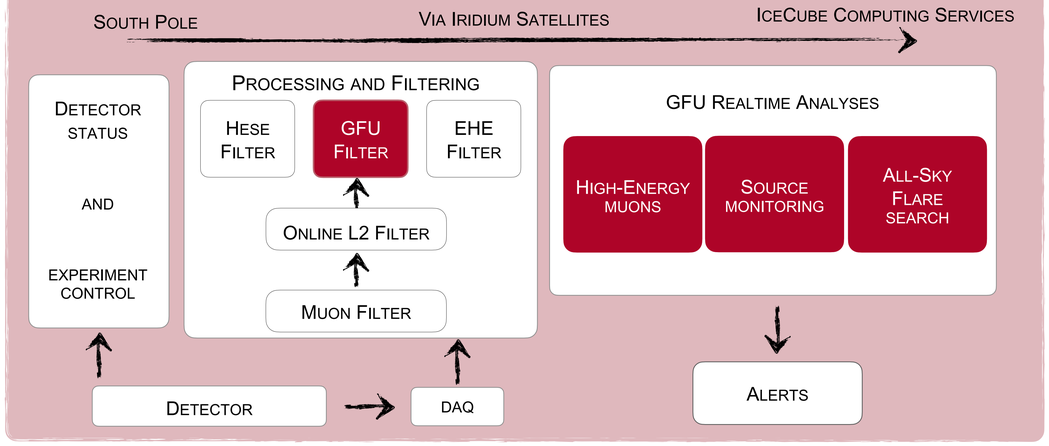
The discovery of an astrophysical flux of neutrinos with IceCube is a milestone for multimessenger astronomy. Neutrinos open a new window on the high-energy Universe. They provide a complementary view on cosmic accelerators and can help solve the long-standing puzzle of the Ultra-high Energy Cosmic Rays origin. Thanks to IceCube's capabilities to observe the sky with almost full duty cycle, it is possible to search for transients and possibly alert the community with low latency. This poster shows a real-time selection pipeline, which allows the identification of muon neutrino candidates. This selection has three products: energetic single neutrinos; neutrino clusters found with a monitoring program of known gamma-ray emitters; clusters found by monitoring the entire sky, without pre-defined source-lists. Alerts are generated from these analyses whenever significant events are recorded, or significant flares develop on time-scales from days to several weeks.

1. THE REAL-TIME ALERT SYSTEM: OVERVIEW OF THE "GFU" PLATFORM



IceCube has a complex real-time infrastructure, developed for transient sources searches of neutrinos [1,2]. The scheme on the right is an overview of the components relevant to this work. Red boxes highlights those parts which are going to be summarised in this poster.

"GFU" means Gamma-Ray-Follow Up. In 2006, the first seeds of this platform were indeed specifically developed for that purpose [3]. However, GFU has now a much broader application.

2. THE GFU FILTER

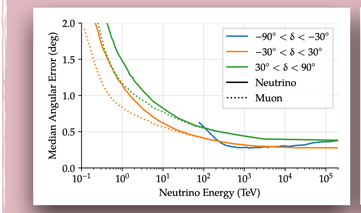


Fig. 2.1: Median angular error of GFU events. Dotted lines show angular distance between the reconstructed direction and the true muon neutrino direction.

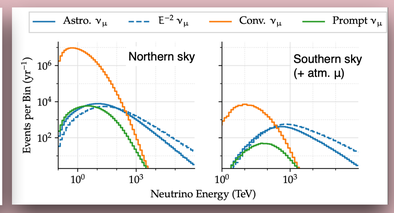
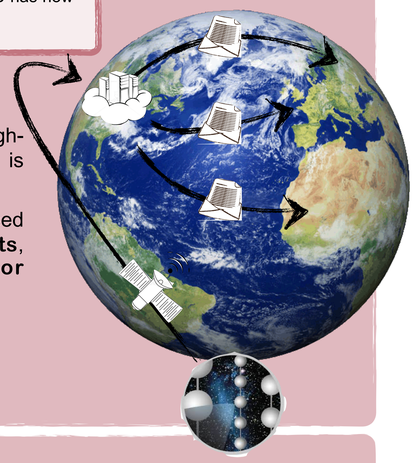


Fig. 2.2: Distribution of the true neutrino energy for muon induced-events selected by the GFU filter.

The **GFU filter** selects through-going muon tracks. The rate is about 6 mHz.

GFU events are further processed and possibly **generate alerts**, **which are either public or private**. See next sections.



3. GFU REALTIME ANALYSIS: HIGH-ENERGY MUONS

From the GFU-filtered events, the events with the highest energies, those that have a high probability (p_{astro}) of being of astrophysical origin, are selected and and **immediately trigger a public alert** through a GCN Notice.

Since 2019, there is a unified alert stream [4]:

- "bronze" (p_{astro}> 30% - 30/year)
- "gold" (p_{astro}> 50% - 10/year)

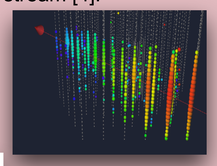


Fig. 3.1: Event view of IC-170922A [5]. It was selected by the EHE filter, whose events are a subset of GFU events.

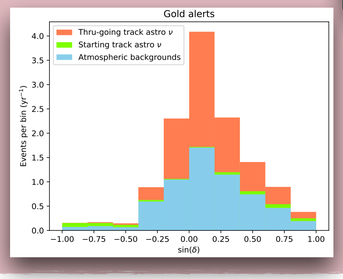
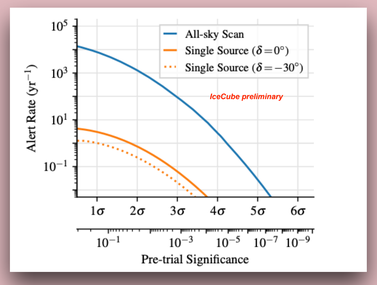


Fig. 3.2: IceCube realtime astrophysical neutrino alert declination distribution for Gold alert level. Atmospheric neutrino components are shown in a stacked histogram.

4. GFU REALTIME ANALYSIS: CLUSTER SEARCHES

The search for neutrino multiplets is based on the maximum-likelihood method [6], modified in order to take into account both spatial and temporal properties of the events, plus a time clustering algorithm [7].

Two programs are ongoing within the GFU platform, **both generating alerts**:



- searches from a list of pre-selected gamma-ray sources;
- unbiased searches from the entire sky

Fig. 4.1: Expected alert rate as evaluated in a background-only scenario. The blue line refers to the rate for the all-sky scan. Orange lines represents alert rates from a monitoring of a single source located at two hypothetical declinations.

4.1 GFU REALTIME ANALYSIS: SOURCE MONITORING

Expected alert rate/year is below 10. Alerts generated from this program are sent privately to Imaging Air Cherenkov Telescopes: MAGIC, VERITAS and H.E.S.S.

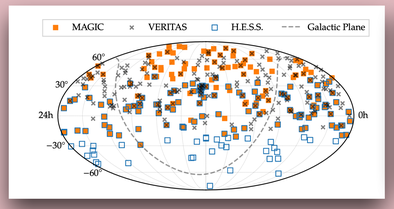


Fig. 4.1.1: Skymap showing the locations of the monitored sources in equatorial coordinates. A total of 339 sources are monitored

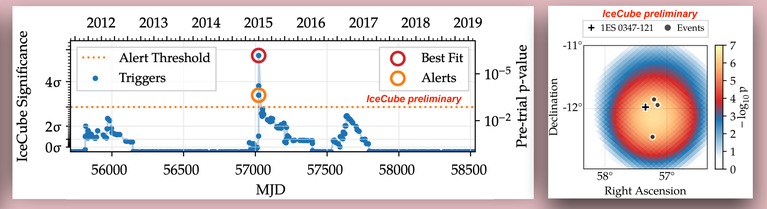


Fig. 4.1.2: Results for 1ES0347-121, which yielded the most significant flare among all monitored sources. The time evolution of the significance is shown between 2011 and 2019 (left). The skymap is focused on the most significant time window (right).

4.2 GFU REALTIME ANALYSIS: ALL-SKY FLARE SEARCH

Expected alert rate from the all-sky monitoring is 1/year. Alerts from this program are currently shared only with MoU partners.

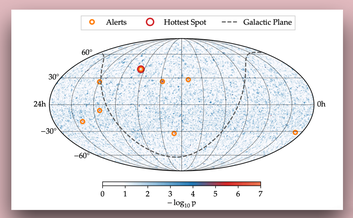


Fig. 4.2.1: Skymap of the time-dependent all-sky scan. The color scale shows the best local p-value in each pixel.

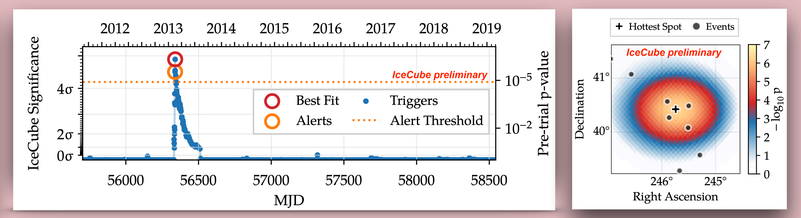


Fig. 4.2.2: Properties of the hottest spot found in the all-sky scan over 7.5 years of data, with an overview of the time evolution (left) and skymap focus on the most significant time window (right)

5. CONCLUSIONS

The IceCube infrastructure at the South Pole and in the northern hemisphere allows a realtime communication of alerts for high quality candidate neutrino singlets and multiplets. The platform here described is a powerful tool for transient searches and multimessenger studies. Continuing efforts will ensure its maintenance and further optimisation.

REFERENCES

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