Neutrino alert system of KM3NeT

Second KM3NeT Town Hall Meeting

Godefroy Vannoye

September 22nd, 2022

Catania, Italy

Outline

Introduction

KM3NeT neutrino alerts

How to maximize the scientific interest of our alerts?

Introduction

Why do we need alerts?

As we are limited by the statistic sample of astrophysical neutrinos we can observe, **alerts** are one of the **best strategy to identify likely astrophysical neutrinos** and **characterize their potential source**.

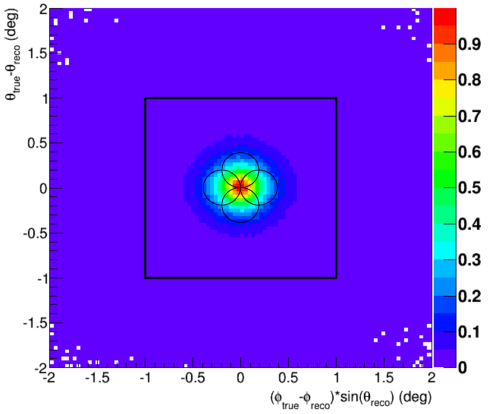
Performing **follow-up observations** in **all of the electromagnetic spectrum** allows to get as much data as possible from the potential sources, which would allow for **better model fits** and, in the end, to **identify the sources of astrophysical neutrinos**.

The remaining question is: **how to maximize the number of follow-up observations to those alerts?**

ANTARES neutrino alerts

Criteria for alerts
– Neutrino doublet (0.04 evts/yr)
– Single neutrino with direction close to local galaxies (1 TeV, 10 evts/yr)
– Single HE neutrinos (7 TeV, 15 evts/yr), with sub-sample of VHE neutrinos (30 TeV, 3-4 evts/yr)

Follow-up
Private alerts in the GCN format
Follow-up observations with optical (ROTSE-III and TAROT) and X-ray (Swift) telescopes
218 alerts followed within 1 day, 55 alerts followed within 1 minute



Angular resolution for a typical HE neutrino alert. Black square: optical telescopes FOV, black circle: Swift FOV

IceCube neutrino alerts

IceCube alerts

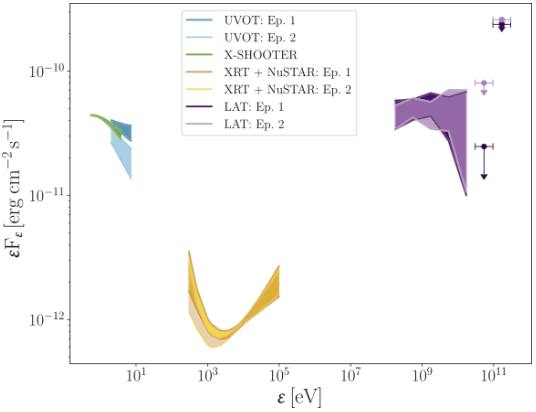
Since 2019, improvement on background rejection and selection on "signalness" $\left(\frac{N_{\text{signal}}}{N_{\text{signal}}+N_{\text{background}}}\right)$ for muon neutrino tracks, with two classification (GOLD for 50% and BRONZE for 30%)

Automatic public alerts through GCN notices, GCN circular few hours later with refined reconstruction and sometimes astrophysical data

TXS0506+056 example

Correlation between a neutrino and a flaring blazar at 3σ on September 2017

Follow-up observations by Swift, NuSTAR, X-shooter and Fermi LAT



Spectral energy distribution for TXS0506+056

KM3NeT neutrino alerts

General overview

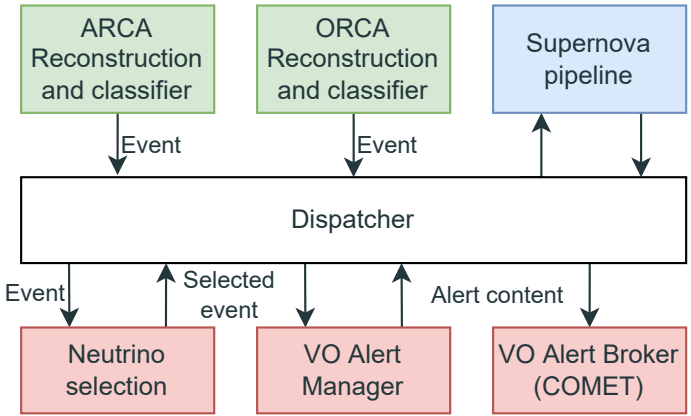


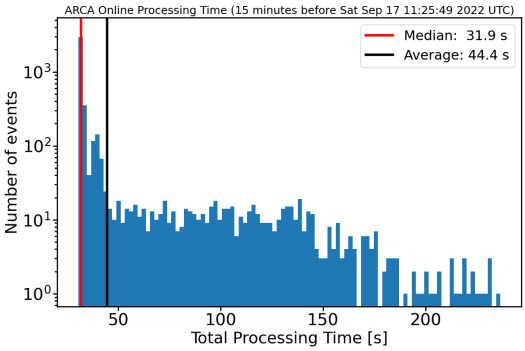
Diagram describing the alert generation

Reconstruction and classifying

What data can KM3NeT provide?
In less than 1 minute, full reconstruction of tracks and showers with direction and energy estimation (for now 20s buffer that will be removed soon)

For every event, we have access to reconstruction as tracks and as showers with:
– probability of neutrino (all flavors) vs muon for low energy
– probability of track vs shower for high energy

With a full detector (230 lines for ORCA, 115 lines for ORCA), we expect between 100 and 200 neutrinos per day



Total processing time of events with ARCA

Neutrino selection and alert content

From hundreds of neutrinos per day, we select a few alerts per month:

(Very) High energy selection
Selection of single neutrinos, the ones which reconstructed energy are the highest of the month

Multiplet selection
In situations where multiple neutrinos are seen from the same direction within a limited time, an alert will be sent

Alert content
General template (VOEvent) filled automatically and checked before sending
Alert distributed publicly through a broker (COMET)

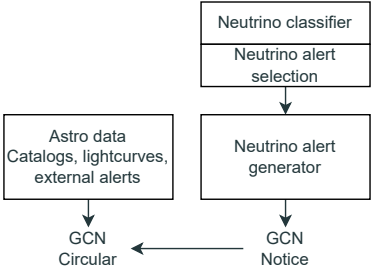
- ID
- Detector (ARCA/ORCA)
- Type of alerts triggerrs
- Number of events in given time and space widows
- Flavor
- Energy
- IsRealAlert
- Time
- RA, Dec, Longitude, Latitude
- Error box 50% and 90%
- Reconstruction quality
- Probability of neutrino
- Probability of astrophysical neutrino

How to maximize the scientific interest of our alerts?

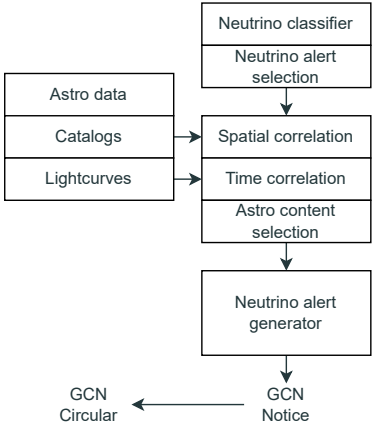
Two parallel selection

Pure neutrino selection
(Very) high energy and multiplet selection

Kept to not introduce bias in case of an unexpected source



Mix neutrino-astro selection
Selection of neutrinos based on both the neutrino properties and the properties of the potential astrophysical source

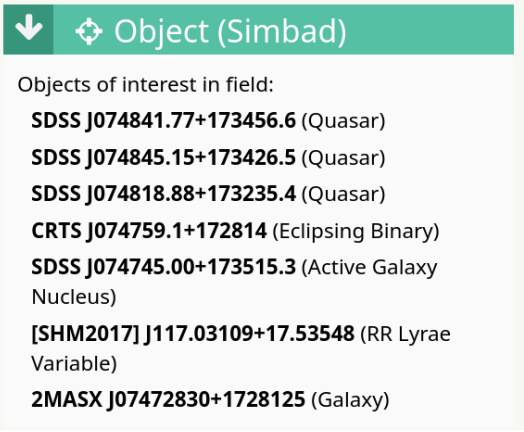


Spatial correlation

Cross-match
For every neutrino alert, crossmatch with CDS (Strasbourg astronomical Data Center) and specific catalogs

Selection of interesting sources, and ranking depending on properties in optical, gamma, radio properties

For the next months, proof of concept with AGNs

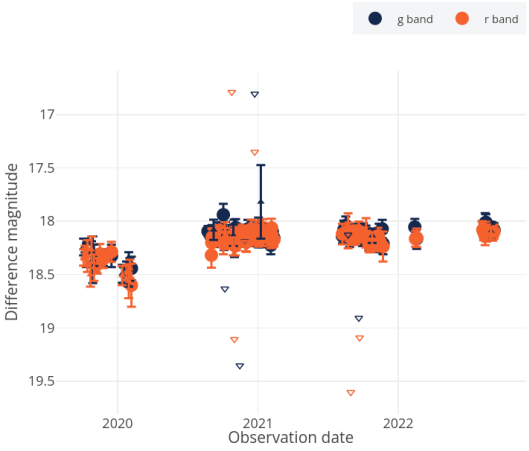


Time correlation

Lightcurves

Once we have a list of potential interesting source, request to ZTF/LSST *via* the Fink broker for optical lightcurves and FAVA (Fermi All-sky Variability Analysis) to check for flares or lack thereof, and other services if available

Reranking of the sources with temporal information



Lightcurve obtained from the Fink broker

Example of sources to consider

Active Galactic Nuclei
Mostly interest in gamma-ray and optical temporal information

Radio profile also important as we can have radio-silent or radio-loud AGN that are potential sources

Tidal disruption events
Neutrino happening more than 100 days after the tidal disruption flare $\rightarrow$ classification should be done at the time of neutrino observation

LSST (Rubin) should give us lots of opportunity to watch those events

Selection mix with neutrino and astrophysical properties

Content of the GCN Notice
Usual properties of neutrinos, and specific "astro contents" part containing results of the spatial and time crossmatch

Selection based on astro content
One of the issues with pure neutrino selection is that the selection is biased depending on which estimators are used

By considering astrophysical properties to select the few neutrinos per month, some neutrinos that would not have passed the energy threshold but are nonetheless interesting can be selected

Having interesting sources to observe also maximizes the chances of having follow-up observations

Summary

KM3NeT alert system
KM3NeT will be able to provide public alerts with a rate of few per month, with a processing time of less than 1 minute
First public alerts planned for Spring 2023

Two parallel selection
To maximize scientific interest, two selection methods will be used: a pure neutrino selection and a selection based on the neutrino properties and the properties of the potential astrophysical sources