

# Real-time correlation analysis with KM3NeT

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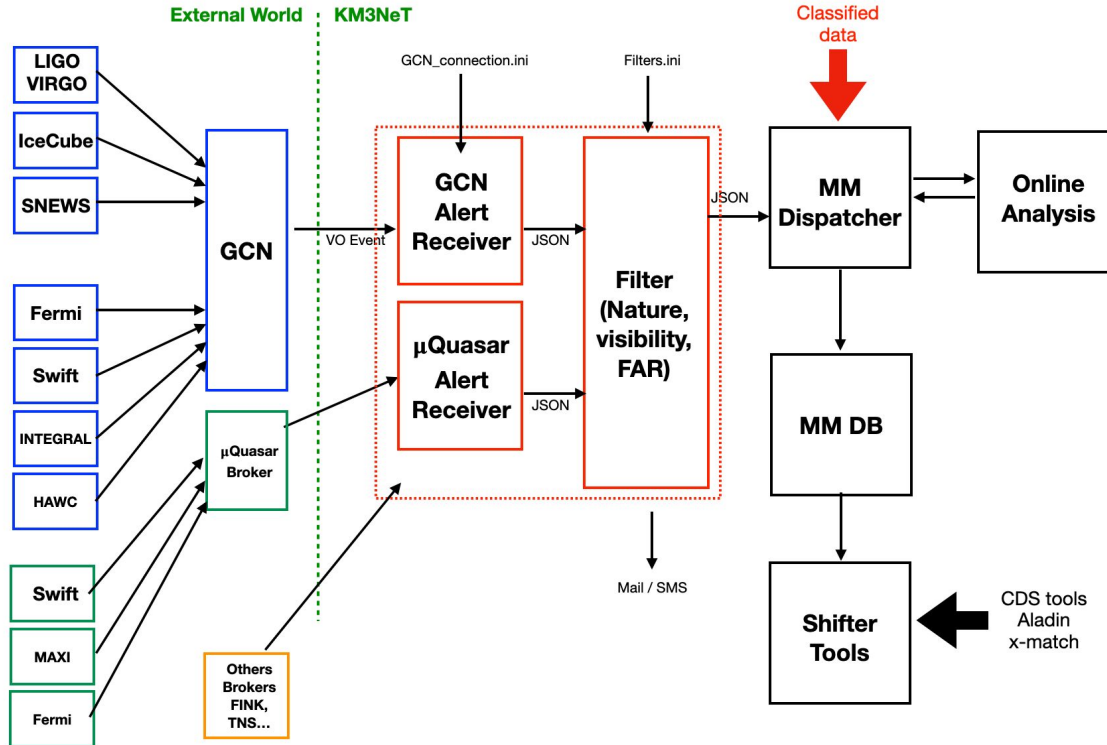


**KM3NeT**

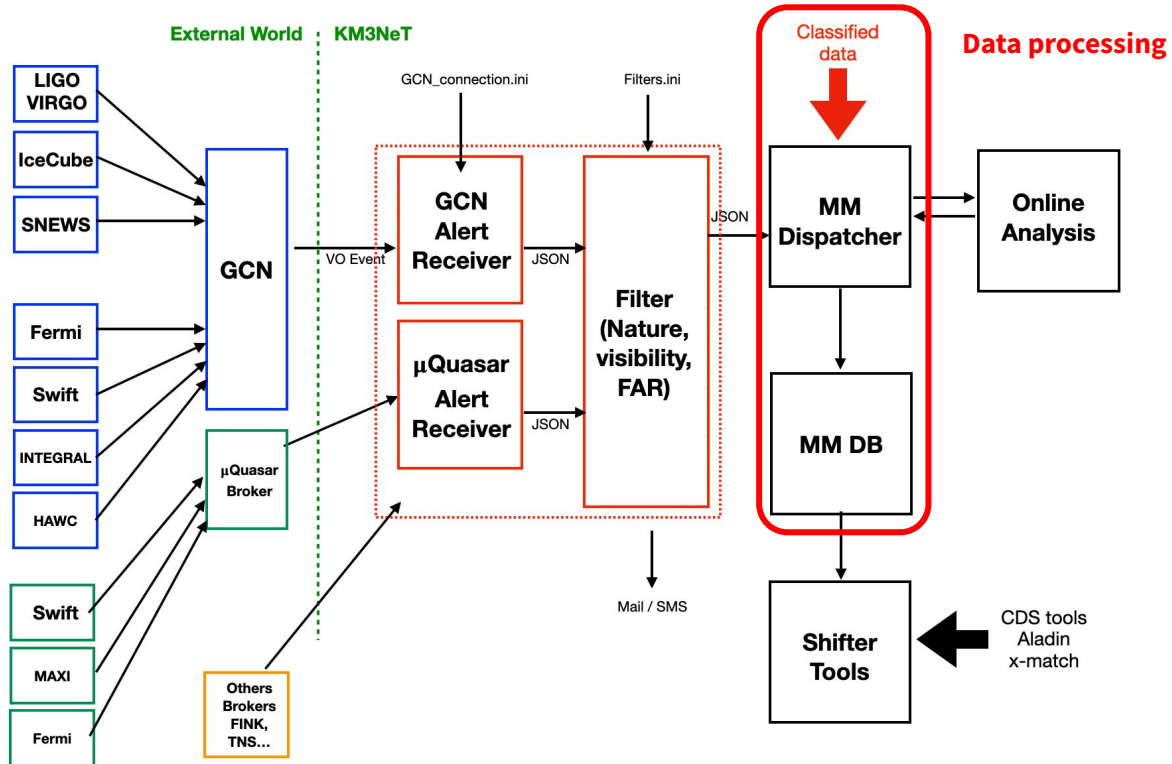
# Introduction

- **Goals:**
  - Find multi-messenger correlated signal
  - Perform neutrino follow-up search from external alerts
  - Send quick results back to the public
  
- **Status:**
  - Online automated analysis framework building in progress
  - Followed up alert to be ready to send 2nd quarter 2023

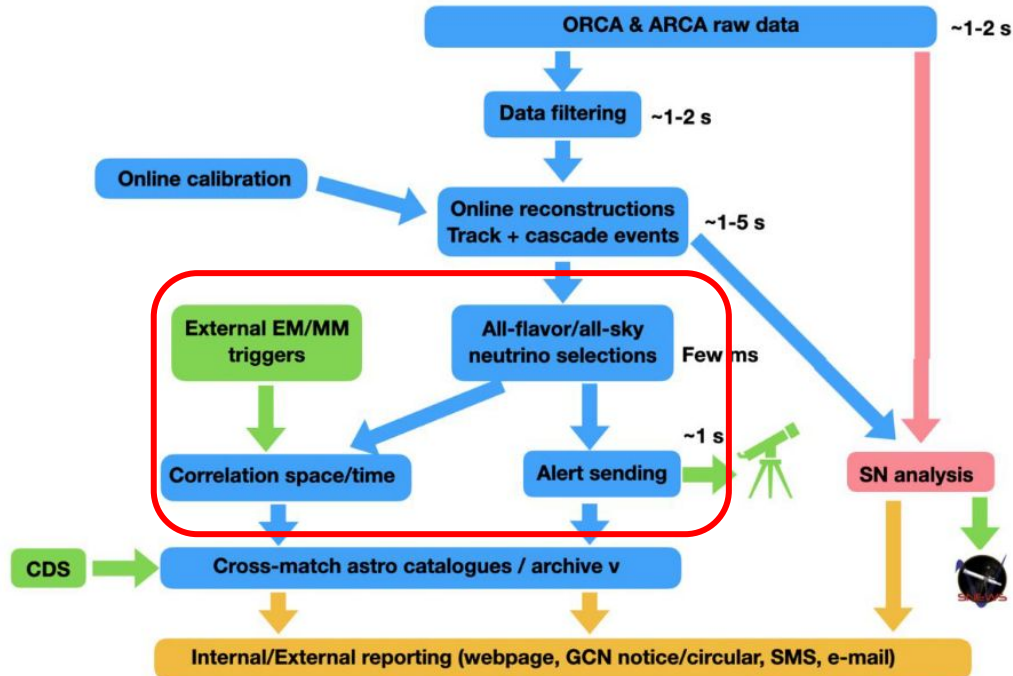
# Alert follow-up system overview



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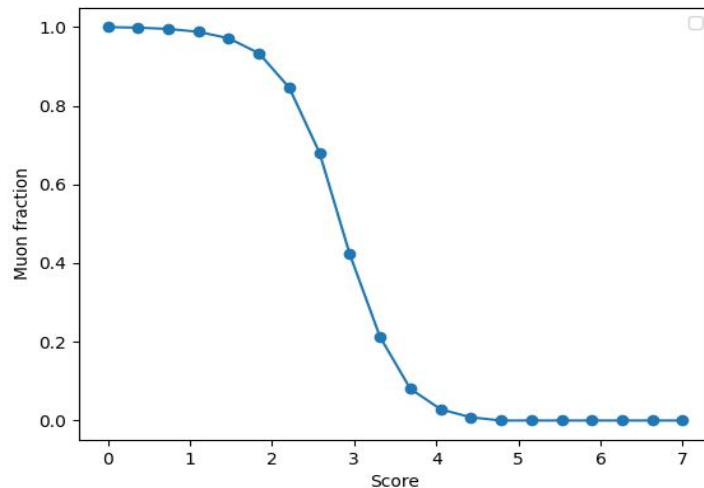


# Alert follow-up system overview



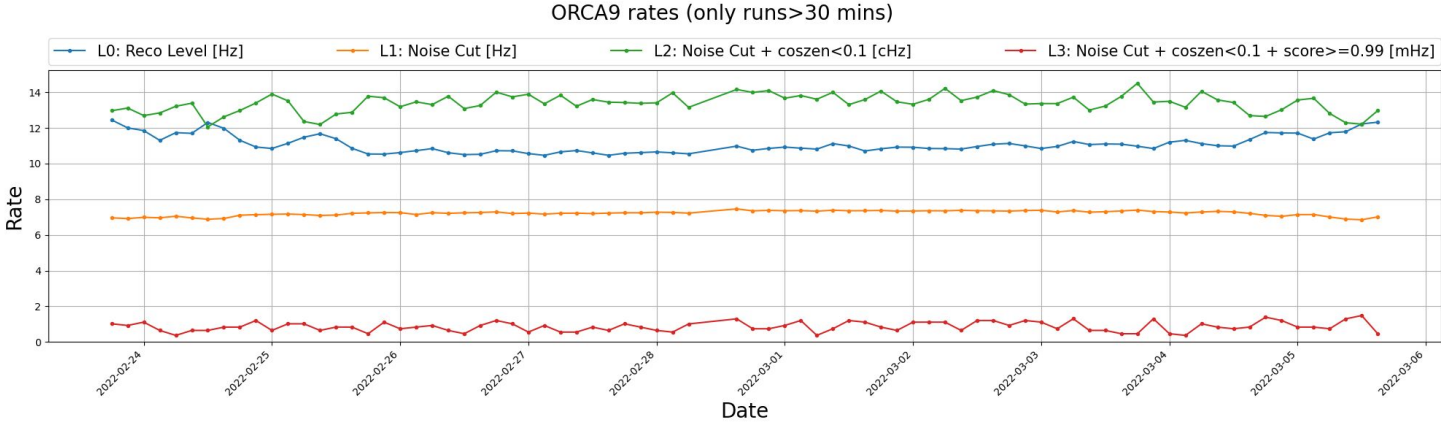
# Data processing and classification

- Event data coming independently from both detectors
- Event parameters reconstructed independently with track/shower algorithms
  - Tracks : 0.3 s/event
  - Showers : 1 s/event
- Event classification:
  - In ORCA: Boosted Decision Tree (XGBoost) to separate muons from neutrinos and showers from tracks
  - In ARCA: Simple cuts (for now)
  - After reconstruction, the classification is done in a few ms
  - Graph Neural Network classifier from low-level data in development

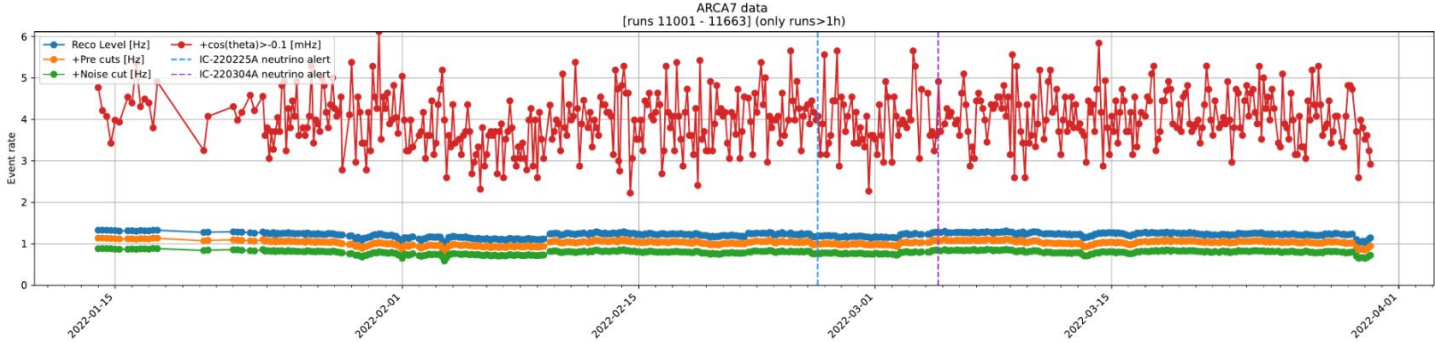


Muons/Neutrinos BDT classifier score

# Data processing - event rates



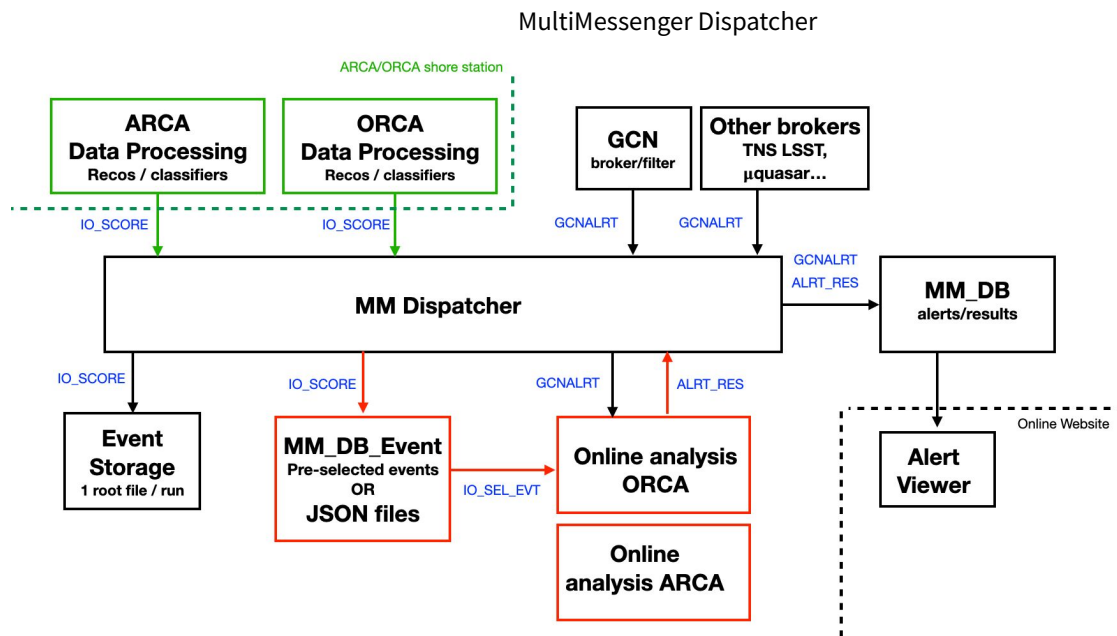
Event rates at different levels for ORCA9 and ARCA7



# System

Local server to centralize transit and save:

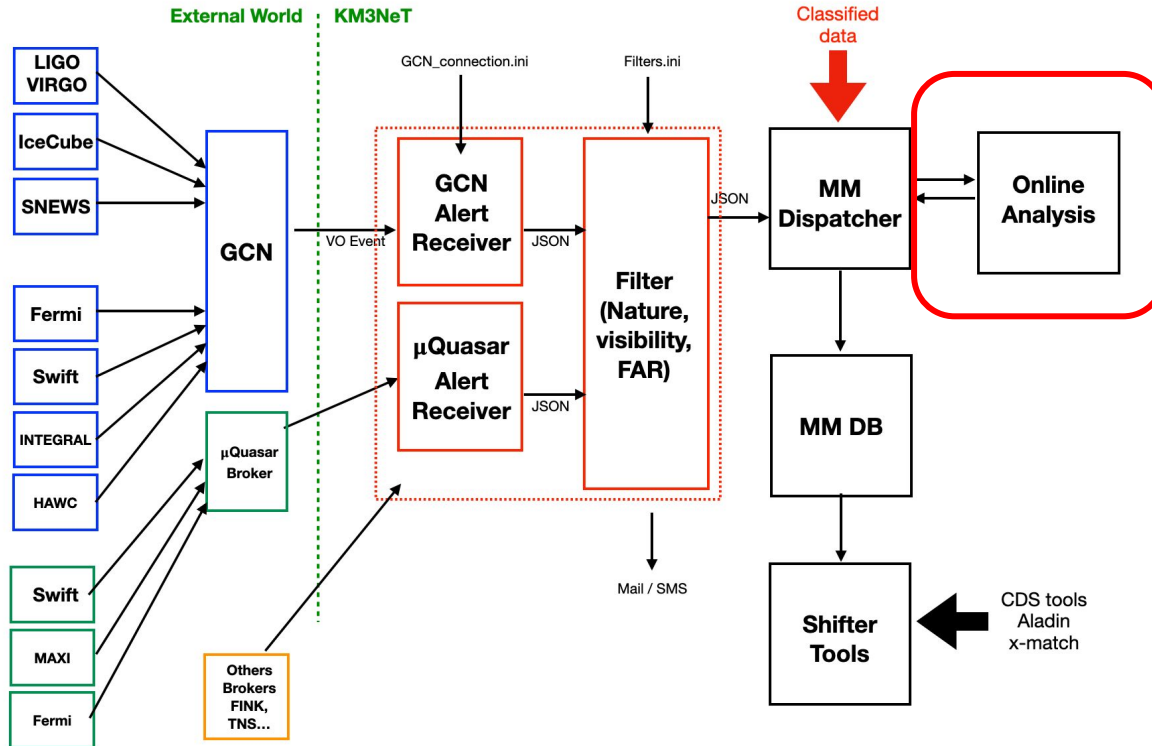
- Events informations
  - Incoming alerts
  - Follow-up results
- 
- Message brokers:
    - Open-source RabbitMQ system
    - Internal tools



⇒ Data stored in database, can be filtered and accessed quickly



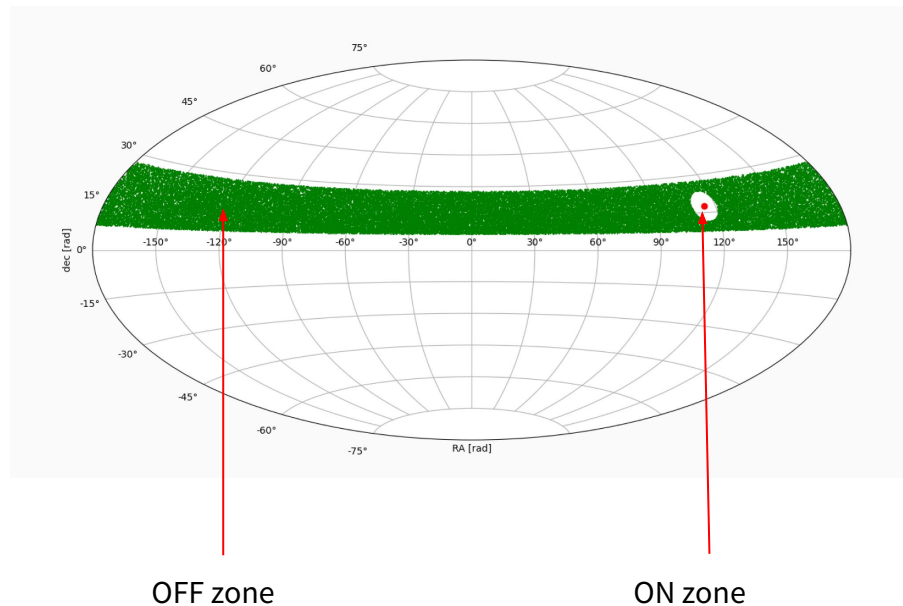
# Alert follow-up system overview



# Analysis method

- Signal search in a ROI around the source
- Binned analysis with an ON/OFF method
- OFF region to evaluate the background rate in the ROI
- Regions definition:
  - ON : Cone around the source
  - OFF: Declination band around the source's declination
- Event selection
  - Optimisation: Model Rejection Factor, Model Discovery Potential
  - Parameters:
    - Angle from the source (ON region size)
    - Neutrino purity: simple cuts, BDT score
- Time window:  $\pm 24$ h around the alert
  - Analysis starts at alert reception and is updated for 24 hours

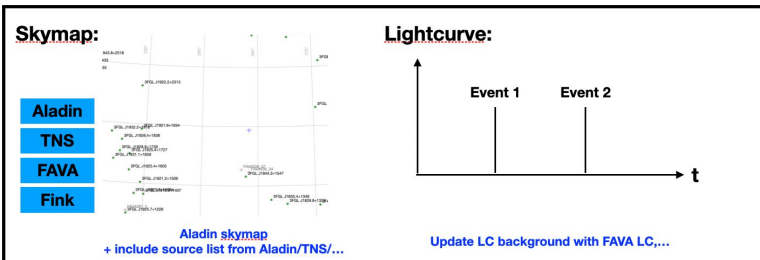
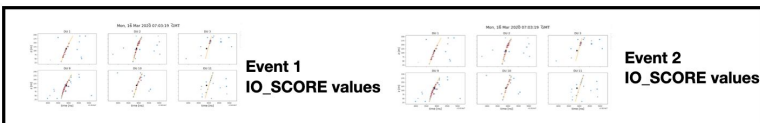
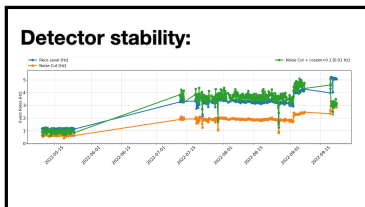
⇒ Analysis performed “offline” on multiple IceCube Alerts associated with blazars



# Analysis Output

**Results:**

$N_S$ :	2
$N_B$ :	1.04
$\mu_B$ :	1.5
P-value :	0.23
U.L. (90% C.L.):	0.12 GeV/cm <sup>2</sup>



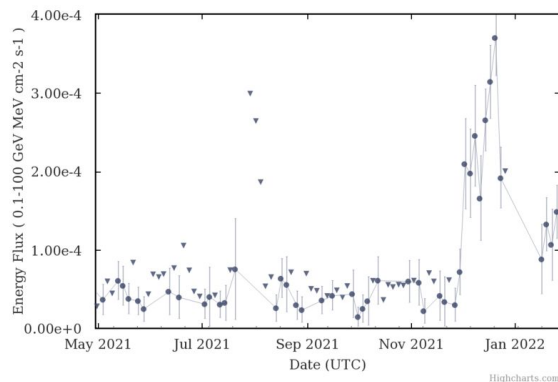
<b>TAG:</b>	"ALRT_RES"
Notice_Name:	"AMON_ICECUBE_CASCADE"
ID_Event:	13700722247606
Date_Event:	"2022-09-09T17:10:30.00"
Detector:	"ORCA"
Pipeline:	"ORCA_BinnedAnalysis"
Iteration:	0
Date_Analysis:	"2022-09-09T20:10:30.00"
nON:	0
nOFF:	13
Expected_Background:	0.11
▼ Additional_Info:	
Stability:	"/data/online_output/refreshed_events/rates.png"
Time_Profile:	" "
▼ Skymap:	"/data/users/lestum/orca_analysis/plots/AMON_ICECUBE_CASCADE_13700722247606_skymap.png"
IOSCORE_Stream:	" "
▼ Event_Display:	"/data/online_output/refreshed_events/3d/latest_neutrino_candidate.js"

⇒ Relevant informations summarized in a report

# Analysis performed 'offline' on IceCube alert associated with blazars

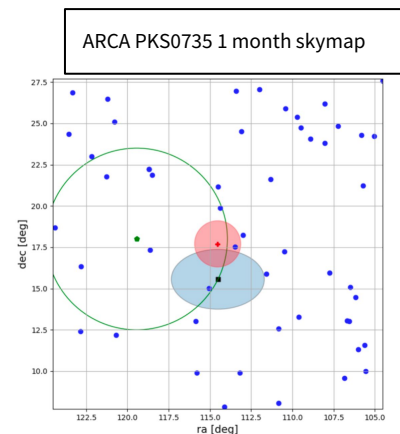
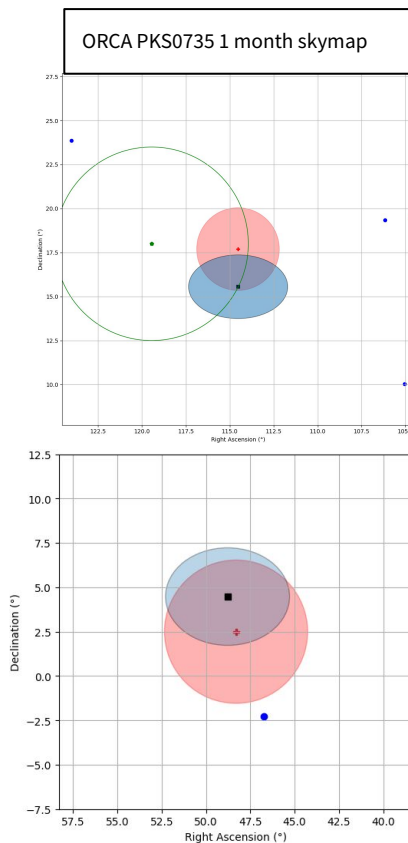
Sources followed up offline with same method as online

- TXS0310 (IC220304A-GOLD)
- PKS0215 (IC220225A-BRONZE)
- PKS1741 (IC220205B-GOLD)
- PKS0735 (IC211208A-BRONZE, GVD211208A, Baksan)
  - Additional 1 month time window motivated by a FERMI flare



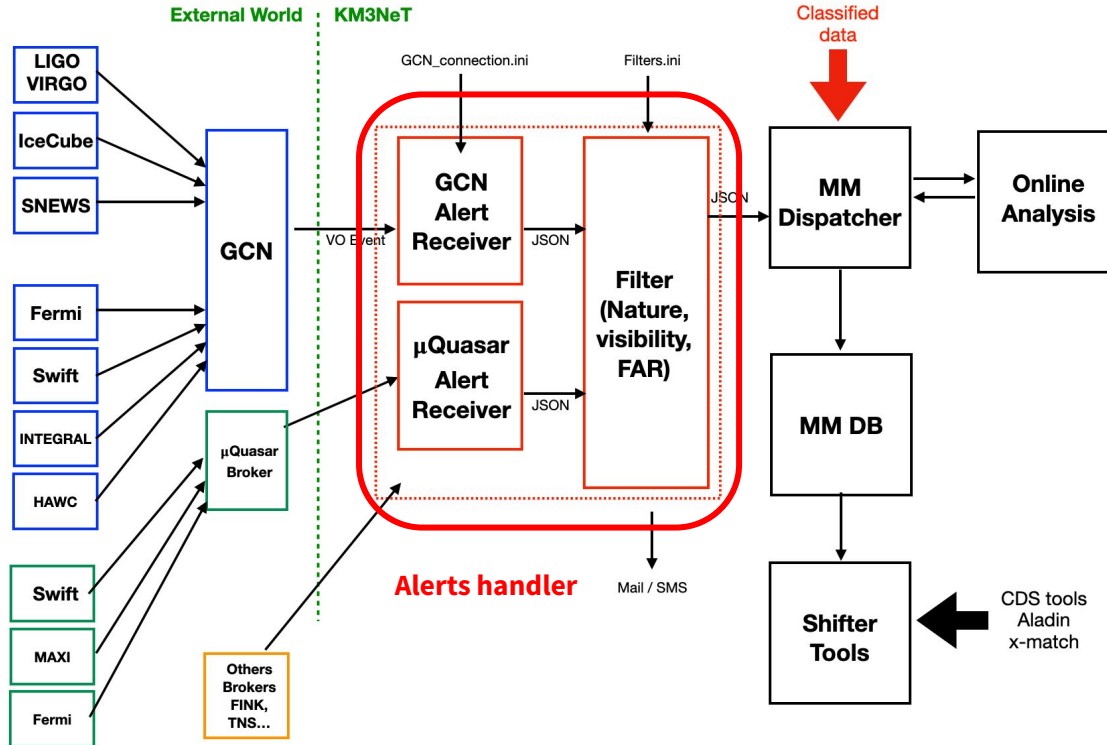
## Results:

- 1 associated neutrino candidate with PKS0735 in the 1 month time window, p-value = 0.14
- No association for the other blazars
- Reported in [ATel#15290](#)



ORCA TXS0310 2 day skymap

# Alert follow-up system overview



# GCN follow-up

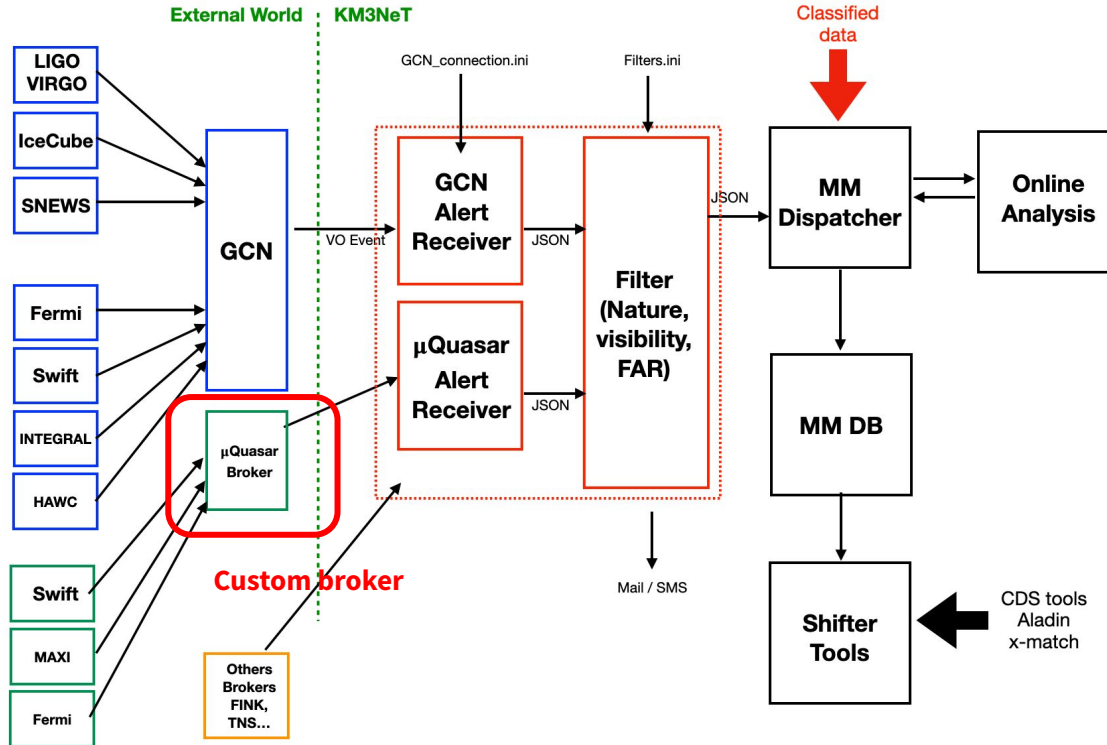
- From public GCN notices:
  - General use in the transient community
  - Multiple sources and event types (GRB, GW, Neutrino events, X-Ray telescopes...)
  - Volume of alerts to increase in the coming years

⇒ Build GCN notices filtering tool:

- Delay between notice and event ⇒ 5 minutes for GRBs
  - Source elevation (Observability) ⇒ Source below horizon
  - Relevance probability
  - FAR
- 
- Alert handler from other brokers to be implemented to follow-up on more channels/phenomena
    - FINK (ZTF/LSST) - Optical
    - TNS - SN/FRB



# Alert follow-up system overview



# Dedicated sources multiwavelength monitoring: Microquasar broker

- Goals:
  - Multiwavelength monitoring of a list of known sources
  - Have an broker **independent** from GCN or ATels reported by other collaborations
  - Potentially trigger joined analysis between HESS and KM3NeT

- From a list of microquasar sources
  - Microquasars: X-Ray binaries with accretion-ejection (jets) phenomena
  - Transient sources with flare periods and spectra state transitions
- Continuous MWL monitoring
- Neutrino search follow-up during flares



V4641 Sgr
XTEJ1550-564
GRO J1655-40
GRS 1915+105
GX339-4
H1743-322
IGRJ17091-3624
V404 Cyg
MAXI J1535-571
MAXI J1348-630
MAXI J1820+070
GRS1716-249
4U1630-472



# Microquasar X-Ray flares detection

⇒ Monitoring new flares from a list of sources

- From publicly available SWIFT/BAT and MAXI lightcurves
- Evaluate signal baseline in a 6 month window before current date
- Check if the most recent flux data point verifies:

$$F - \delta F > \mu_{BL} + N\sigma_{BL}$$

Flux, error

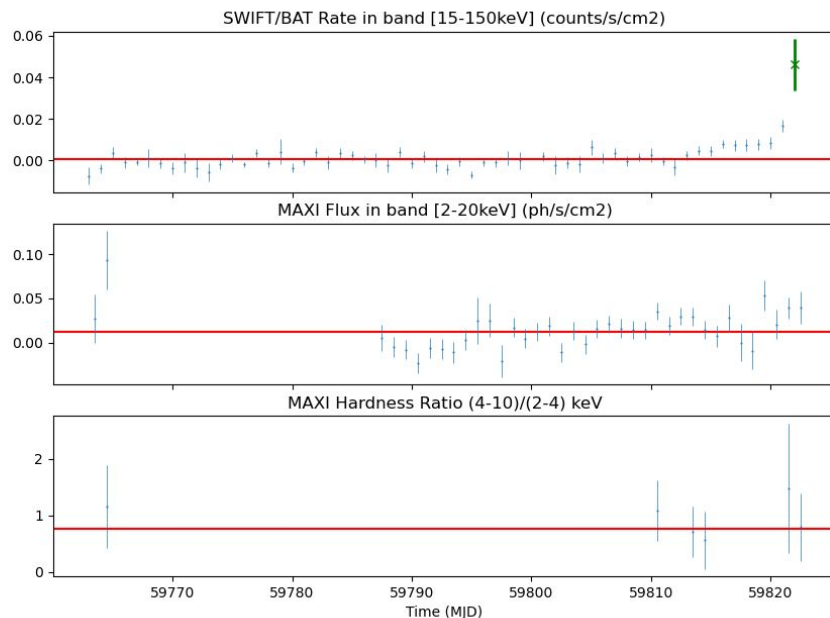
Baseline mean

Baseline Std. Dev

- And if hardness ratio (between 2 energy bands):

$$|H \mp \delta H| > |\mu_{BL} \pm N\sigma_{BL}|$$

(State transition)



GX339-4 recent flare (reported in ATel#15578)

Baseline is shown in red, alert sent from green data point

# Microquasar flares detection

If an flare is detected, send alert as a VOEvent through a COMET server

⇒ Follow-up with FERMI/LAT Analysis (HE gamma)

- Binned Likelihood Analysis
- Search for new, uncatalogued, source at the alert position
- Time window: 24h before alert time up to last available data

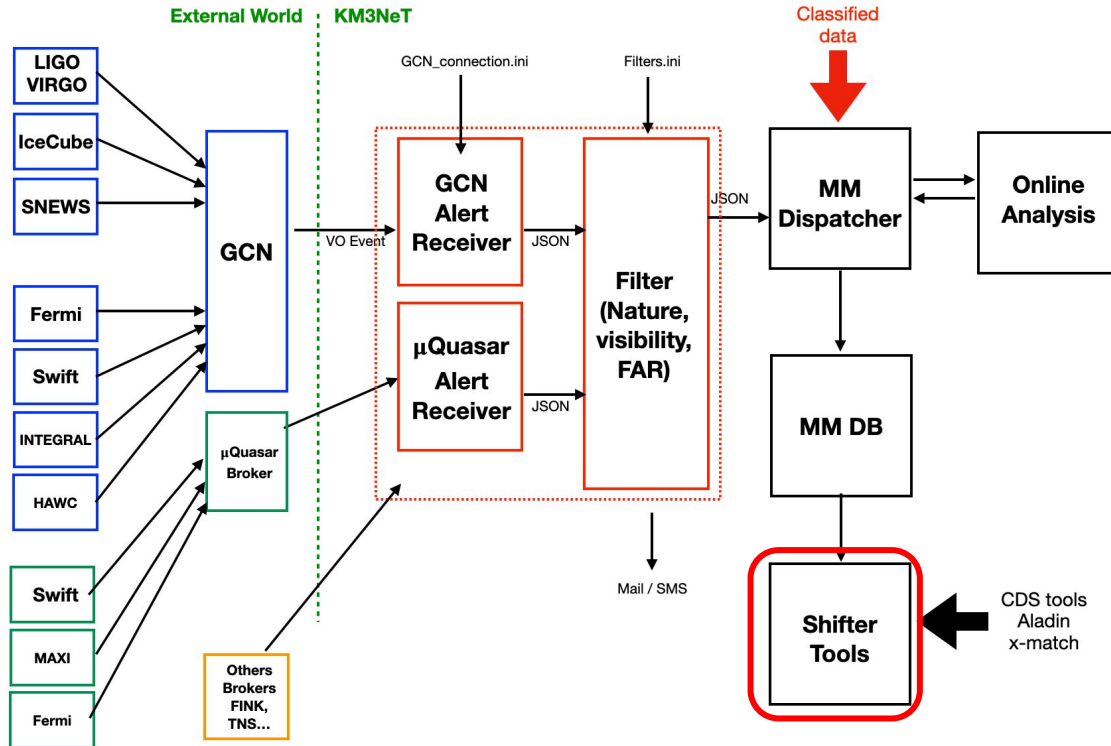
Alert levels:

- Level 1: X-Ray flux increase OR hardness ratio transition
- Level 2: X-Ray flux increase AND hardness ratio transition
- Level 3: FERMI HE gamma signal

⇒ KM3NeT follow-up analysis

- Time window: +/- 1 day around alert time (TBD with alert level)

# Alert follow-up system overview



# Shifter capabilities

- **Shifters on-call for incoming alerts**
- Monitoring of automated follow-up results
- Dedicated website built to facilitate the task for non-experts
- Analysis can be launched manually through a web interface
- Manual alert reporting back to the public through GCN or ATels

⇒ Trial shifts to start in the next few weeks  
⇒ Shifters will check for results reliability during commissioning

The screenshot shows the 'KM3NeT Shifter Tools home page' interface. At the top, there is a navigation bar with the title 'KM3NeT Shifter Tools' and several dropdown menus: 'ORCA', 'ARCA', 'MM', 'CCSN', 'Alerts', and 'Tools'. The user's name 'Sebastien LeStum' is visible in the top right corner. Below the navigation bar is a large blue header with the text 'KM3NeT Shifter Tools home page'. A green status bar indicates 'Status: all services are up' with a timestamp 'Wed Sep 21 2022 12:24:46 GMT-0200 (heure d'été d'Europe centrale)'. The main content area is a grid of buttons for various monitoring and reporting tools, including 'ORCA high-level monitoring', 'ORCA RTA dashboard', 'ARCA high-level monitoring', 'ARCA RTA dashboard', 'MM dashboard', 'CCSN monitoring', 'External triggers', 'KM3NeT alerts', 'Manual search', 'Elog', 'Rocket chat', 'GCN writer', 'Current shift report', 'All shift reports', and 'Shifters calendar'.

Shifter interface

# Future prospects

- Follow-up System fully operational spring 2023
- Alert responses sending
- Multiple dedicated analyses will run in parallel:
  - Short-timed  $\Rightarrow$  GRBs
  - Extended regions  $\Rightarrow$  Gravitational Waves, next run (O4)
- Bigger detectors  $\Rightarrow$  better selection/better performances

**Thank you for your attention!**