Multi-messenger real-time analysis framework of the KM3NeT neutrino telescope

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On behalf the KM3NeT Collaboration

Groningen — 2019/03/28

Context

Open questions:

- Origin of high-energy cosmic rays: which sources? What acceleration mechanisms? Which source evolutions? (mysteries of UHECR ?)
- Origin of IceCube HE astrophysical neutrinos
- Disentangle astrophysical models with multi-messenger observations
- Study of galactic (and extra galactic) propagation of CR with neutrinos as tracers
- Test the neutrino sector of the SM and BSM physics

So far, GW170817, IC170922, ANT150901, etc have demonstrated the capabilities of doing real-time multi-messenger follow-ups:

- Most of the HE sources are time-dependent with the flux quickly varying

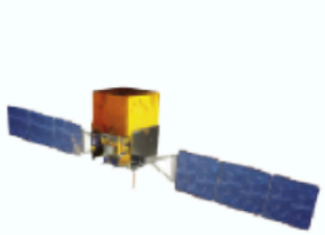
- Provide accurate positions (required for redshift, host measurements)

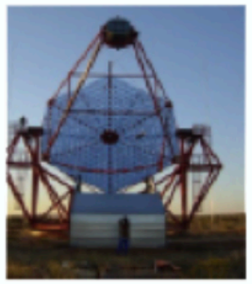
- Maximize the scientific return of this event having a larger and more complete follow-up.

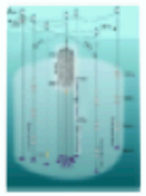
- Achieve simultaneous observations of transient phenomena by pointing instruments (so important for the modelisation)

- Determine the nature of a single event

Multi-messenger analysis



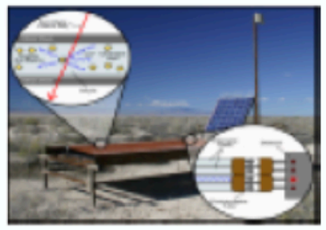




neutrinos
IceCube, GVD, SNEWS

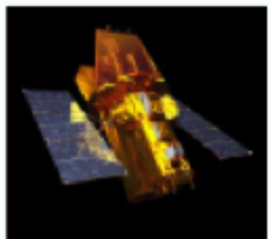
GeV-TeV γ-rays
Fermi, HESS, HAWC, CTA

UHECR
Auger, TA



only spatial coincidence

ANTARES



Receive alerts
Generate alerts

Radio/Optic /X-ray
TAROT, MASTER, Swift, INTEGRAL, MWA

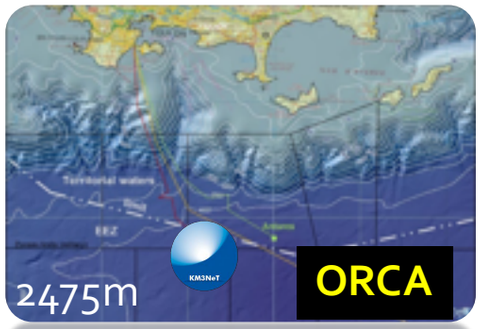
Gravitational Waves
VIRGO, LIGO

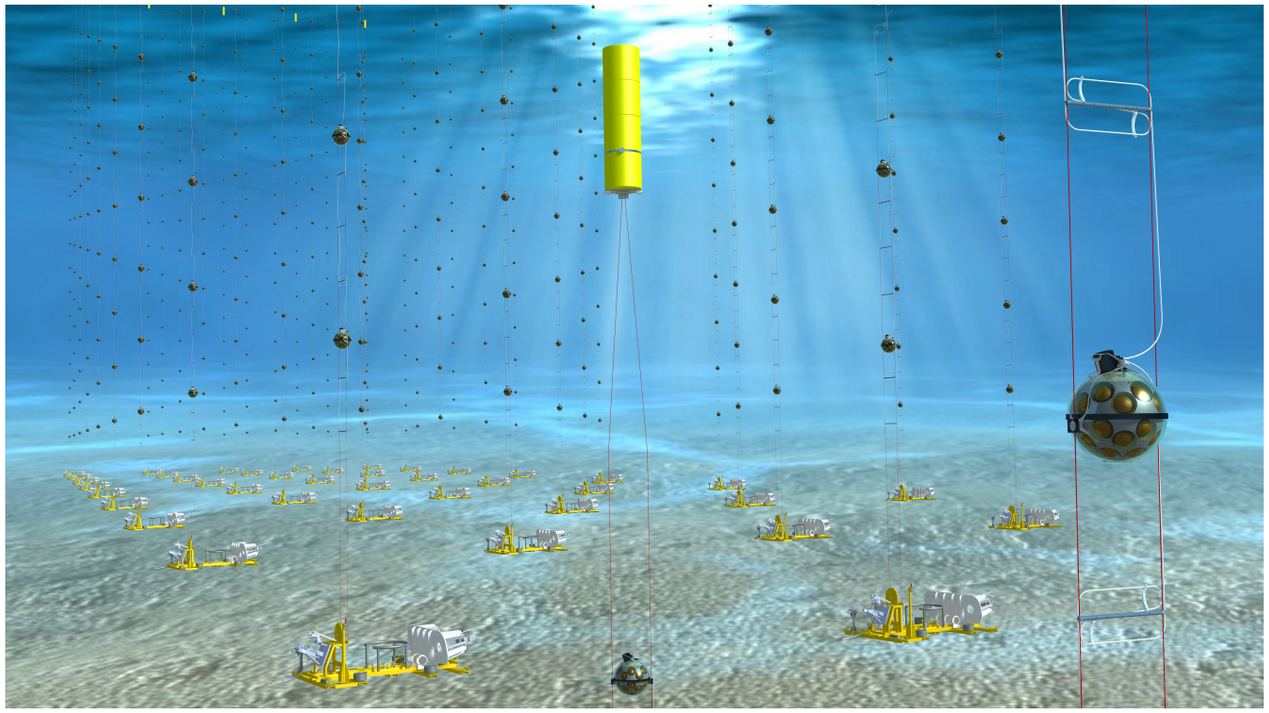
KM3NeT

KM3NeT is the neutrino research infrastructure in the deep Mediterranean Sea

Oscillation **R**esearch with **C**osmics In the **A**byss

ORCA: off shore Toulon, France





Astroparticle **R**esearch with **C**osmics In the **A**byss

ARCA: off shore Capo Passero, Italy

Main characteristics:

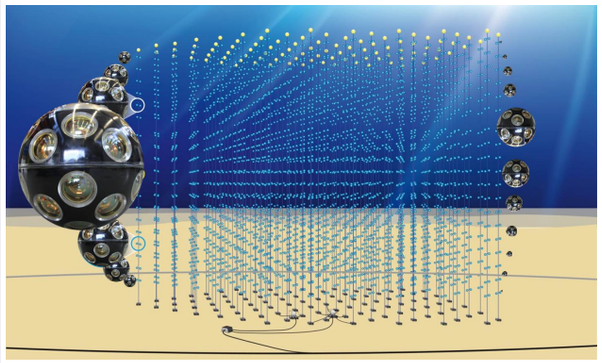
- Extended energy range: 3 GeV → 10 PeV (+ 10-40 MeV)
- Full sky coverage with the best sensitivity for the galactic sources
- High duty cycle (> 90-95%)
- All-flavour neutrino detection
- Good angular resolutions

$\Longrightarrow$ Construction on-going: 1 DU working in ARCA & ORCA + 5 DUs ready for deployment in ORCA (+300 DOMs builded)

$\Longrightarrow$ Mid 2020, better sensitivities than ANTARES in the whole energy range.

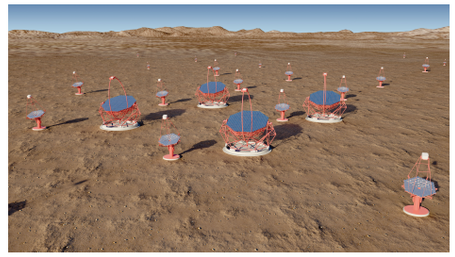
KM3NeT multi-messenger analyses

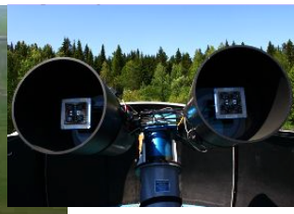
KM3NeT

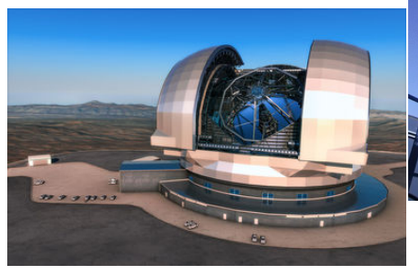


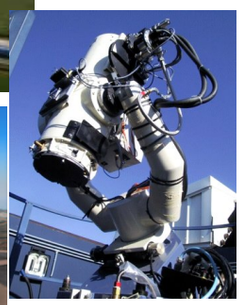
- **Follow-up of neutrino alerts**
- **Joint sub-threshold analysis**

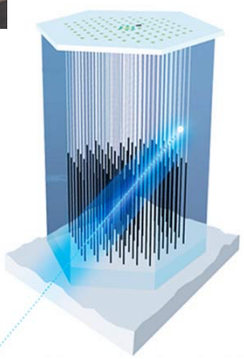
EM/MM external communities



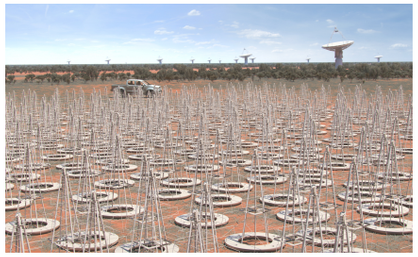


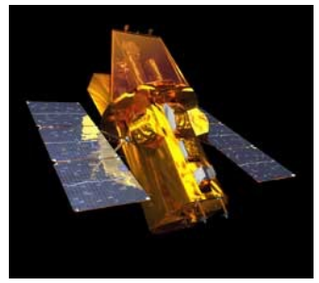






- **Follow-up of EM/GW alerts**
- **Offline time/space correlation search with catalogues (GRB, AGN, XRB, SN, FRB…)**





- **ARCA dedicated to neutrino astronomy:**

  $\Longrightarrow$ Tracks (100 TeV - 10 PeV) with the excellent angular resolution (<0.2º)

  $\Longrightarrow$ Cascades (100 TeV - 10 PeV) thanks to the good angular resolution (1-2º) taking the advantage of the low atmospheric background contribution

- **ORCA can do also astronomy:**

  $\Longrightarrow$ Tracks & cascades at low energy (few GeV - 10 TeV), looking for time/space clusters

  $\Longrightarrow$ Example sources: winds of binaries, chocked GRBs, hidden jets in core-collapse SN

- **ORCA & ARCA:** detection of MeV neutrinos from core-collapse SN

ANTARES online framework

ANTARES Shore Station:
O-line reconstruction
Trigger decision
Alert message (GCN format)
Online follow-up of external triggers

EM transients (GRB, FRB, blazar flare, ccSN, etc)
IceCube neutrinos
GW events from LVC

ANTARES
Neutrino Telescope

Real time

Low latency alerts (<10 sec)

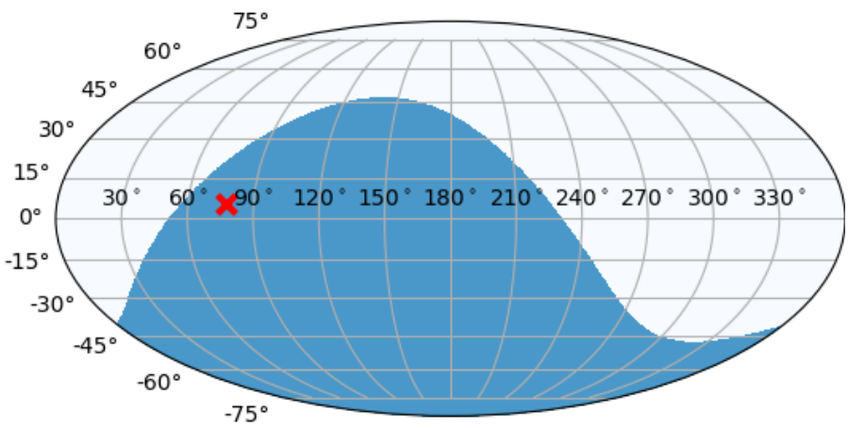
- 292 alerts sent to robotic telescopes [84 DIR + 208 HE]
- 17 sent to Swift
- 15 sent to Integral (3 followed)
- ~20 to MWA (4 followed)
- 2 to HESS

Examples of online ANTARES analyses

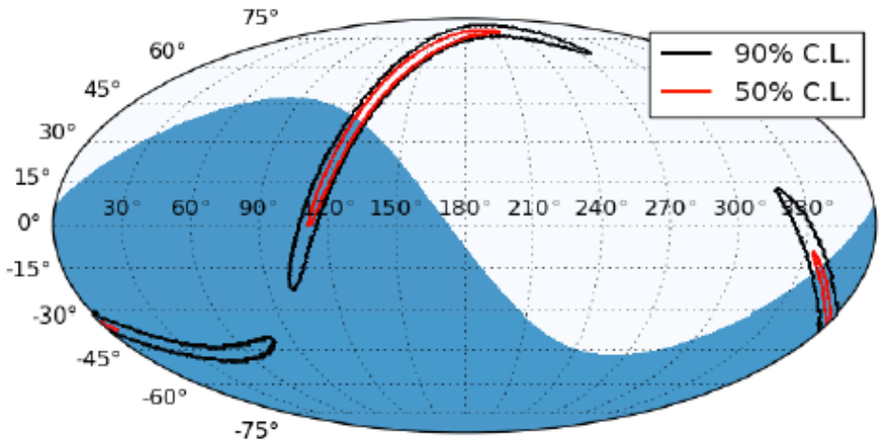
Follow-up of EM/MM triggers: IceCube, LVC + GRBs, FRBs

(±500 s & ±1 h)

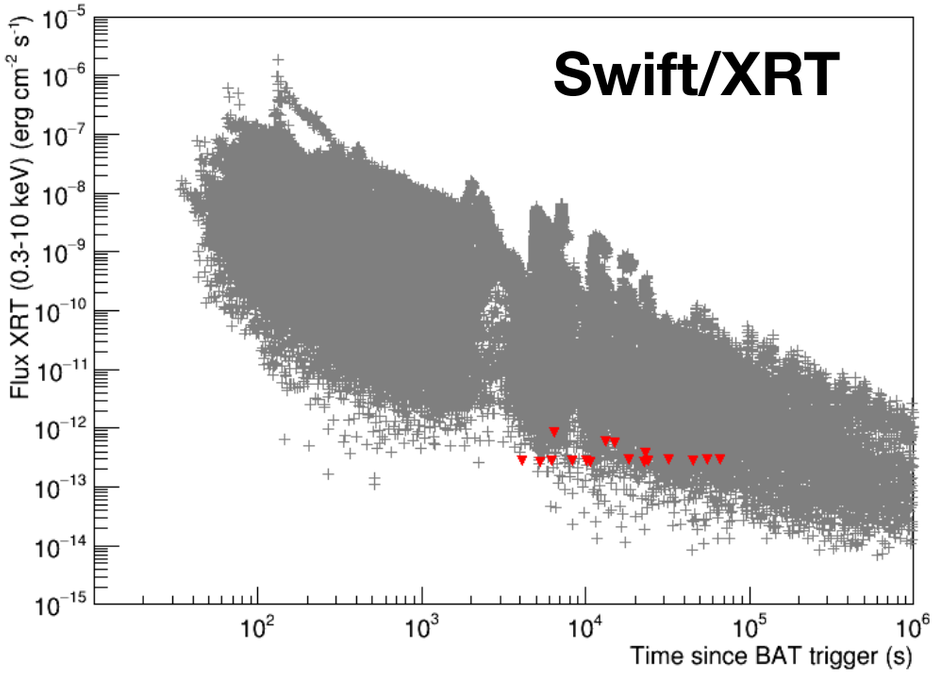
IC170922

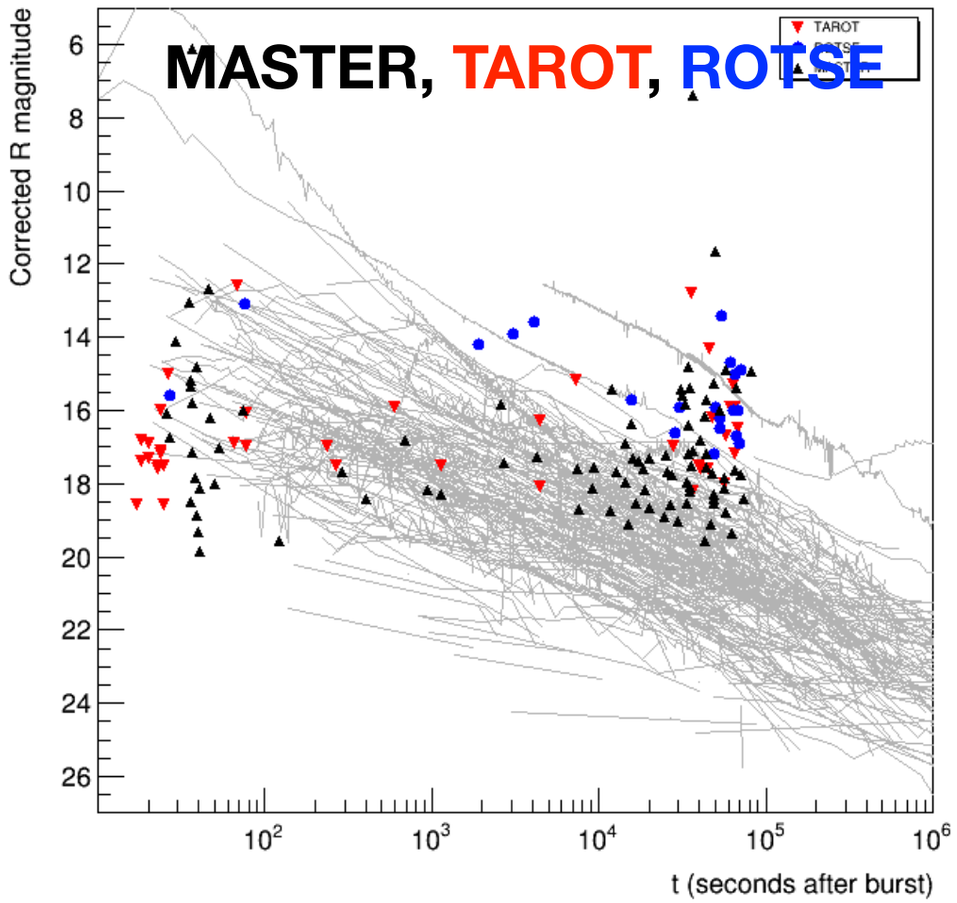


GW170104

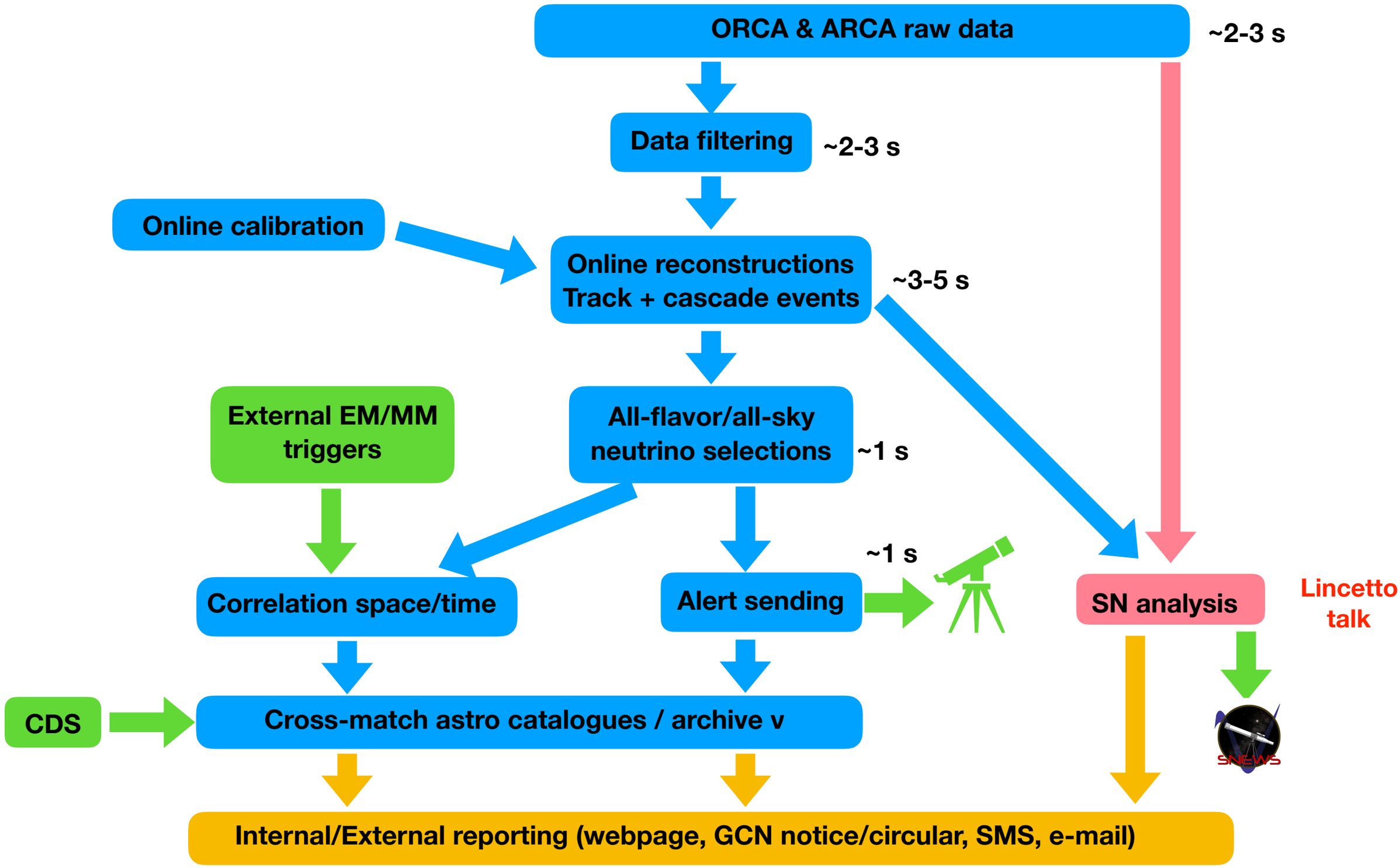


Follow-up of ANTARES alerts



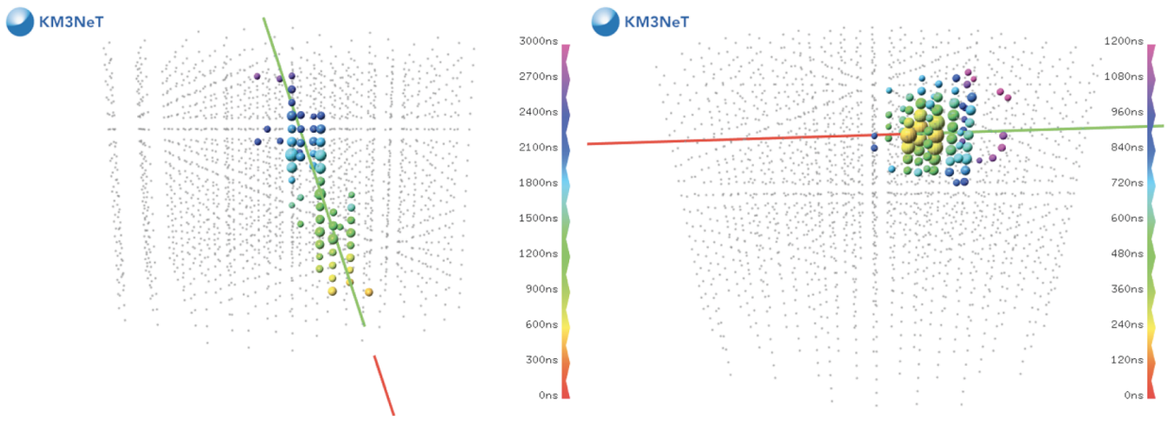


KM3NeT real-time framework



Online event reconstructions

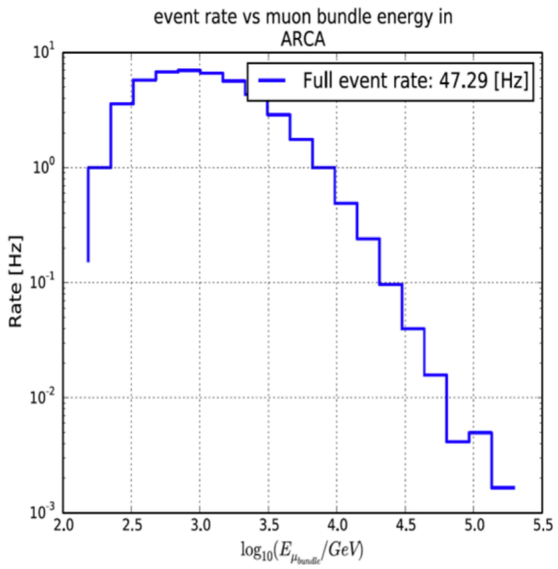
*** All-flavor (track+cascade) event reconstructions: same framework and the same reconstruction tools as in offline**

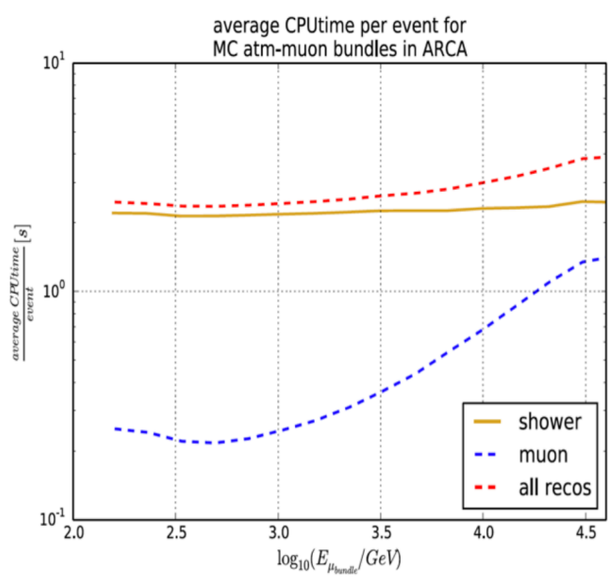


Tracks:
ARCA: < 0.2º (>10 TeV)
ORCA: 1 - 2º (100 GeV - 1 TeV)

Cascades:
ARCA: 1.5 - 2º (>10 TeV)
ORCA: ~4 - 5º (100 GeV - 1 TeV)

*** Time to reconstruct all events: Trigger rate: ~100 Hz ⟹ Neutrino rate: 1-2 mHz**





SHOWER;	
90TeV < E_ν < 110TeV	2.30 sec/event
900TeV < E_ν < 1100TeV	2.80 sec/event
TRACKS	
90TeV < E_ν < 110TeV	0.85 sec/event
900TeV < E_ν < 1100TeV	1.95 sec/event

⟹ Need 2 farms of 200 CPUs

Sending alert system

Alert sending policy:

➡ Typical alert rate: few per month

➡ Standard alerts will be distributed through private channel to observing teams upon MoU agreements like ANTARES.

➡ After a commissioning phase, notable events will trigger alerts that will be distributed publicly to the astro community [**Open Public Alert program**]

Alert distribution:

➡ Distribution via the GCN network

➡ Message: VO event (XML file)

➡ Only 2 brokers for public and private alerts for both KM3NeT detectors

Reporting:

➡ SMS/e-mail to alert KM3NeT shifters

➡ Automatic GCN notices in case of very interesting neutrino signals

➡ KM3NeT subgroup shifters (check detector stability, update reconstructions, etc)

➡ GCN circular sent for refined information or identified counterpart (+ retraction).

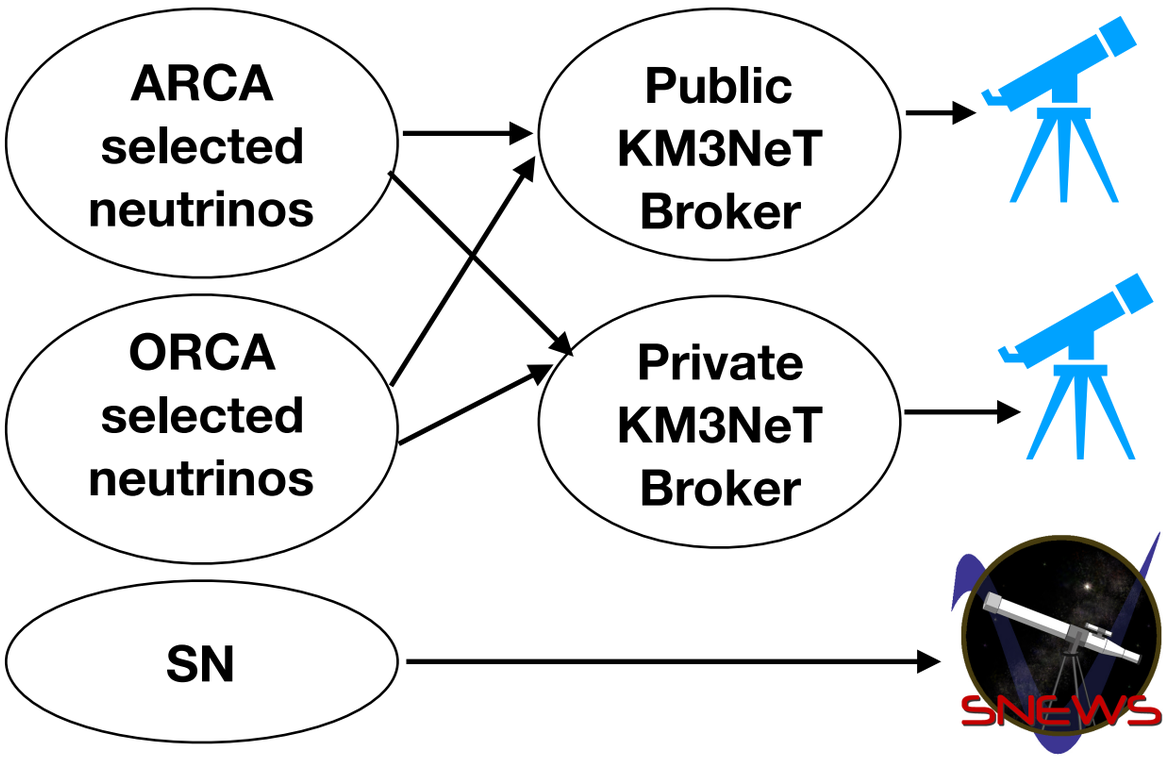
➡ Results displayed in public/internal webpages

KM3NeT neutrino alerts

ANTARES alert distributions:
* GCN socket: TAROT, ZADKO, MASTER, INTEGRAL
* VO Event: MWA, HESS, SVOM, AMON
* Mail: Swift

For ANTARES, neutrino information is private. Need MoU with external partners.

Alert Message: Only one real-time message
* ID
* Time,
* RA, DEC, error 50%
* Energy proxy
* Reconstruction quality
* probability neutrino
* Multiplicity, type of trigger



For KM3NeT: define a standard VO event:
* ID
* Detector (ORCA/ARCA)
* Time
* RA, DEC, error 50, 90%
* Energy estimate
* Reconstruction quality
* Probability neutrino
* Type of neutrino
* Multiplicity
* Type of trigger

+ develop one alert broker for ORCA & ARCA with different types of alerts

Summary

- **Despite its small size, ANTARES has performed plenty of multi-messenger analyses with more than 10 years of data, some really competitive with IceCube. Existing experiences for setting KM3NeT multi-messenger program.**

- **By observing astrophysical neutrinos with an unprecedented angular resolution, an extended energy range and a full sky coverage, KM3NeT will play a key role.**

- **The construction of ORCA and ARCA is on-going. First data looks good and first data analysed to validate the detector performance.**

  $\Longrightarrow$ Setting the data acquisition using standard tools (IVOA, ASTERICS, CDS) and prepare the multi-messenger analyses.