Multi-messenger real-time analysis framework of the KM3NeTneutrino telescope

D. Dornic

HAL Id: in2p3-02282916
https://hal.in2p3.fr/in2p3-02282916

Submitted on 19 Mar 2020

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

D. Dornic (CPPM/CNRS)

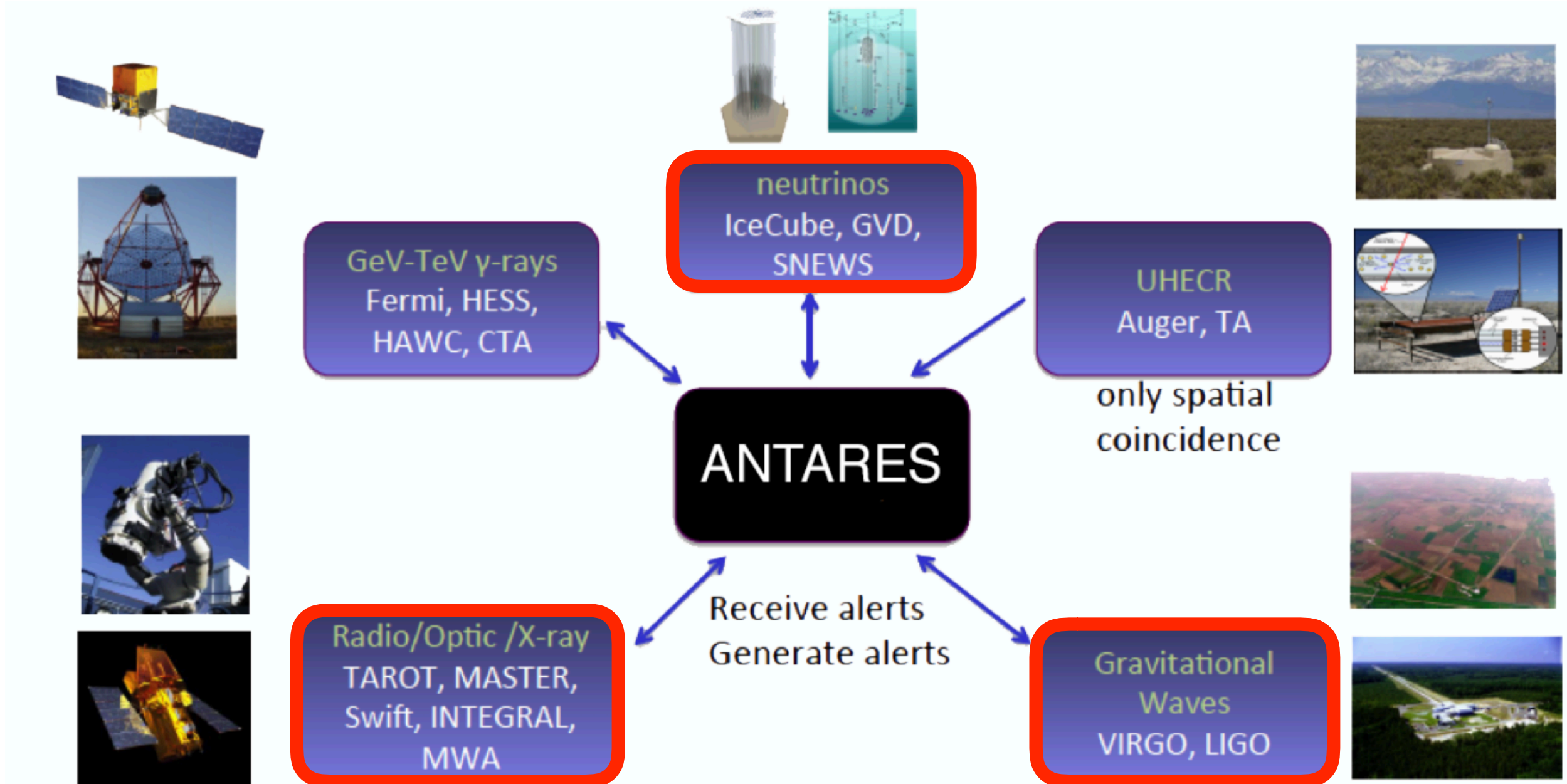On behalf the KM3NeT Collaboration

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

ANTARES

only spatial
coincidence

Receive alerts
Generate alerts

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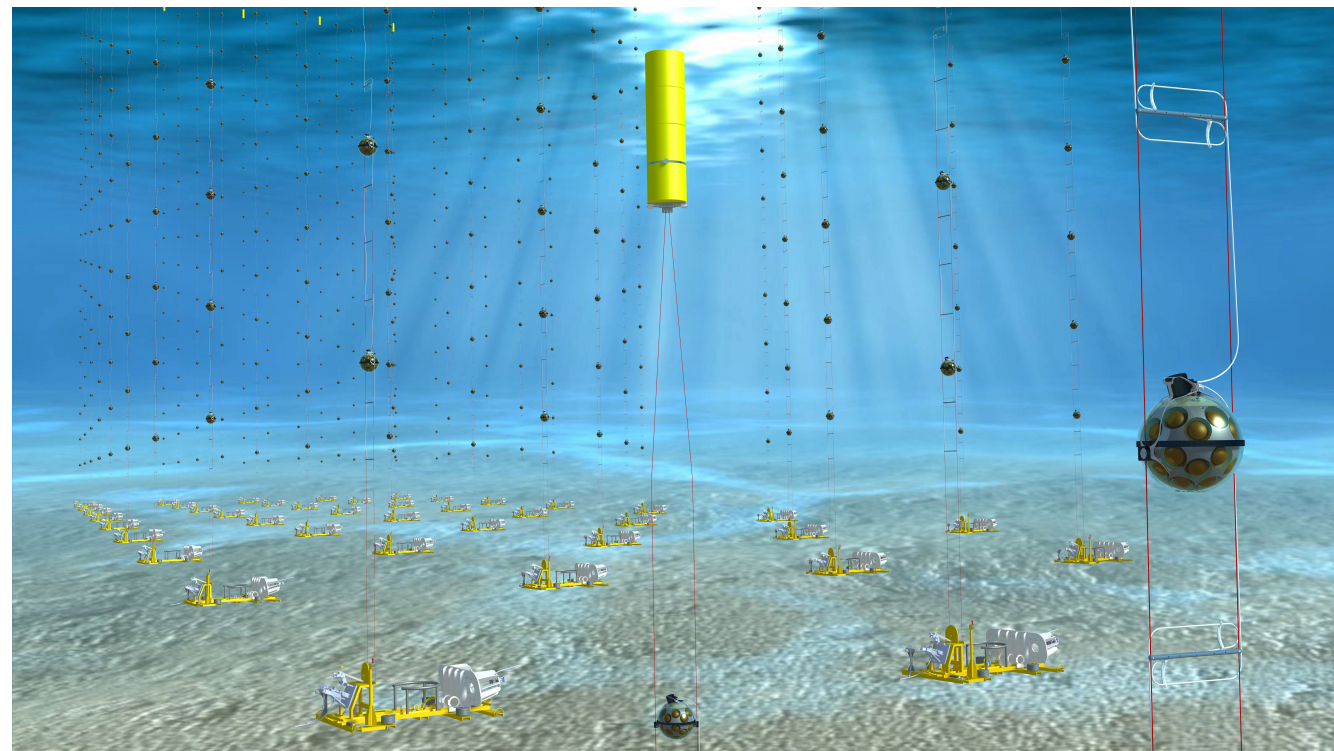MWA

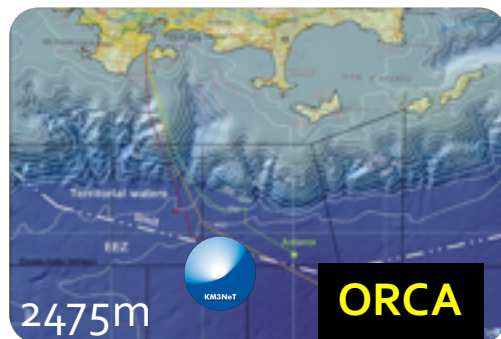Gravitational
Waves
VIRGO, LIGO

KM3NeT

3

KM3NeT

KM3NeT is the neutrino research infrastructure in the deep Mediterranean Sea
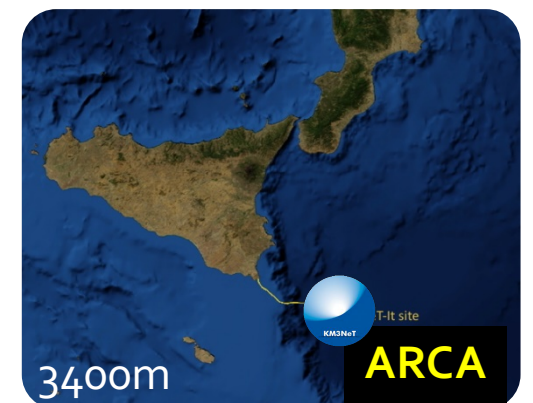

Oscillation
Research
with Cosmics
In the Abyss

ORCA: off shore
Toulon, France

Astroparticle
Research
with Cosmics
In the Abyss

ARCA: off shore
Capo Passero, Italy

2475m ORCA

3400m ARCA

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%)
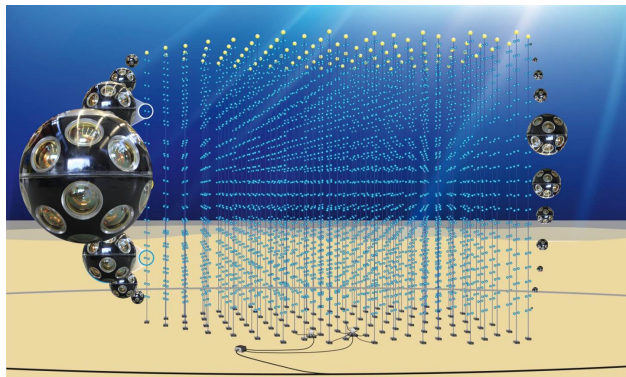- All-flavour neutrino detection
- Good angular resolutions

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

⟹ Mid 2020, better sensitivities than ANTARES in the whole energy range.
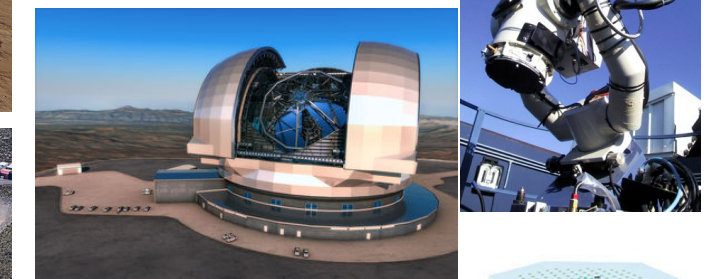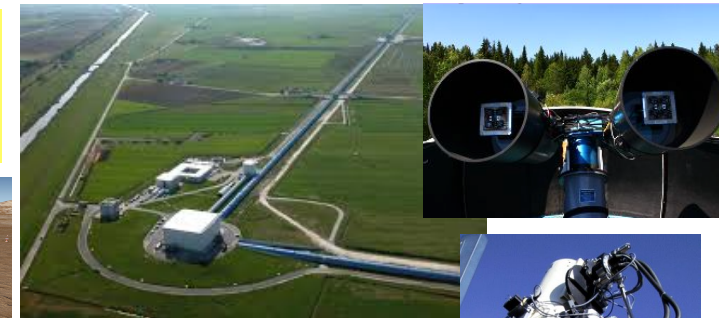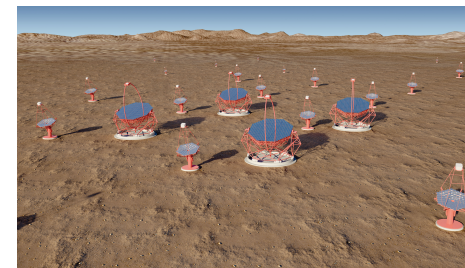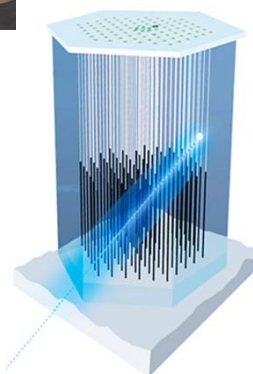
KM3NeT multi-messenger analyses
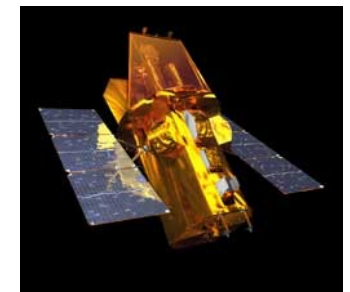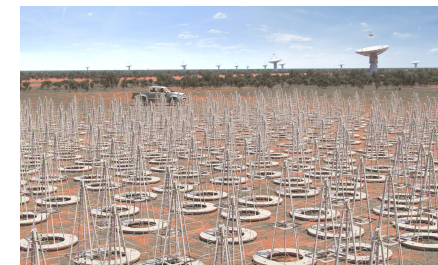
- **ARCA dedicated to neutrino astronomy:**

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

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

- **ORCA can do also astronomy:**

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

  $\implies$ 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

ν

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

SWIFT INTEGRAL

HAWC

TAROT

HESS

MWA

MASTER

SVOM
GWAC

ZADKO

ROTSE

6

Examples of online ANTARES analyses

Follow-up of EM/MM triggers: IceCube, LVC + GRBs, FRBs
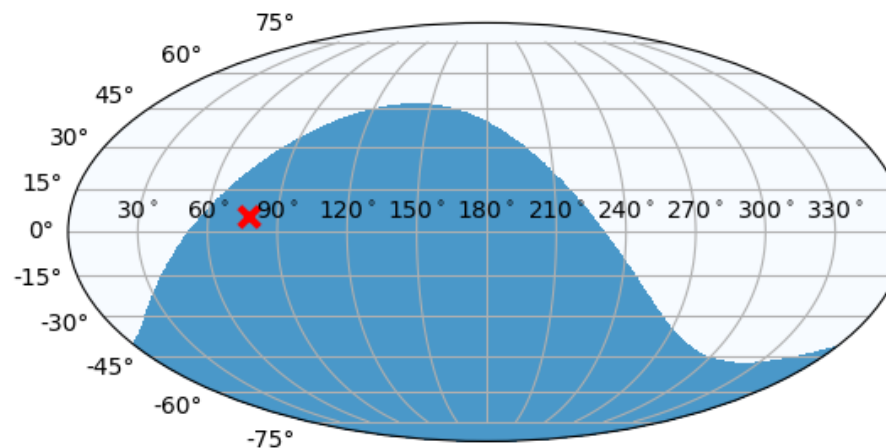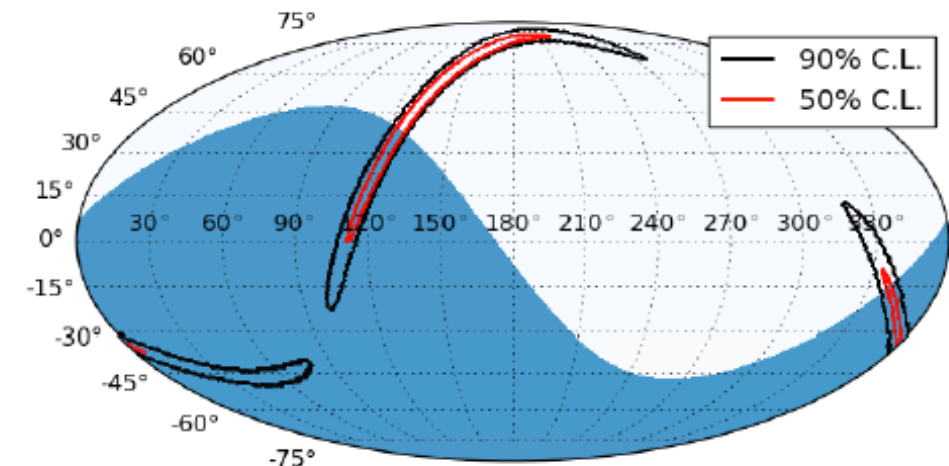
(±500 s & ±1 h)

IC170922

GW170104

Follow-up of ANTARES alerts

Swift/XRT

MASTER, TAROT, ROTSE
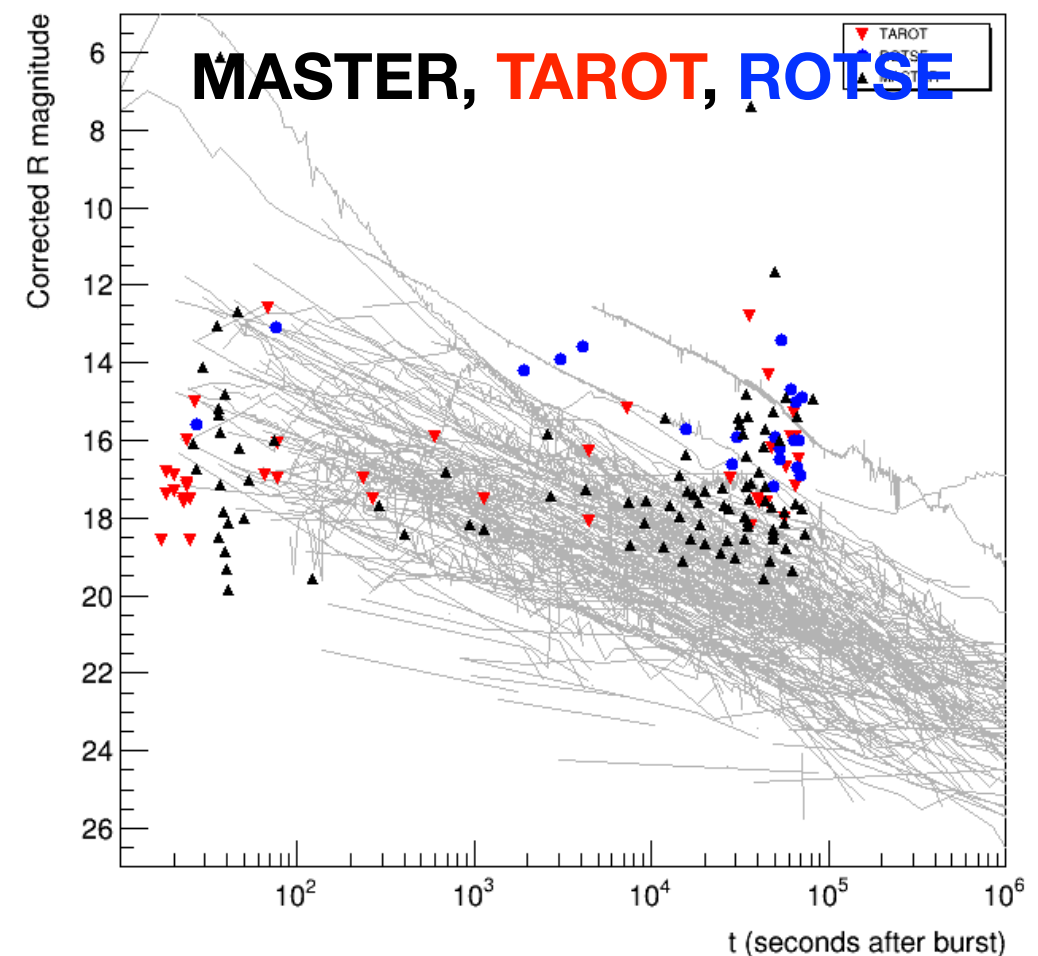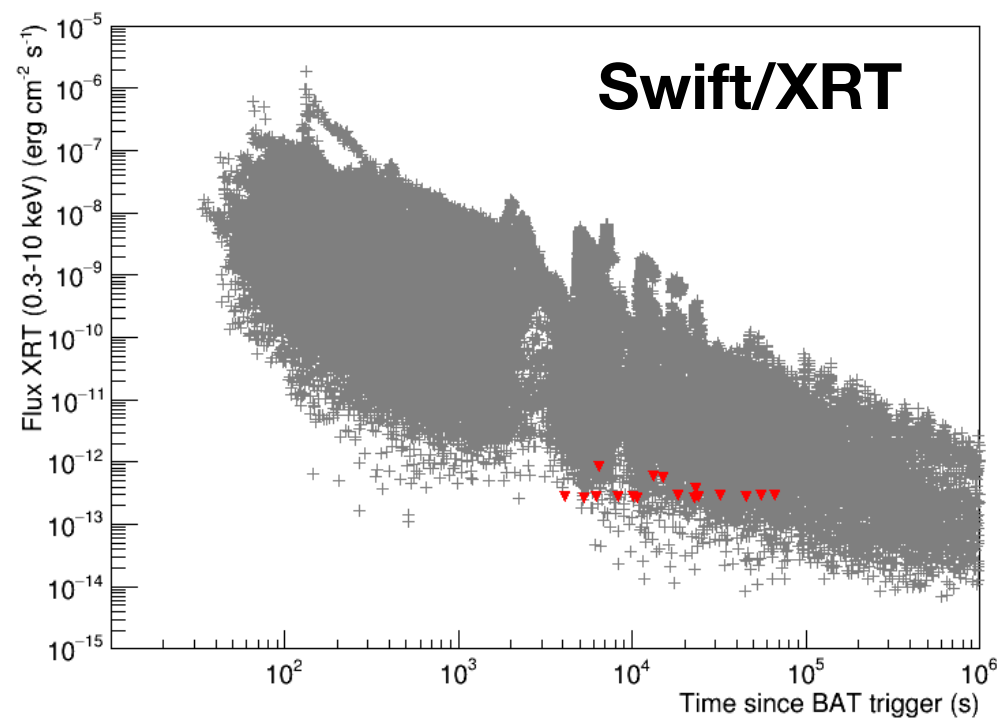
KM3NeT real-time framework

KM3NeT

ORCA & ARCA raw data — ~2-3 s

Data filtering ~2-3 s

Online calibration

Online reconstructions Track + cascade events ~3-5 s

External EM/MM triggers

All-flavor/all-sky neutrino selections ~1 s

~1 s

Correlation space/time

Alert sending

SN analysis

Lincetto talk

CDS

Cross-match astro catalogues / archive ν

SNEWS

Internal/External reporting (webpage, GCN notice/circular, SMS, e-mail)

8

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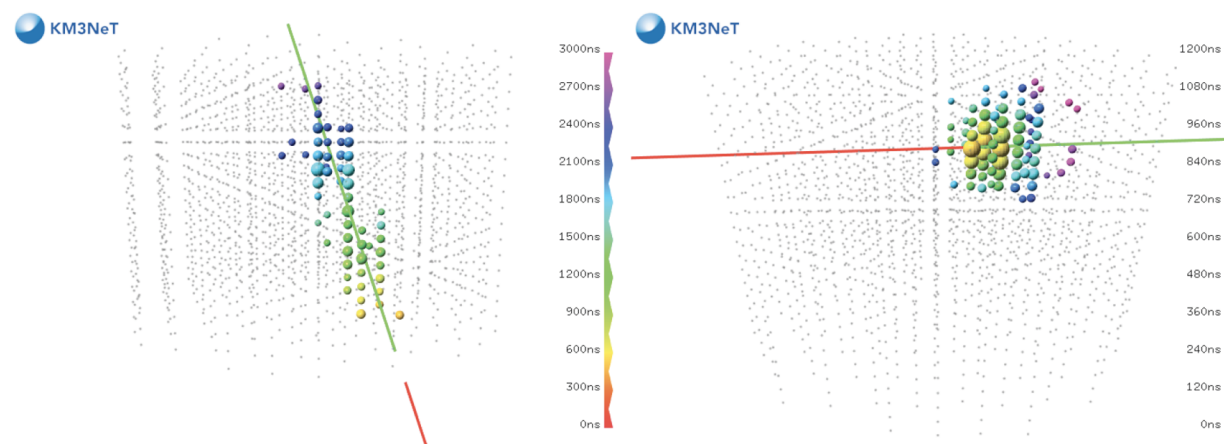
* All-flavor (track+cascade) event reconstructions: same framework and the same reconstruction tools as in offline
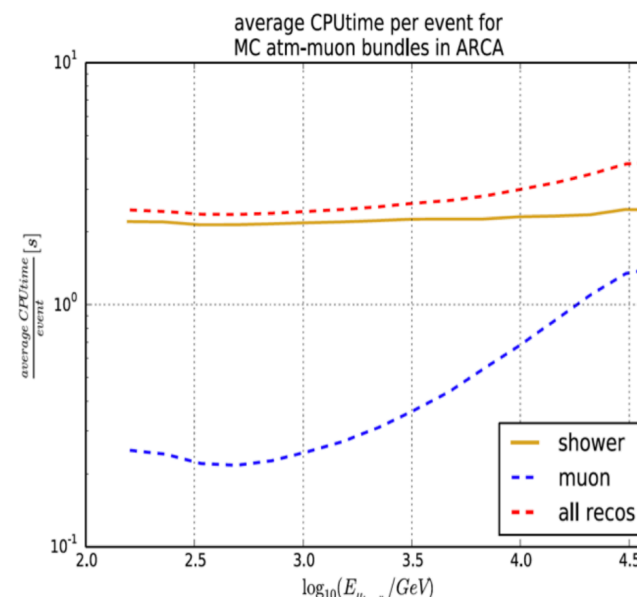

Tracks:
ARCA: < 0.2º (>10 TeV)
ORCA: 1 - 2º (100 GeV - 1 TeV)

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

* Time to reconstruct all events: Trigger rate: ~100 Hz $\Longrightarrow$ Neutrino rate: 1-2 mHz
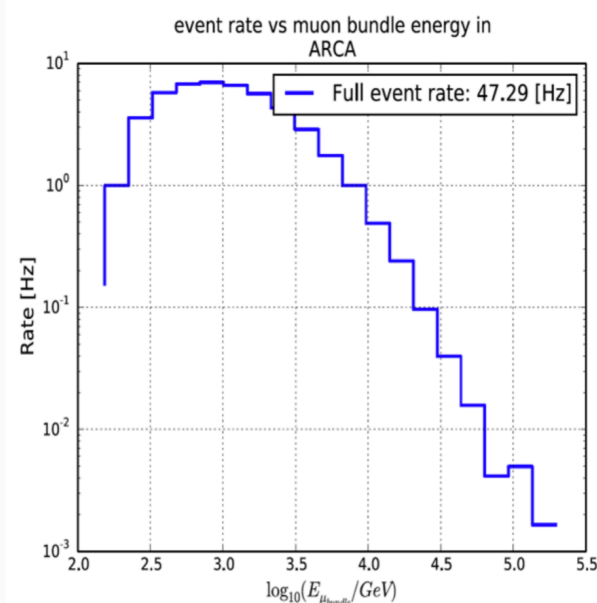
SHOWER	
$90\,TeV < E_\nu < 110\,TeV$	2.30 sec/event
$900\,TeV < E_\nu < 1100\,TeV$	2.80 sec/event
TRACKS	
$90\,TeV < E_\nu < 110\,TeV$	0.85 sec/event
$900\,TeV < E_\nu < 1100\,TeV$	1.95 sec/event

$\Longrightarrow$ **Need 2 farms of 200 CPUs**

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
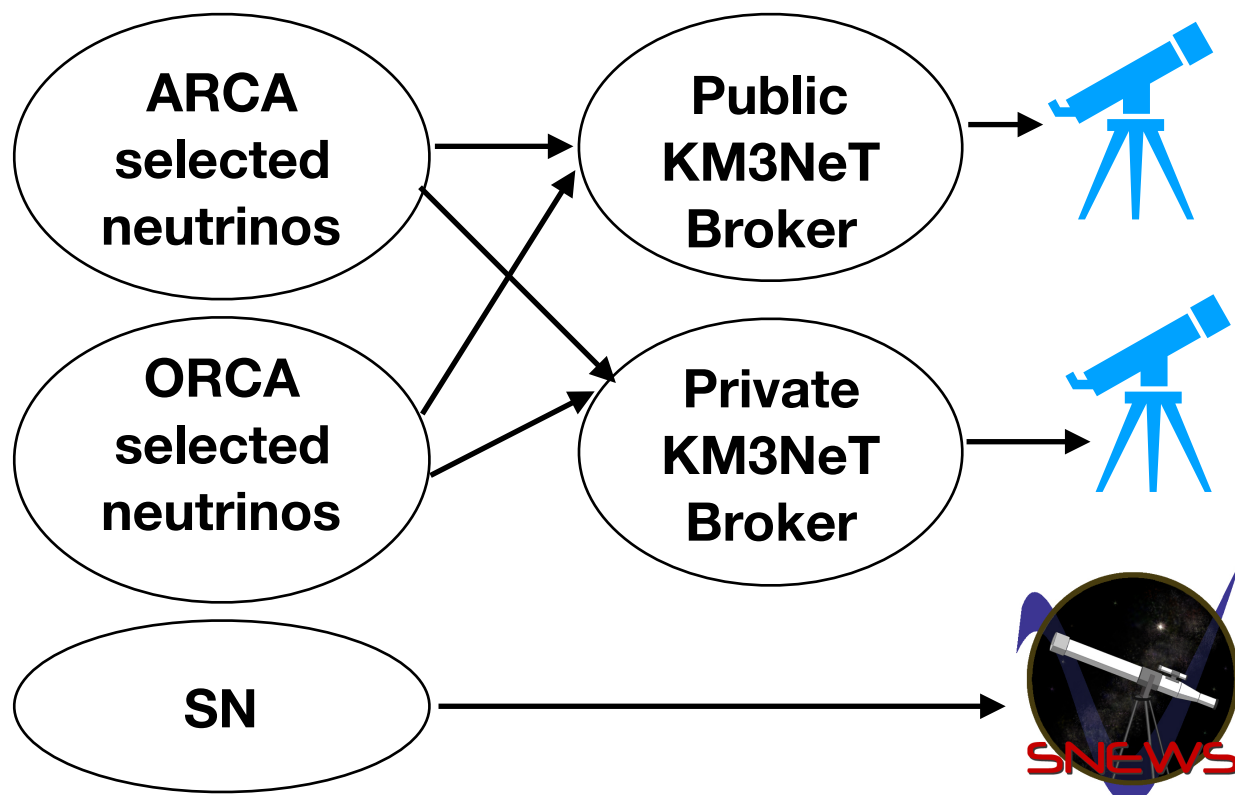
For KM3NeT: define a standard VO event:
 * ID
 * Detector (ORCA/ARCA)
 * Time
 * RA, DEC, error 50, 90%
 * Energy estimate
 * Reconstruction quality
 * Probability neutrino
 * Type of neutrino
 * Multiplicity
 * Type of trigger
+ develop one alert broker for ORCA & ARCA with different types of alerts

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