Real-time multi-messenger analysis framework of KM3NeT

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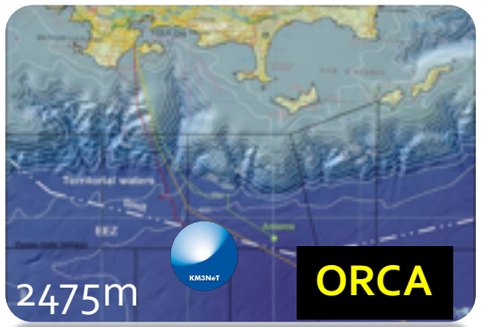
On behalf the KM3NeT Collaboration

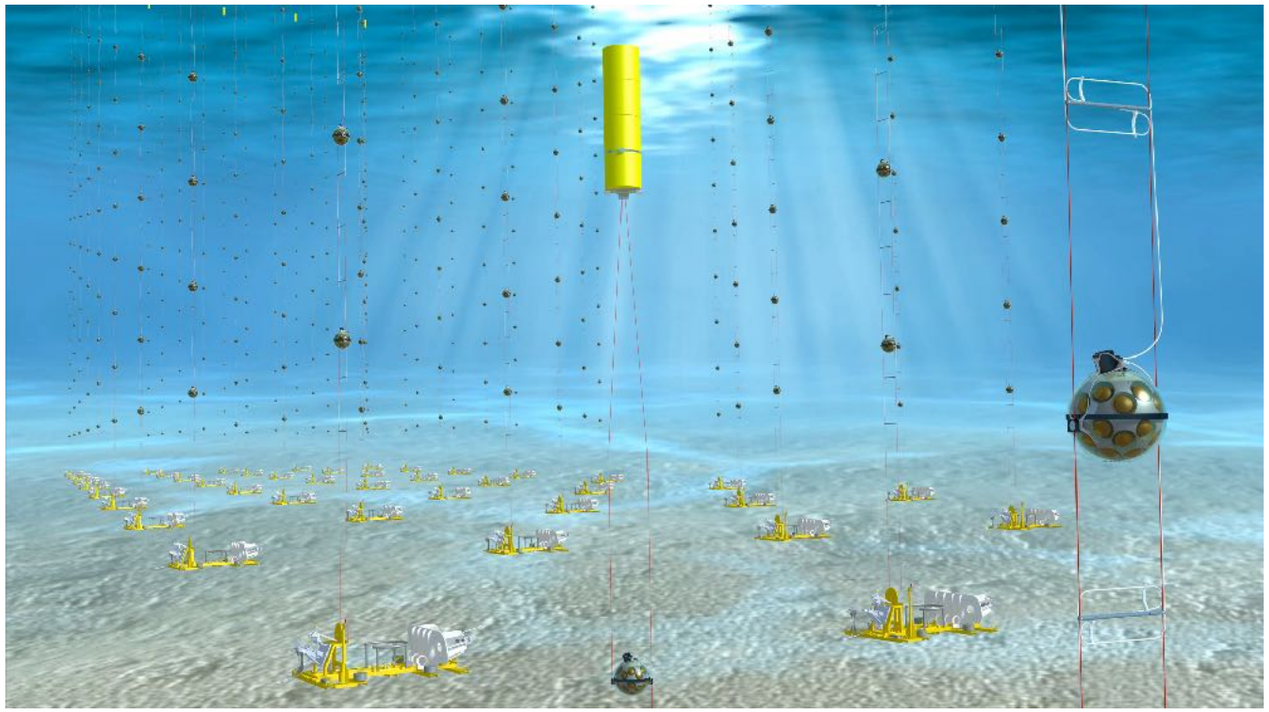
KM3NeT

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



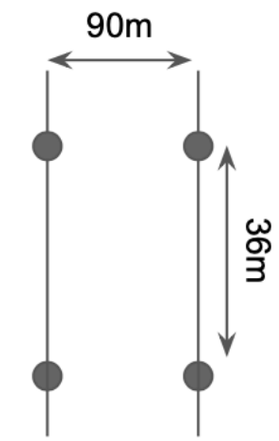


Astroparticle **R**esearch with **C**osmics In the **A**byss

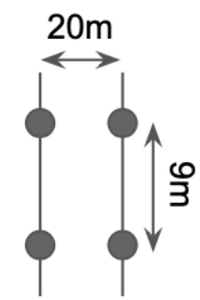
ARCA: off shore Capo Passero, Italy

Main characteristics:

- Extended energy range: 1 GeV → 10 PeV (+ 10-40 MeV)
- Full sky coverage with the best sensitivity for the galactic sources
- High duty cycle (> 95%)
- All-flavor neutrino detection
- Good angular resolutions

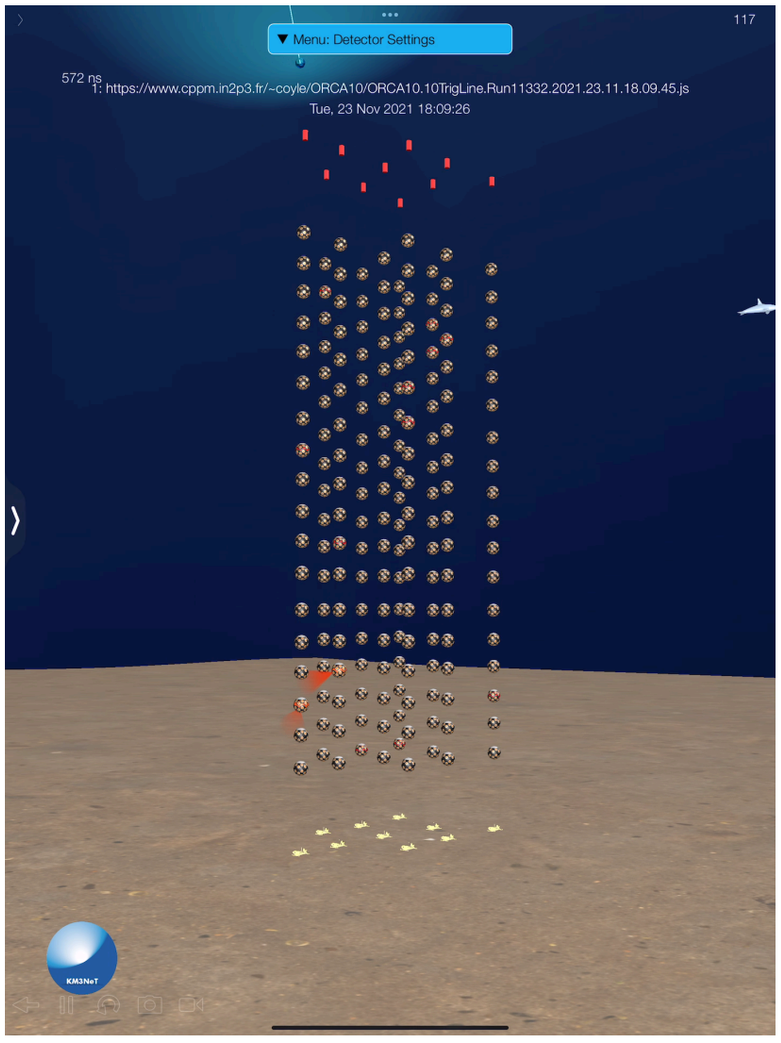


ARCA
2x500Mton
230 DUs, 128340 PMTs



ORCA
7Mton
115 DUs, 64170 PMTs

Last news of KM3NeT



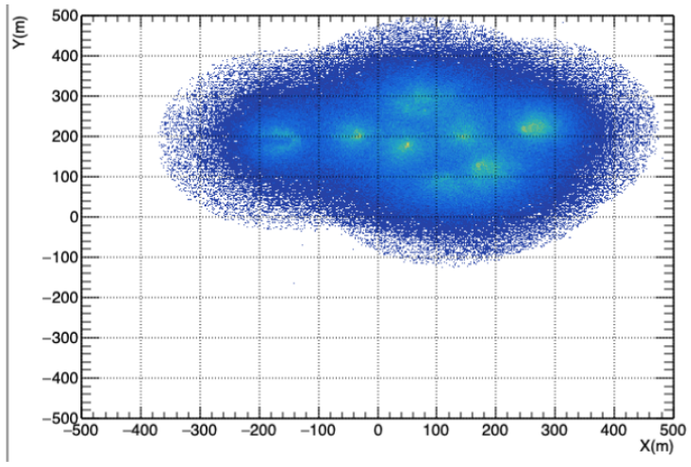
ORCA: 1 GeV - few TeV (~10% deployed)

10 strings in operation (~1.5 years of ORCA6 data)

$\Longrightarrow$ Already better performances at low-energy than ANTARES and IceCube

$\Longrightarrow$ First results on oscillation promising

$\Longrightarrow$ Continuous construction: +13 in 2022 (20%)



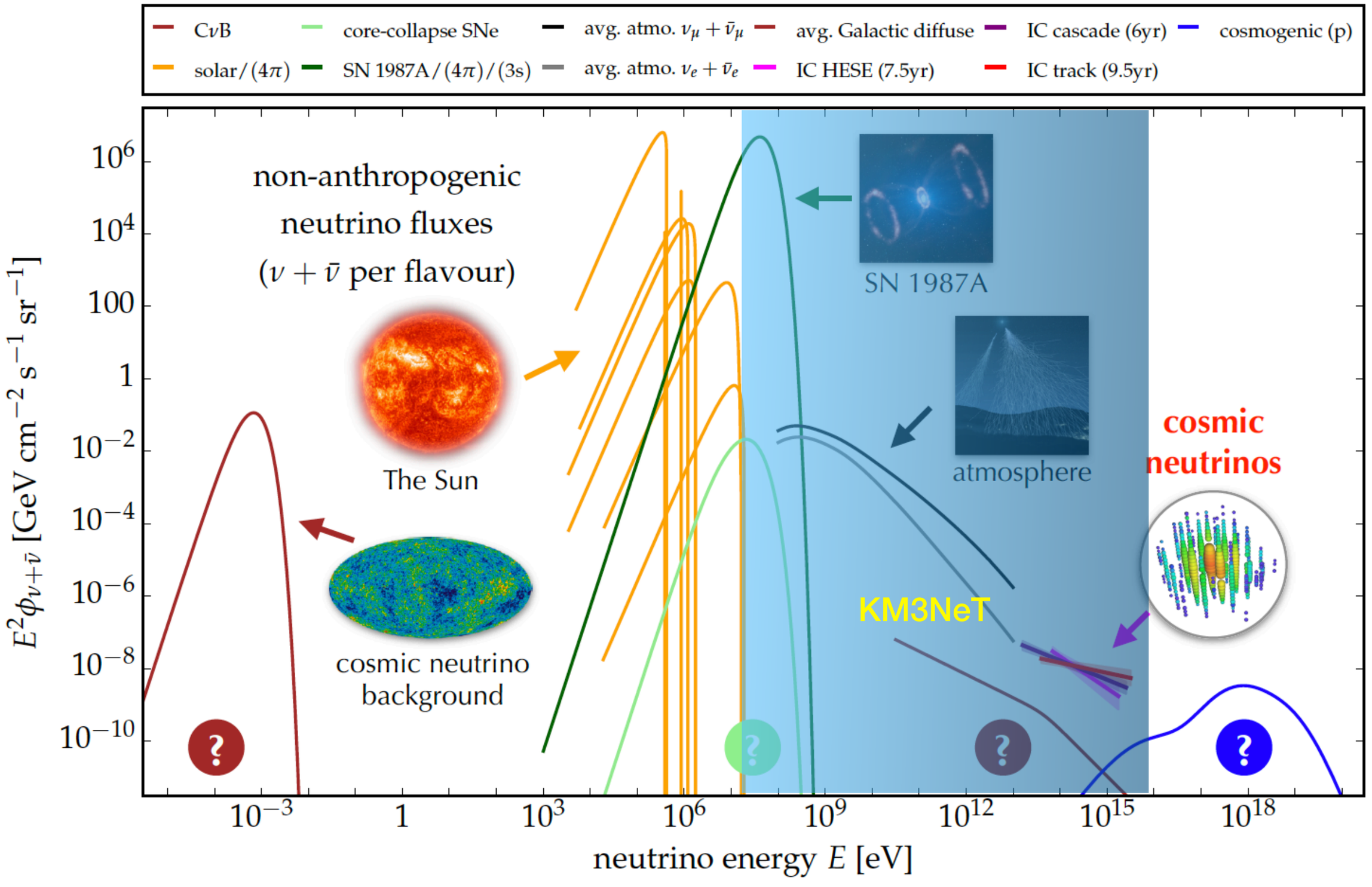
ARCA: 100 GeV - few PeV (~3.5% deployed)

8 strings in operation (6 months of ARCA6 data)

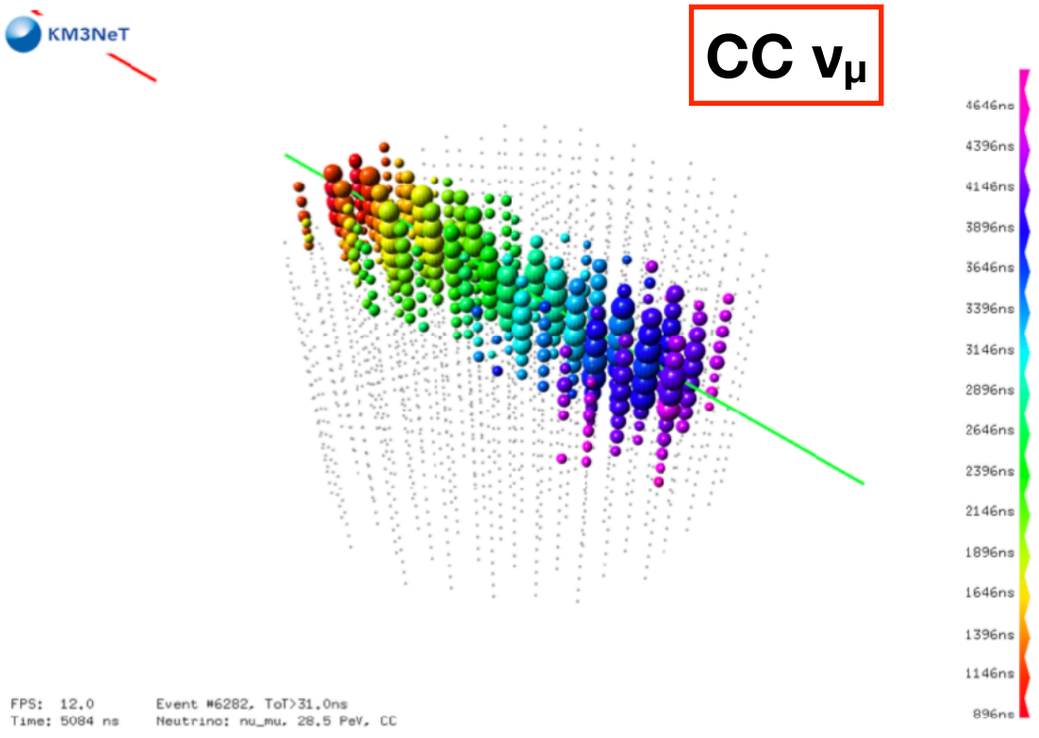
$\Longrightarrow$ Almost similar performances than ANTARES

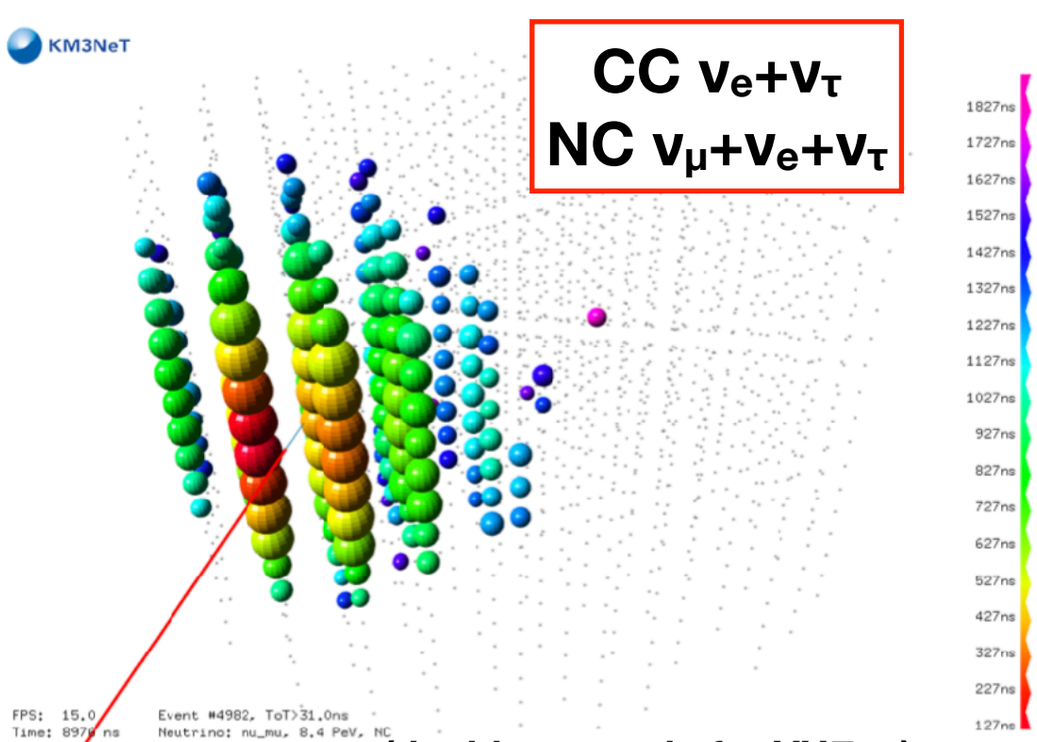
$\Longrightarrow$ Continuous construction: +25 in 2022 (15%)

Astrophysical neutrino fluxes



All-flavor neutrino detection





(double cascade for VHE ν_τ)

For ARCA:

- ➡ Gal. sources: 0.2º at 10 TeV
- ➡ Extra-gal. sources: 0.1º at 100 TeV
- ➡ VHE: 0.06º at 10 PeV
- ➡ Energy resolution 0.2 in Log10(E)

For ORCA:

- ➡ 7º at 10 GeV, 2º at 100 GeV, <1º at 1 TeV
- ➡ Energy resolution ~20-30%
- ➡ Very large statistics

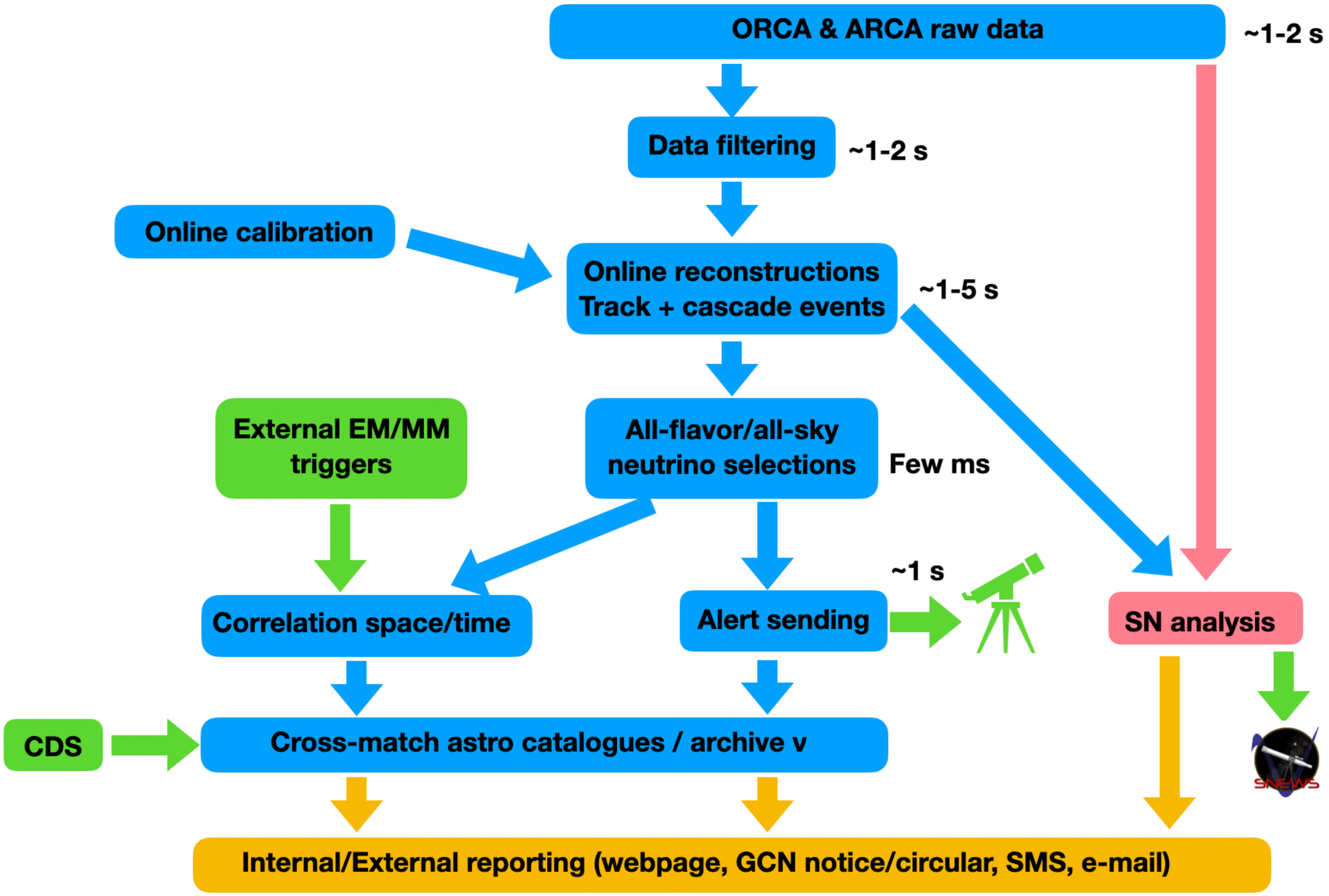
For ARCA:

- Vertex: 6-8m (long), 0.5m (perp)
- Direction: ~1.5º for E > 50 TeV
- Energy: 5%

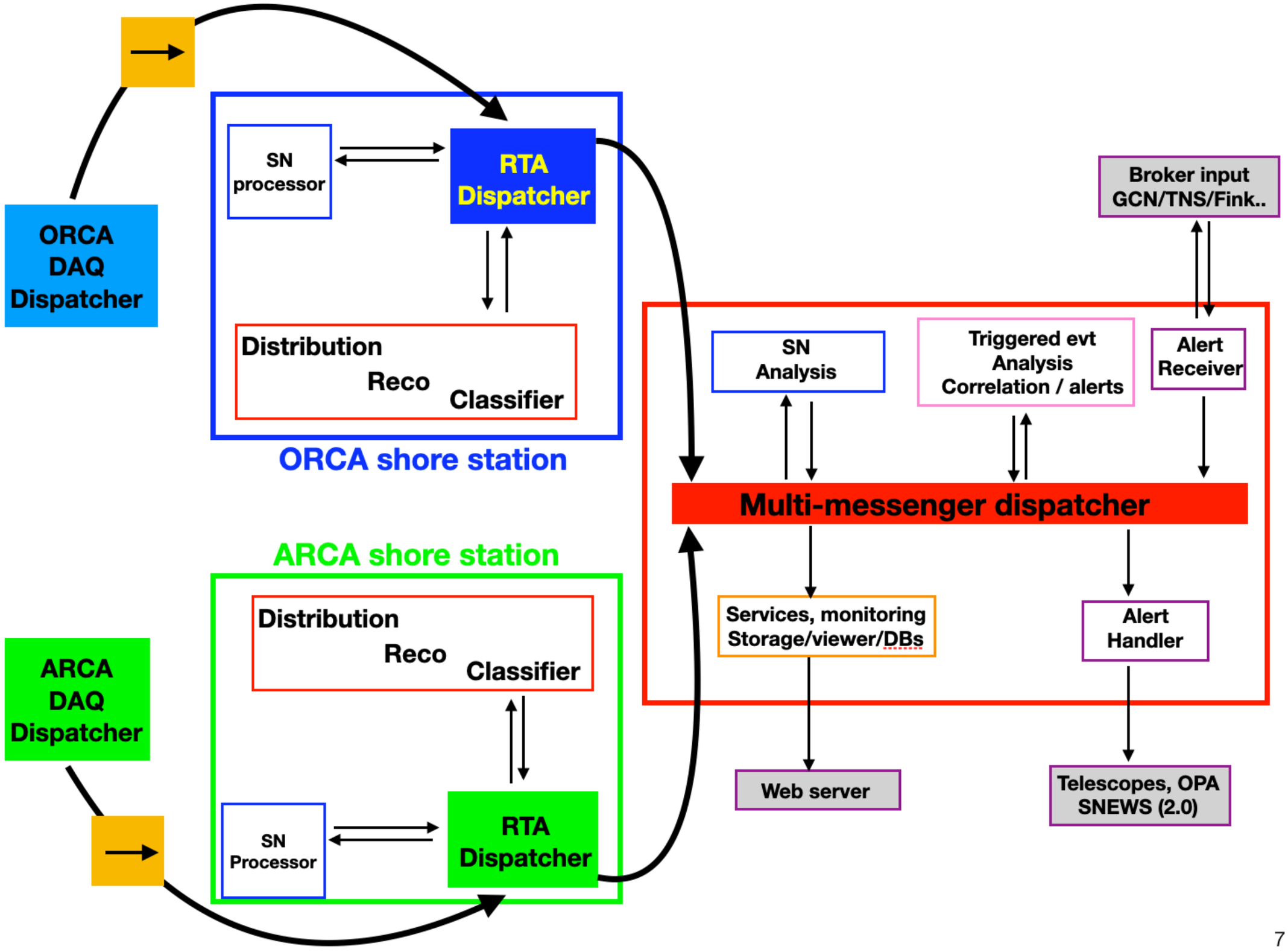
For ORCA:

- Direction: 7º at 10 GeV, 3-4º at >50 GeV
- Energy: ~20-30%

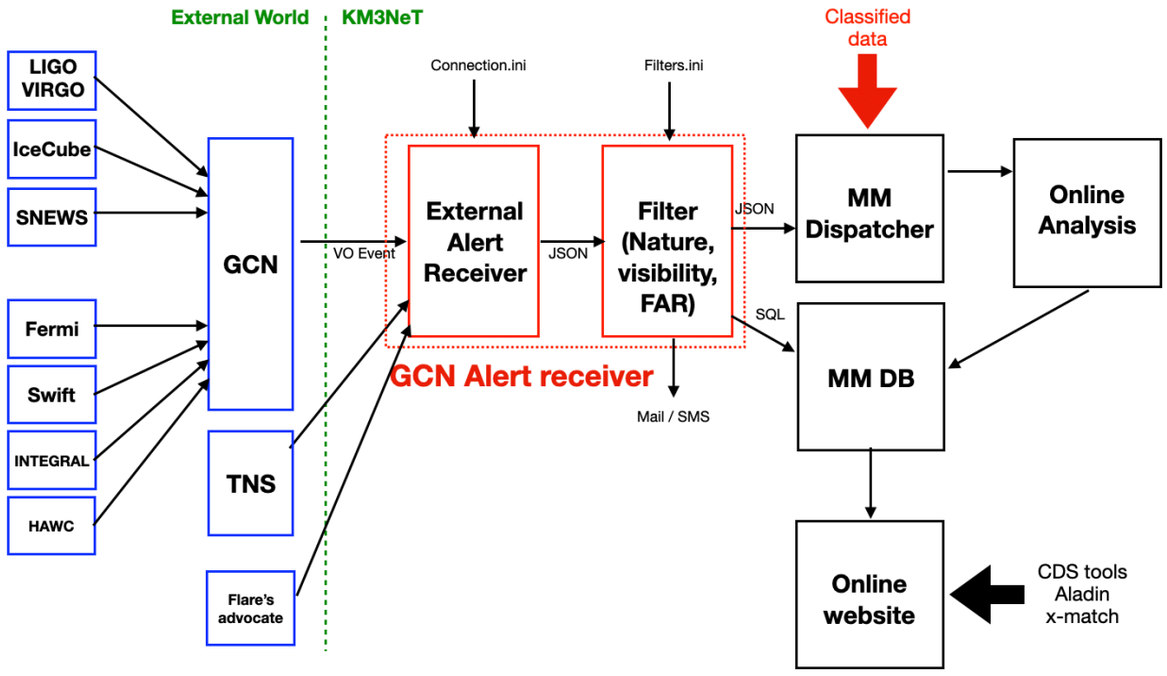
Real-time analysis framework



Real-time analysis framework



KM3NeT interfaces with the external world



External trigger reception:

$\Longrightarrow$ Connection to different brokers (GCN, TNS, Flare's advocate…)

$\Longrightarrow$ Filtering module to select the triggers (visibility, nature, FAR, delay)

$\Longrightarrow$ GCN chain ready and in operation

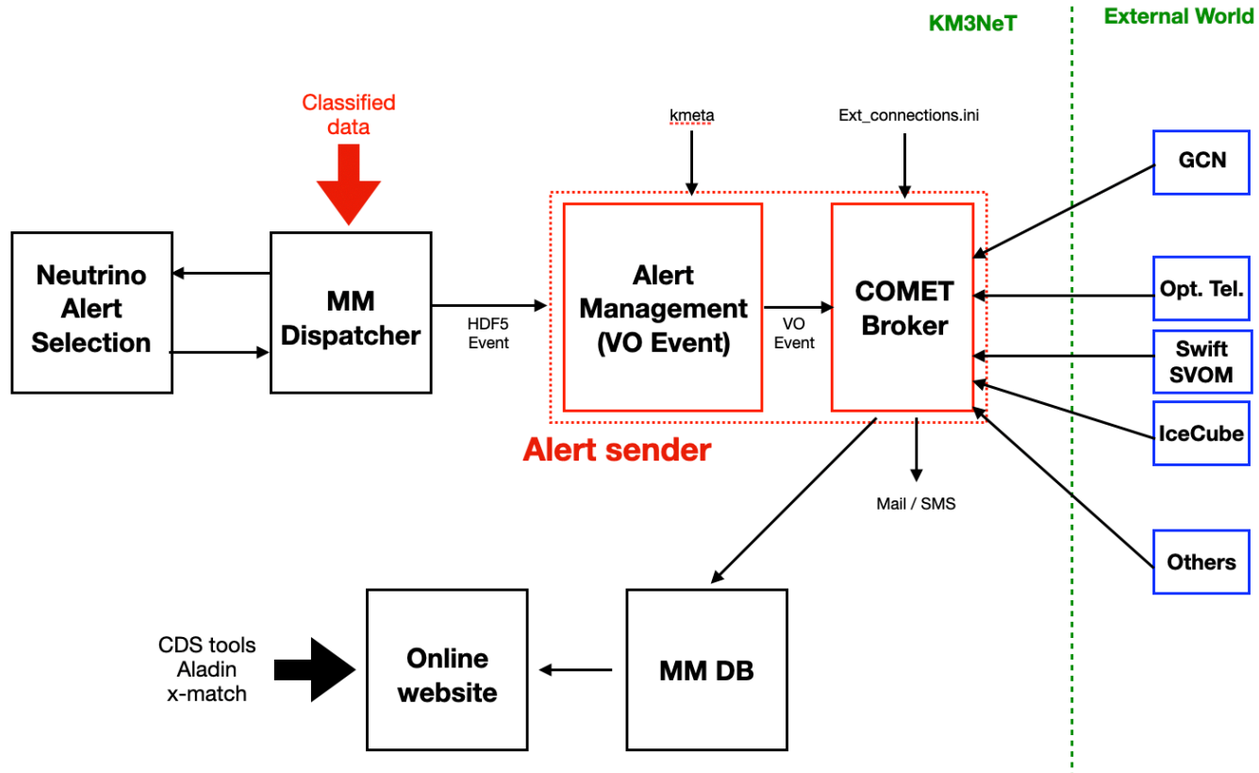
KM3NeT alert sending:

$\Longrightarrow$ Alert distribution performed by Comet using only VO event (XML file)

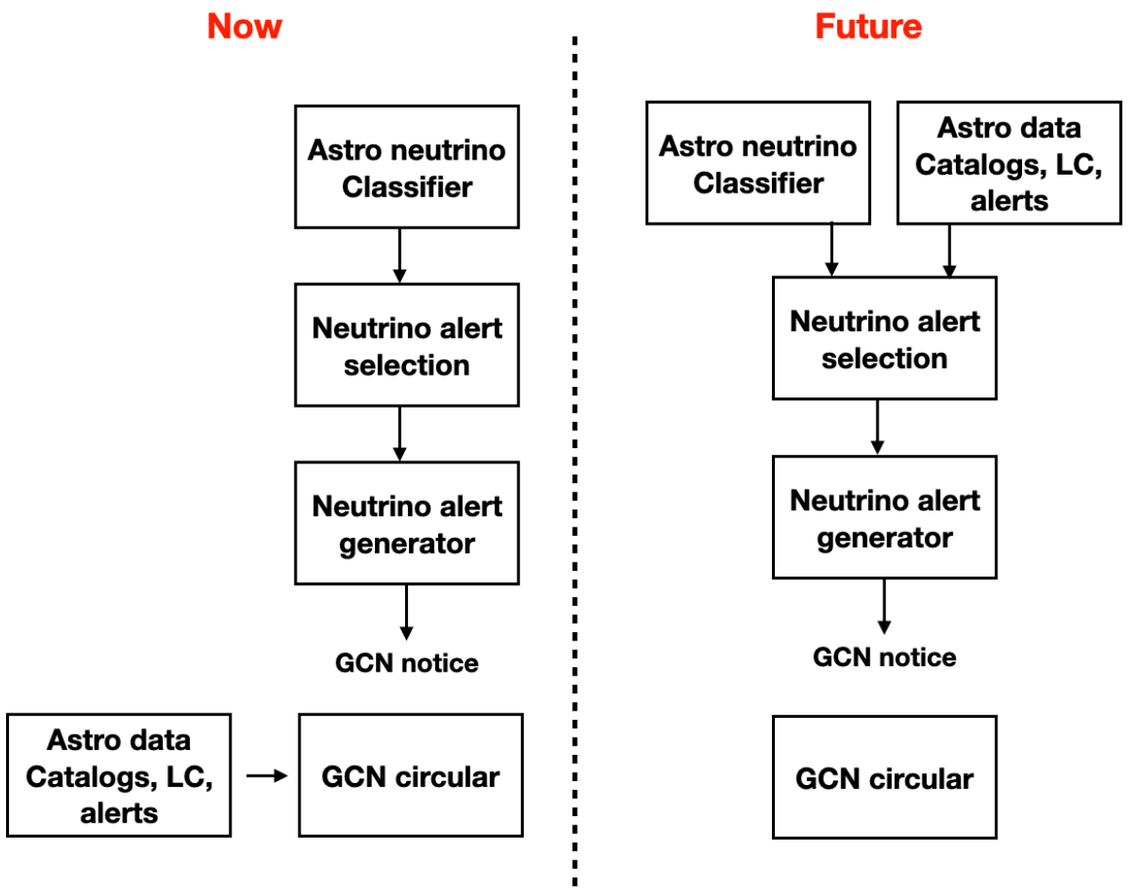
$\Longrightarrow$ Alert management module validates automatically the content of the VO event using kmeta data

$\Longrightarrow$ After commissioning, we will start an open public alert program

$\Longrightarrow$ A test version is in operation



KM3NeT neutrino alerts >mid 2022



Alert neutrino selection:

$\Longrightarrow$ Neutrino alerts: burst of LE neutrinos, single VHE, single + specific direction, auto-correlation

$\Longrightarrow$ Move from a pure neutrino selection (a la IC and ANTARES) to a mix neutrino-astro selection. Of course, for the peculiar events, neutrino alerts can be sent whatever its astro content to be not biased.

$\Longrightarrow$ Definition of the astro content: direction cross-matches with astro catalogues (BZCAT, 3HSP, 4FGL, RFC…) and adding the time cross-matches with Fermi-LAT real-time analysis, connection with LSST/ZTF brokers…

Alert content:

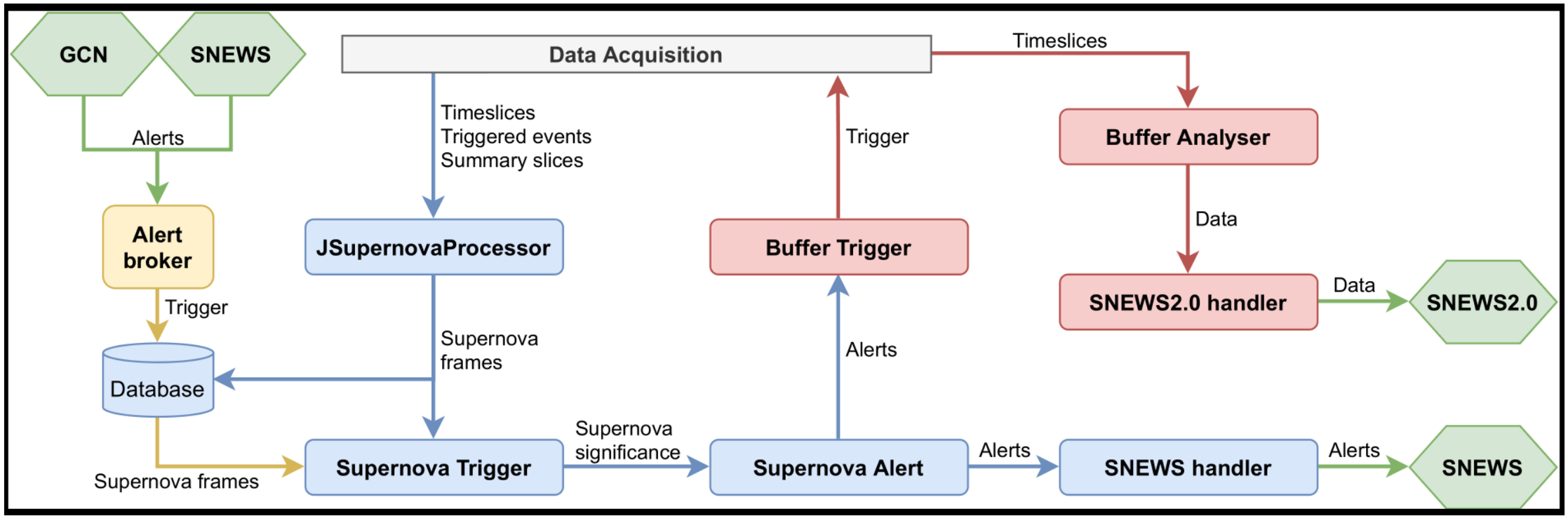
$\Longrightarrow$ Rate: 1-2 per month

$\Longrightarrow$ Working on the detailed content of the VO

Event alert message and on the automatisation to obtain all the quantity

VO content:
* ID
* Detector (ARCA/ORCA)
* Type of alert triggers
* Multiplicity (i.e. number of events in given time and space windows)
* Flavor PID
* Energy
* IsRealAlert
* Time
* RA, DEC, Longitude, Latitude
* Error box 50%, 90% (TBC)
* Reconstruction quality
* Probability of neutrino (anti-muons)
* Probability of astrophysical neutrino
* Ranking
* Astro contents

CCSN neutrino alerts



KM3NeT CCSN neutrino analyses:

$\Longrightarrow$ Very complex software organisation: 3 parallel analyses are in operation: Real-Time Analysis, Quasi-Online Analysis and Triggered analysis.

$\Longrightarrow$ Connected to SNEWS and send regularly alerts with a FAR of 1/8 days [provide only the time of the neutrino signal]

$\Longrightarrow$ Start to upgrade the system to be able to answer to SNEWS 2.0 requirements of the 3 alert tiers. We are now able to provide the time of the alert, the significance at any time on request and the neutrino light curve (1-10 ms time bin depending of the strength of the signal) and the estimation of the time of the neutrino signal.

$\Longrightarrow$ The triggered analysis allow to provide the significance for a MeV neutrino signal at any time

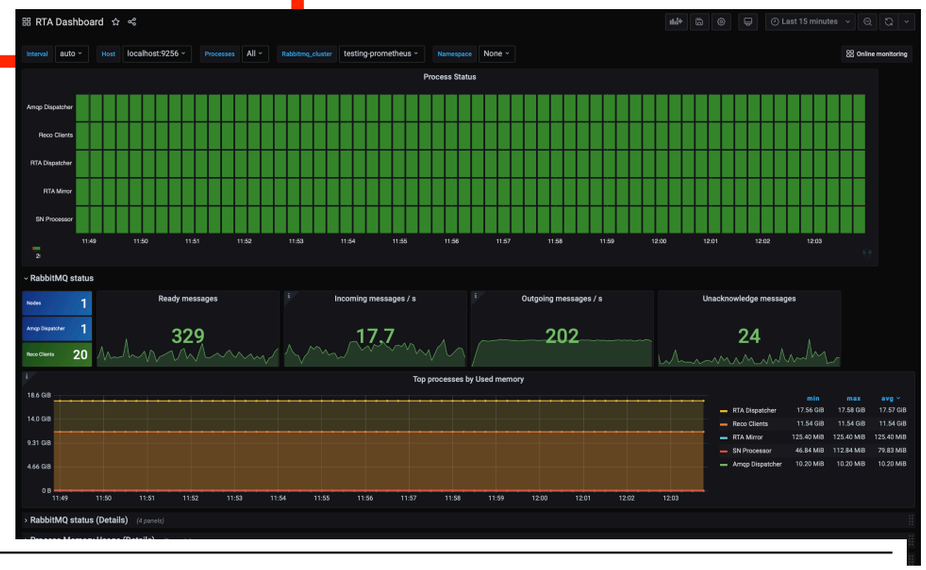
Online shifter organization

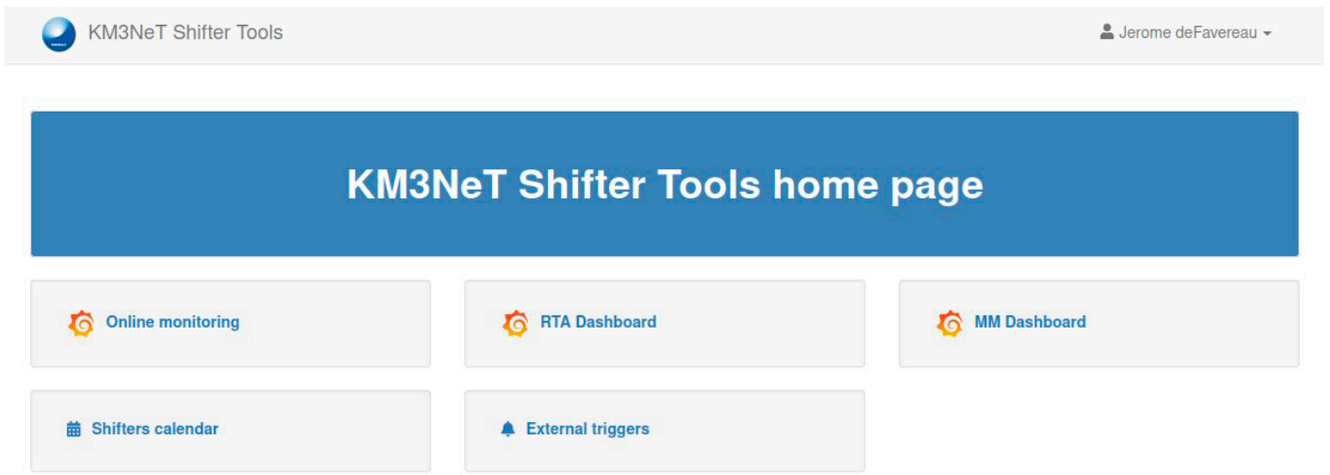
<u>Goal</u>: build an online analysis group that will take care of the real-time follow-up of the KM3NeT internal alerts and EM/MM external triggers.

<u>Duties</u>:

- Monitor the health of the online processes (reco, classifiers, SN processes), the network and the high-level neutrino performances.
- Monitor the outgoing broker
- Organize follow-up for our alerts
- Monitor the EM/MM trigger receptions and the online analyses
- Report the results

Website with all the required tools

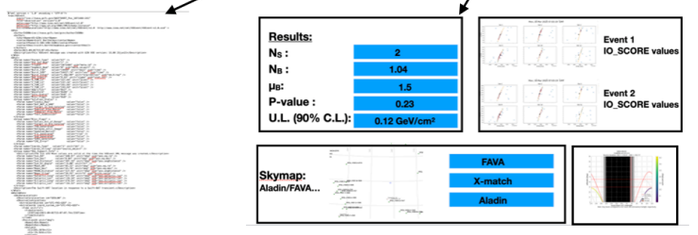




(in progress)

Name	Source	Parameters	Inputs	Results
GRB210902A	GRB	1071488, 20210902T040507, 122.278 -32.388, 0.12, Swift	Links_GCN	Link_res_ana1 / Link_res_ana2
GRB210901A	GRB	652326622, 20210901T140407, 160.238 +2.398, 5.20, Fermi	Links_GCN	Link_res_ana1 / Link_res_ana2
IC210831A	Neutrino	13591_36044887, 20213108T063657, 58.788 +34.576, 0.38, IceCube	Links_GCN	Link_res_ana1
SN210702A	CCSN	210702_040507, 20210702T040507, , SNEWS	Links_SNEWS	Link_res_ana3
S210702A	GW	S200316bj, 20210701T101507, skymap_GW, LVKC	Links_GCN	Link_res_ana1 / Link_res_ana2

MM_DB **GCNALRT** **VO Event** **Online analysis**



Summary

- KM3NeT has just arrived at the same or better effective area compared to ANTARES (11 yrs) in less than 1 yr of operation. The construction rate will increase (~15-20% of the detector next year)

- KM3NeT is implementing a real-time analysis platform as automatized as possible that includes online correlation analyses with external triggers and the neutrino alert sending. We plan to start the online activity in Spring 2022 (first alerts for Summer)

- Simultaneous MWL/MM follow-up is the key to resolve the neutrino sources (too few statistic in the neutrino side)