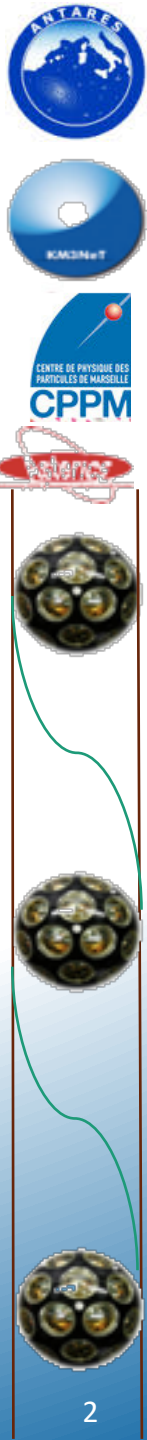
ANTARES and KM3NeT programs for the supernova neutrino detection

V. Kulikovskiy (CPPM/CNRS)

Detection strategies

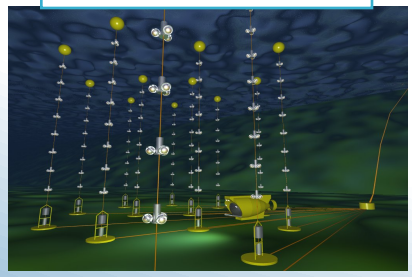
- ANTARES and KM3NeT are ν telescopes made of 3D PMT arrays in the deep sea water well shielded from atmospheric muons.
  - **Prompt SN emission** (20 MeV neutrinos) should produce the increase of PMT rates in the detector. No event reconstruction but high sensitivity in time domain.
  - **Hidden jets** (~GeV-TeV neutrinos) can be promptly detected (fast event reconstruction, ν direction and energy estimation). Alerts can be forwarded to the followers (GCN, ASTERICS-CLEOPATRA…).
  - **Supernova Remnants** can be efficient high energy hadron accelerators (~GeV-TeV neutrinos). (Steady) point-source searches on the sky, candidate list searches with long-term statistics (~years).



Undersea neutrino telescope sizes

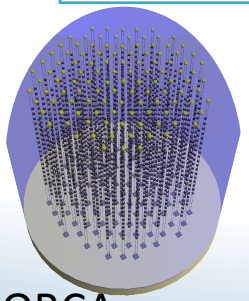
	ANTARES	ORCA (denser)	ARCA (larger)
Eff. Mass	10 Mt	5.7 Mt	1 Gt
Line length	350 m	200 m	650 m
Interline distance	70 m	20 m	90 m
Vertical spacing	14.5 m	9 m	36 m

12 lines
25 sectors/line

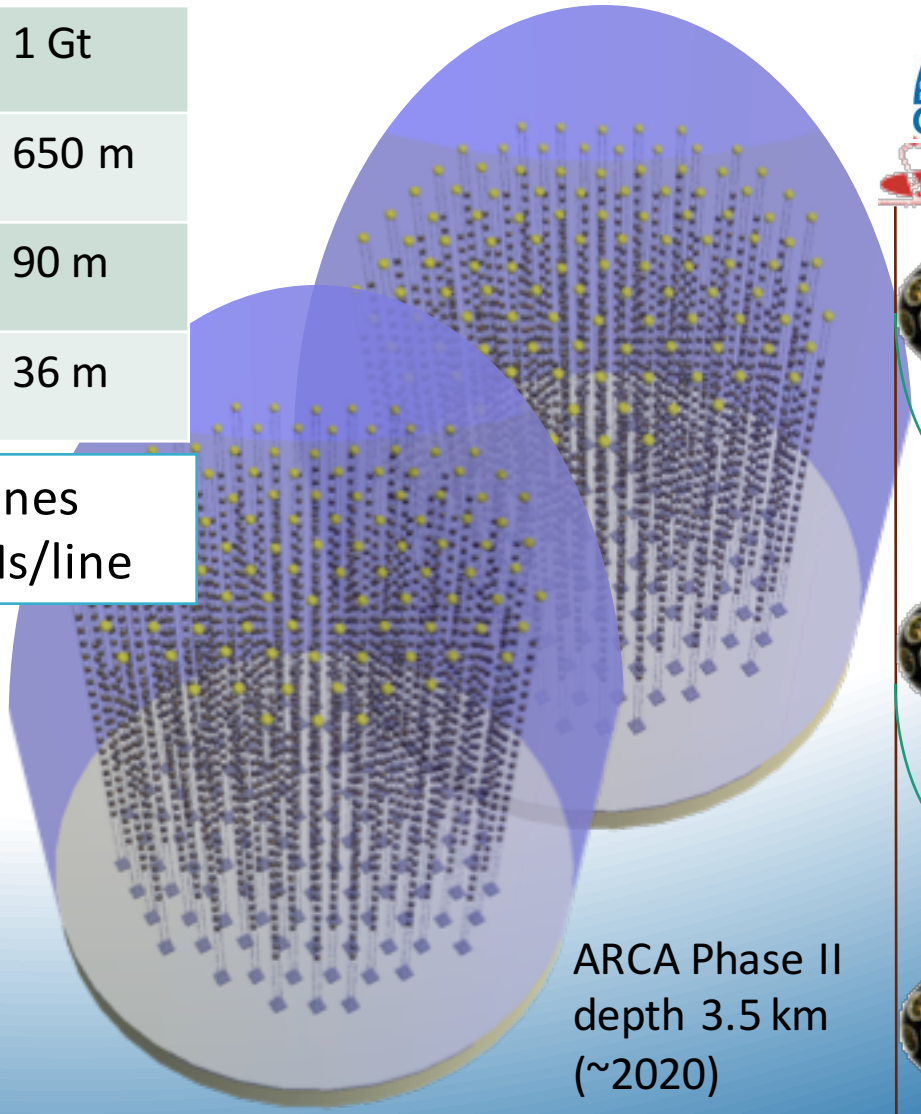


ANTARES
depth 2.5 km
(completed since 2008)

115 lines
18 DOMs/line



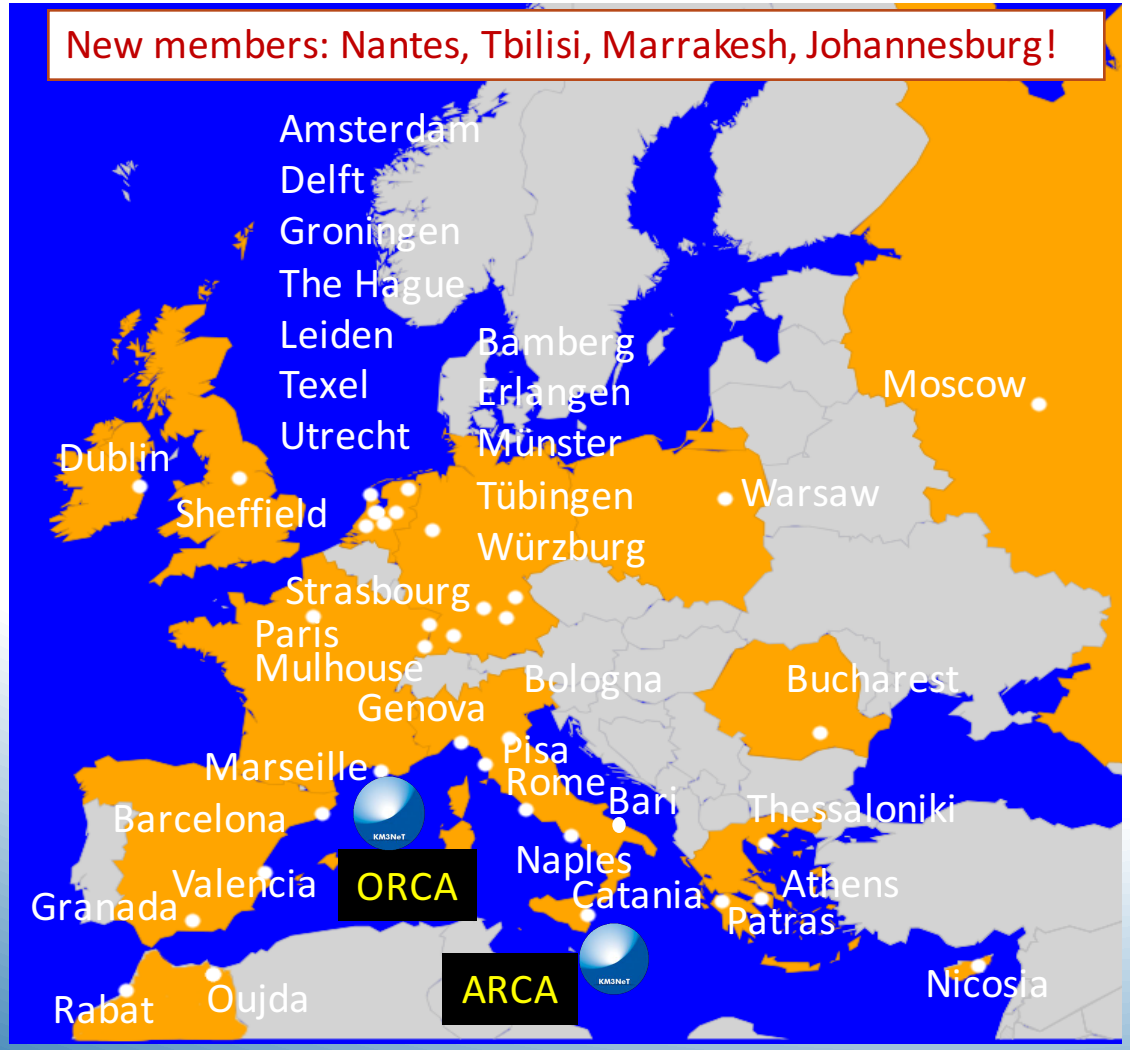
ORCA
depth 2.5 km
(~2020)

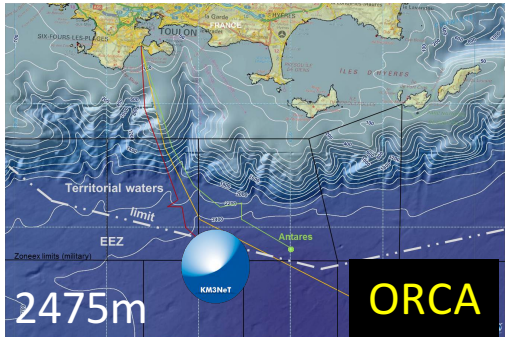


ARCA Phase II
depth 3.5 km
(~2020)

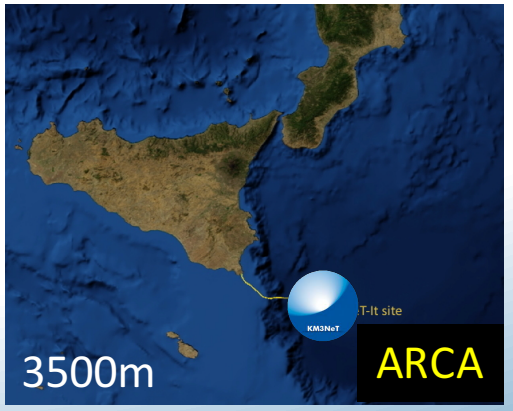
KM3NeT

Multi-site deep-sea neutrino research infrastructure





ν mass hierarchy study
(GeV ν)



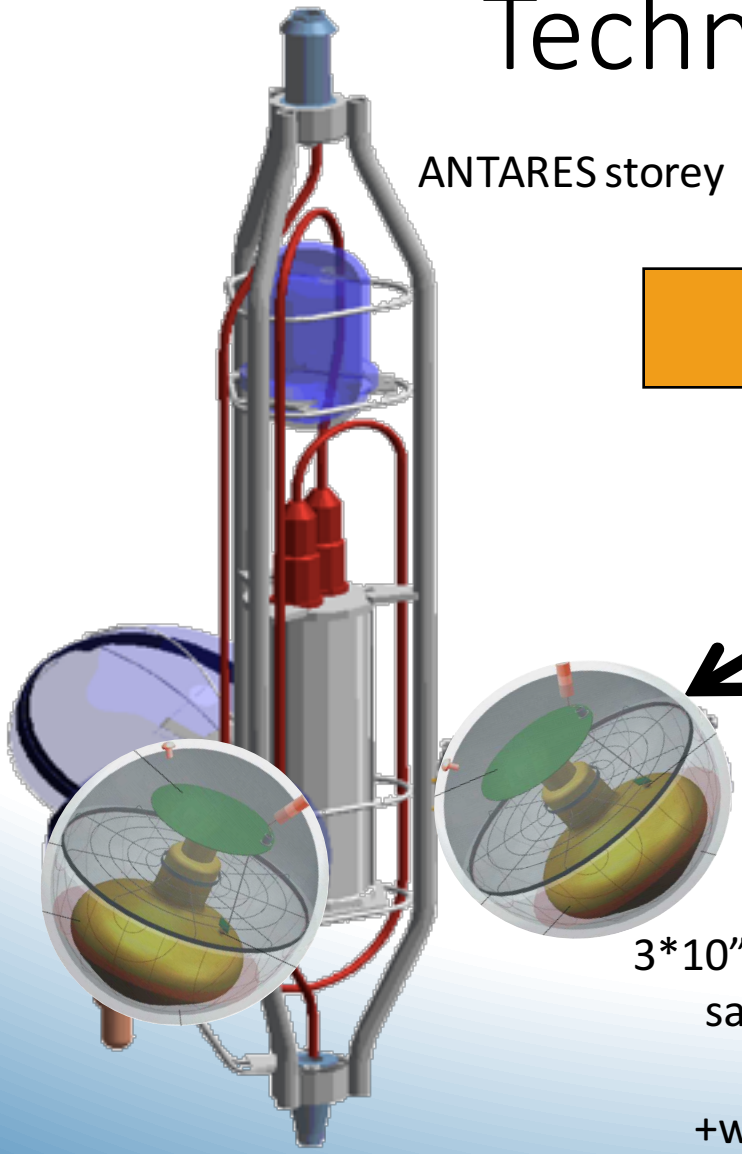
HE ν astronomy
(TeV ν)

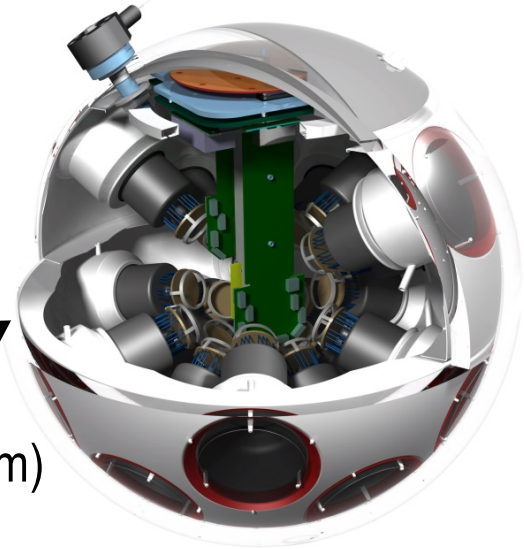
Single Collaboration, Single Technology

Technologies

ANTARES storey

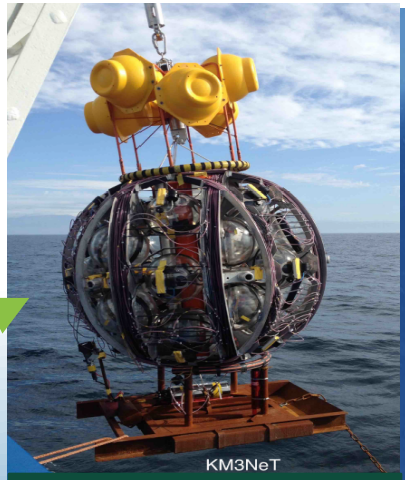
DOM

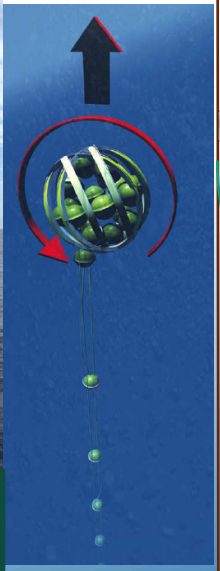




Same size (43cm)

3*10” PMTs -> 31*3” PMTs
same sensitive area
+compactness
+wider angle of view
+directional information
+digital photon counting
+cost reduction

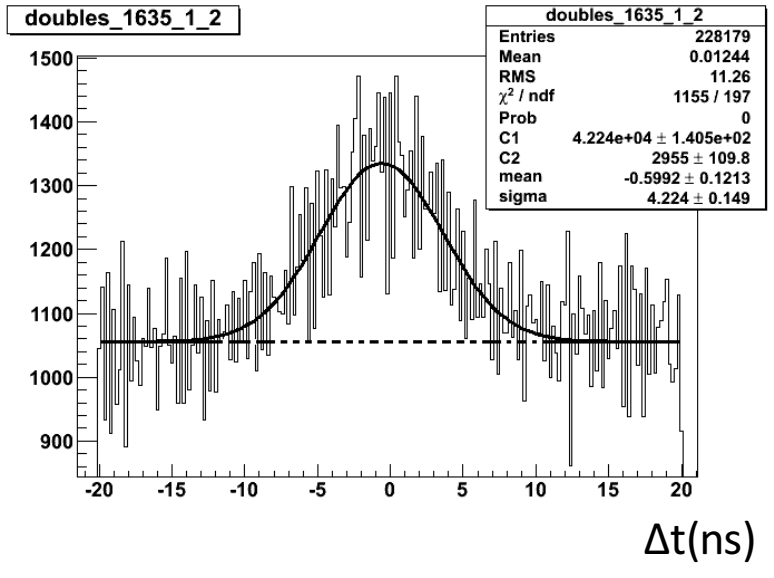


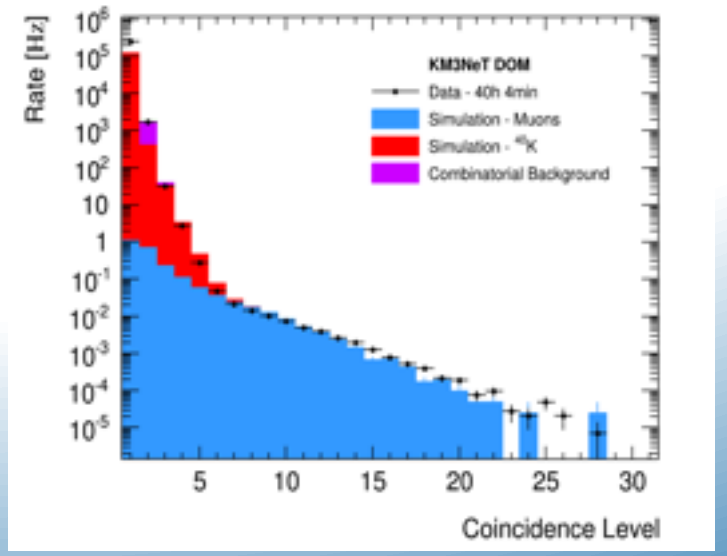


rapid deployment
autonomous unfurling
recoverable

Supernova prompt neutrino detection

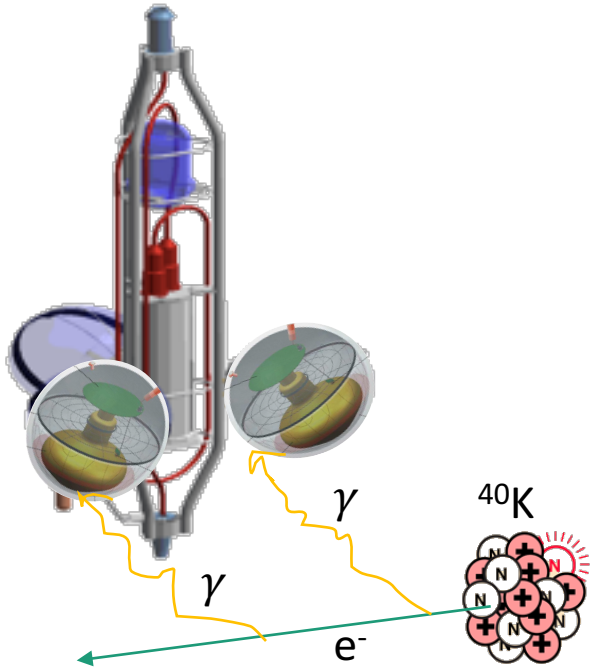
- The main channel – inverse beta decay.
- e^+ of ~10 MeV instantly populate the detector volume.
  - Event reconstruction is not possible.
  - Coherent increase of the light in the detector can be seen.
  - KM3NeT DOM – PMT coincidence level (total p.e. charge) gives an indication about the released energy.
- ^{40}K decay represents the main source of the optical background.
  - Usage of coincidences between PMTs to suppress it.





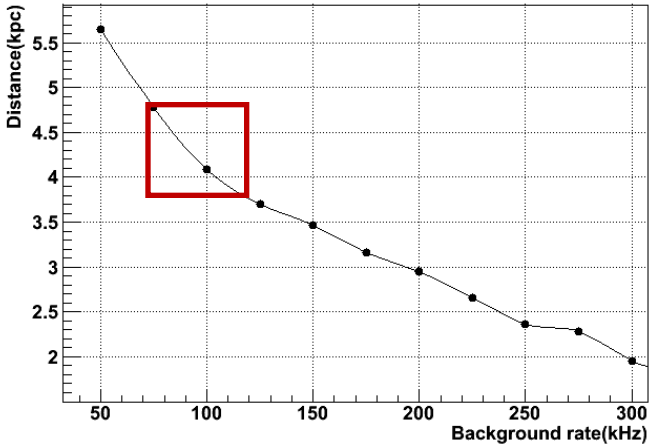
📖 Eur. Phys. J. C (2014) 74:3056

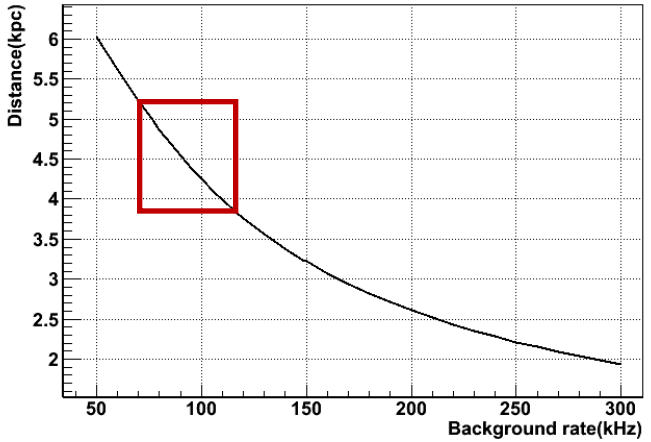
ANTARES



- Double coincidence rates due to ^{40}K decay (~1.3 MeV e^-) are extensively used in ANTARES for PMT efficiency and time calibration.
- This rate depends on the water salinity and it is extremely stable in time.
- e^+ due to SN increase PMT coincidence rates.

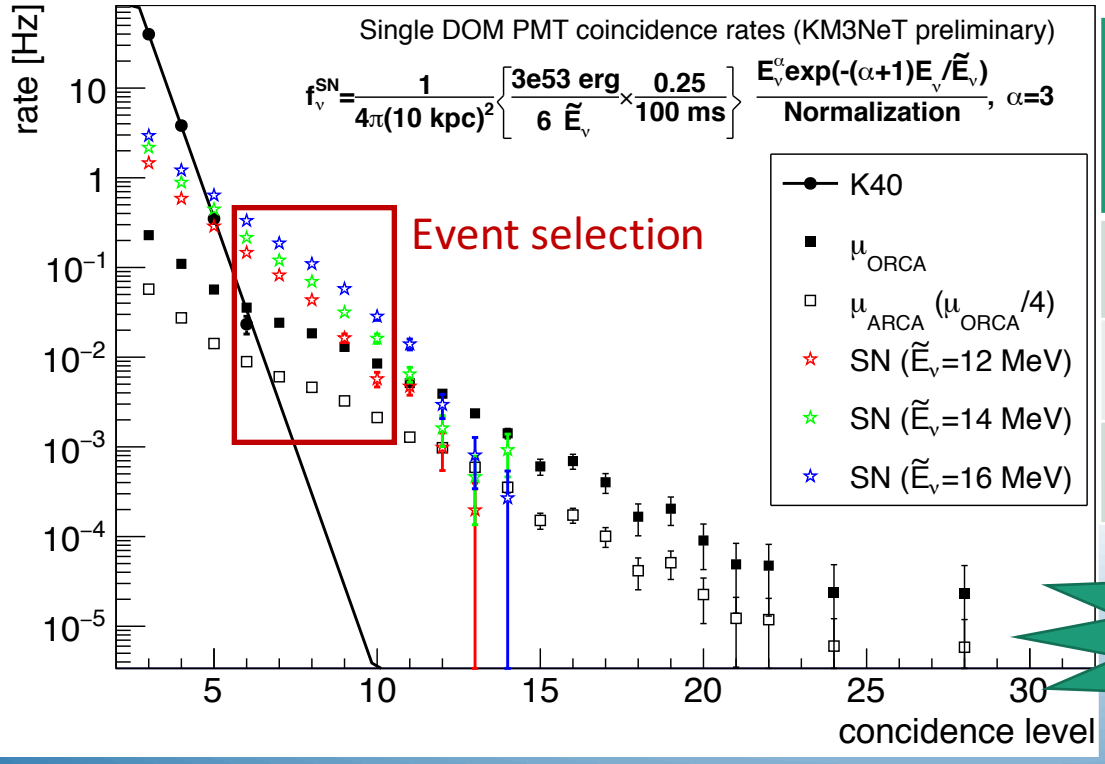
5 σ sensitivites (📖 Proceedings of ICRC2011)





KM3NeT preliminary sensitivities

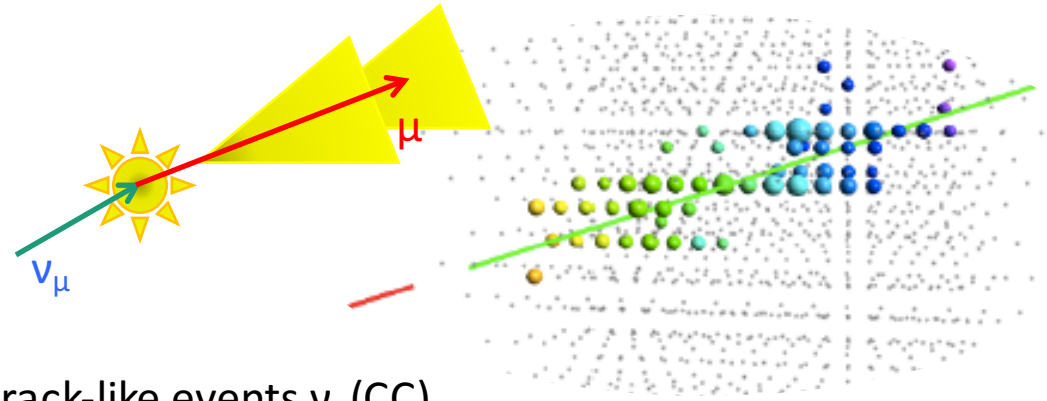
- Simulation (SN1987A-like): 10 kpc, 3e53 erg, 1/6 in $\bar{\nu}_e$, 25% in the first 100 ms.
- Spectra: $f = E_\nu^\alpha e^{-(\alpha+1)E_\nu/\tilde{E}_\nu}$, α=3, $\tilde{E}_{\bar{\nu}_e}$ =12, 14 & 16 MeV.
- Supernova coincidence distribution is harder than ^{40}K but softer than for muons.
- Rates for muons depend on the depth (~4 times larger in ORCA then in ARCA due to depth).
  - Smoothed extrapolation from PPM-DOM data was used. 📖 Eur. Phys. J. C (2014) 74:3056
  - They can be additionally suppressed by vetoing the signal if it is in the coincidence with a DOM above (downgoing muons) and/or from upward looking PMTs. The work is in progress.
- Results are very preliminary and conservative. (in future: time window optimisation, muon veto using coincidences between DOMs and topological features…).



$\tilde{E}_{\bar{\nu}_e}$ MeV	N_{ev} per block	$D_{5\sigma/3\sigma}$ (kpc) ARCA	$D_{5\sigma/3\sigma}$ (kpc) ORCA
12	60	23/30	16/20
14	100	29/37	19/25
16	150	37/47	24/31

>80% of all Galactic SN with a single detector block!

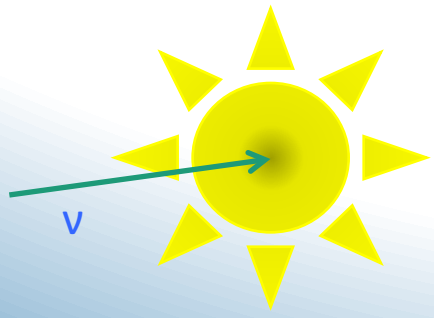
High E_ν: Neutrino events reconstruction



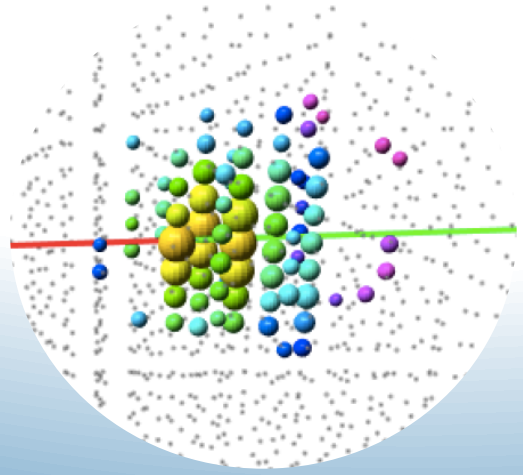
track-like events ν_μ(CC)

Angular resolution:
ANTARES: <0.4° (full, E>10 TeV)
ARCA: <0.2° (full, E>10 TeV)
ORCA: < 5° (zenith, E> 10 GeV)

Energy resolution:
ANTARES: <0.5 (log E_μ)
ARCA: <27% (E_μ)
ORCA: <30% (E_ν)



shower-like events
ν_μ(NC), ν_e, ν_τ

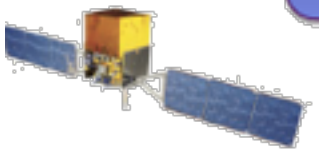


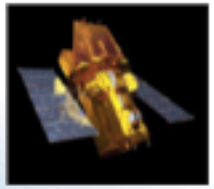
Angular resolution:
ANTARES: ~3° (full, E>10 TeV)
ARCA: ~2° (full, E>10 TeV)
ORCA: < 5° (zenith, E> 10 GeV)

Energy resolution (E_ν):
ANTARES: ~25%
ARCA: <5%
ORCA: <26%

Multi-messenger programs

following ANTARES





GeV-TeVγ-rays
Fermi / HESS…

UHECR
Auger

HE neutrinos

Optic / X-ray
TAROT,MASTER,
ROTSE / Swift,
ZADKO

HE neutrinos
Icecube

Gravitational
Waves
Virgo / Ligo

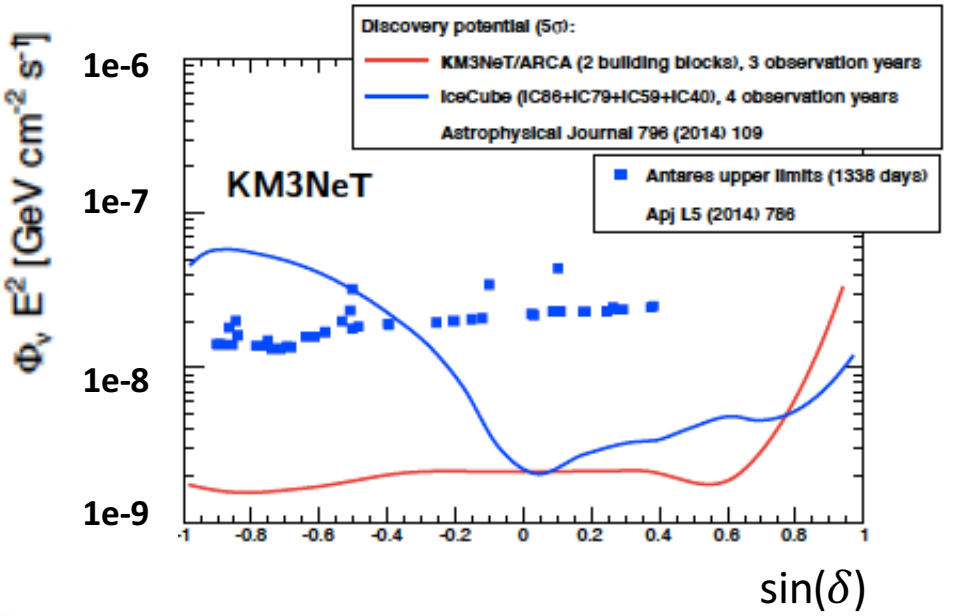
* participation to AMON
Astrophysical Multimessenger Observatory Network

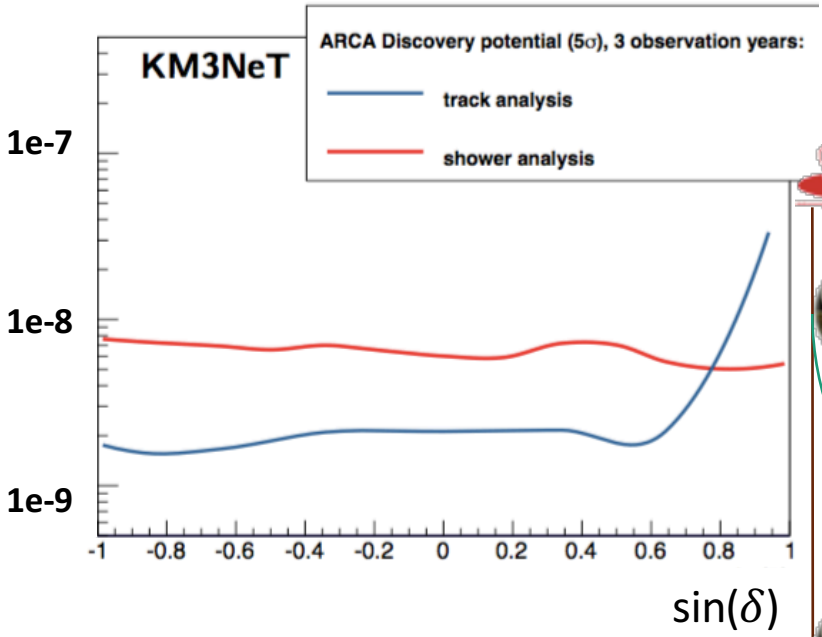
+SNEWS for low E_ν:
receiving alerts for ANTARES
sending with KM3NeT?

Asterics

Bringing together the astronomy, astrophysics and particle astrophysics communities.

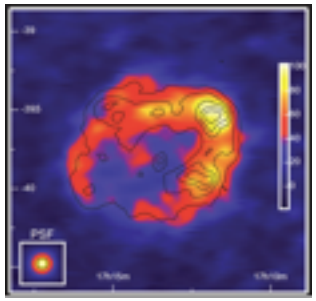
Long term observations (SNR)

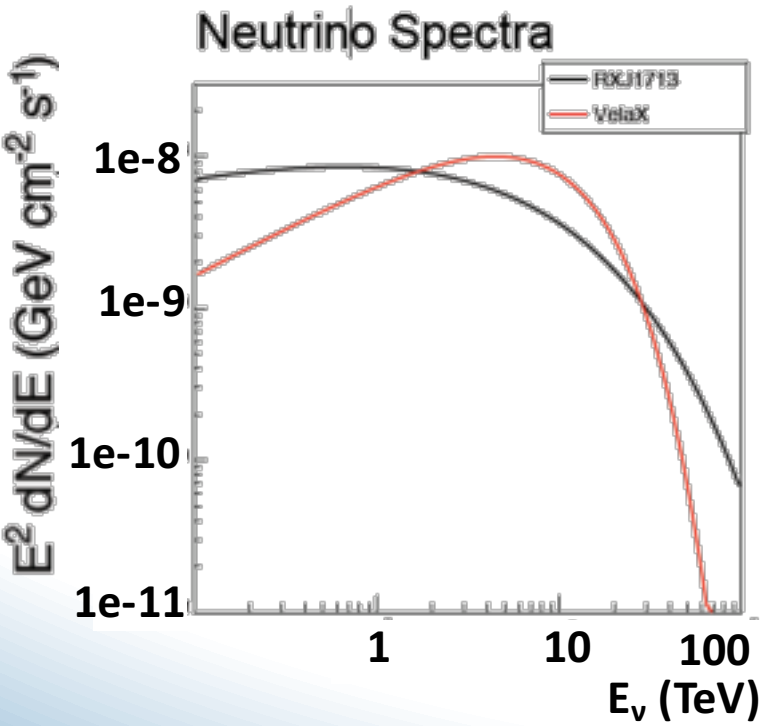


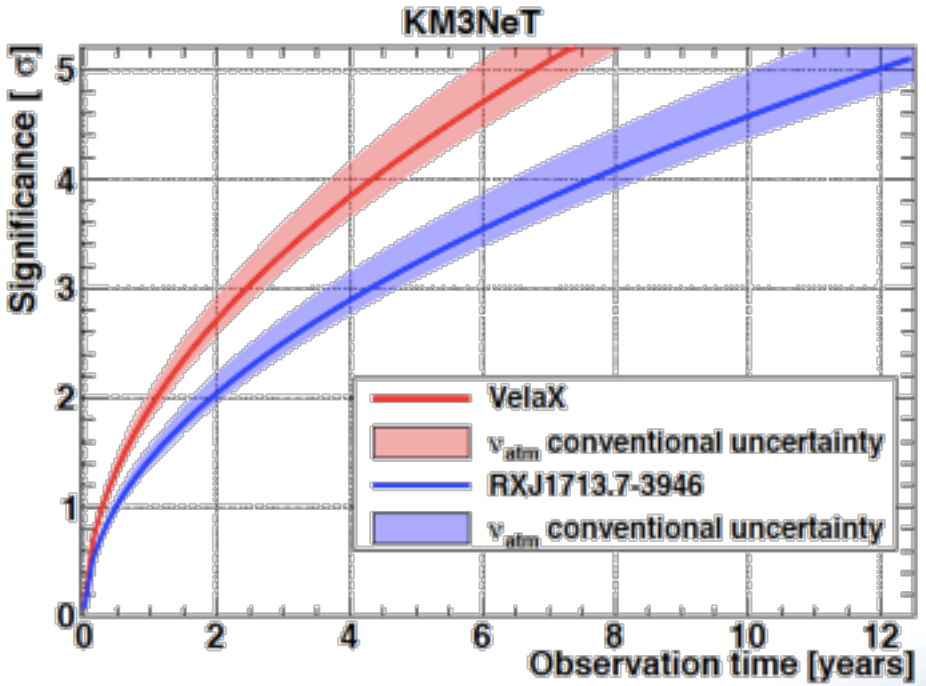


- KM3NeT sensitivity for point-like sources with unbroken E^{-2} spectrum. ANTARES upper limits.
- Shower channel is also promising (especially for N.H.).
- *SNRs are almost point-like sources for the ν telescopes.*

RXJ1713 (test case SNR)





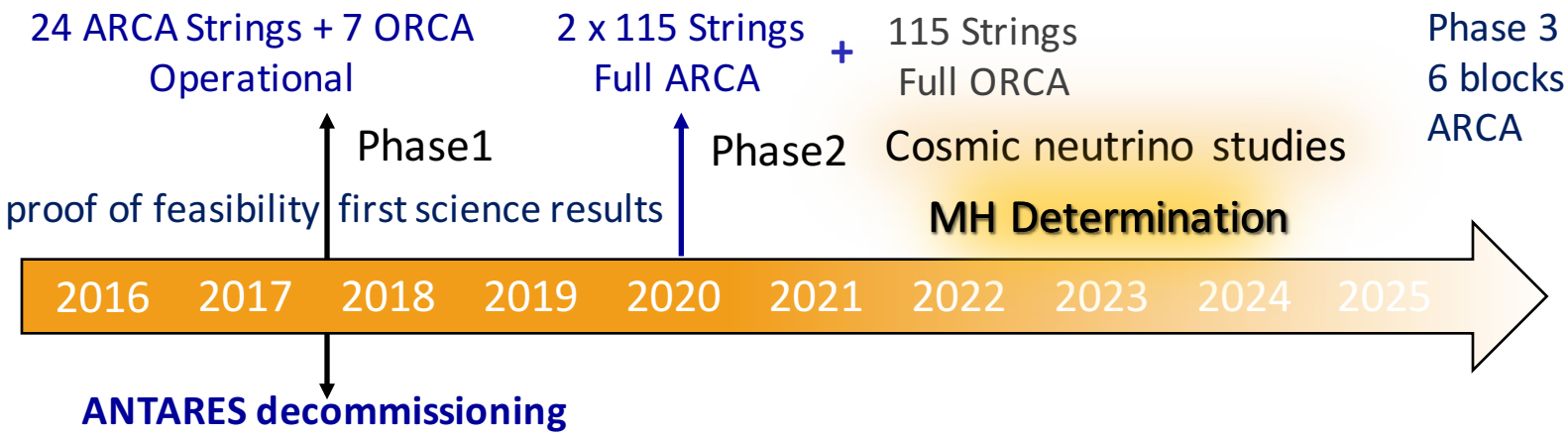


Neutrino fluxes estimation from the measured gamma-ray flux (H.E.S.S.) and assuming a pure hadron model

F. Vissani, Astropart. Phys. 26, 310 (2006).
S. R. Kelner et al, Phys. Rev. D 78 039901 (2009)

Even few neutrinos detection would be
an ultimate argument for hadronic/leptonic accelerator debates.

Achieved and planned goals



- ANTARES is on its 10th year of data taking
- DOM prototype tested in situ (2500 m) — 🕮 Eur. Phys. J. C (2014) 74:3056
- DU prototype tested (3 DOMs) in situ (3500 m) — 🕮 Eur. Phys. J. C (2016) 76: 54
- Detector geometries well defined
- Letter Of Intent is published — 🕮 J. Phys. G: Nucl. Part. Phys. 43 (2016) 084001
- Data taking at ARCA is ongoing with two DUs already
- ORCA infrastructure is ready to operate the first DUs
- Mass production of the DUs is in preparation (for ORCA and ARCA)
- KM3NeT 2.0 is in ESFRI Roadmap 2016

Summary and Perspectives

- ANTARES:
  - Prompt low E_ν: SNEWS alert receiving, modest sensitivity (~5σ at 5 kpc).
  - Hidden jets: broad real time multi-messenger programs (in particular, to/from optical, X-ray, V.H.E. gamma telescopes).
  - Long term point sources searches (SNR).
- KM3NeT: phased construction of a next-generation neutrino detectors (ARCA & ORCA).
  - Both detectors: encouraging preliminary sensitivities for galactic **SN prompt emission** (future big player in time domain).
  - ORCA: optimised for low energy (GeV) neutrinos (**hidden jets**).
  - ARCA: great capabilities for point-like search (**SNR**).






Prepare and be patient to see the new explosion.
Mnt. Etna