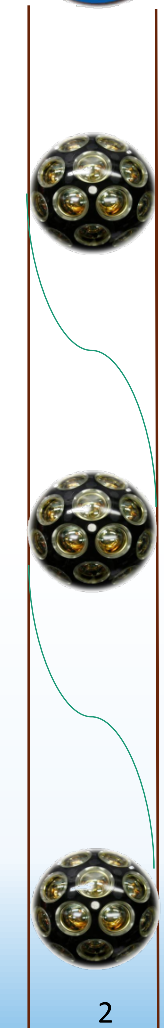
ANTARES and KM3NeT programs for the supernova neutrino detection

V. Kulikovskiy (INFN Genova) on behalf of KM3NeT

Detection strategies

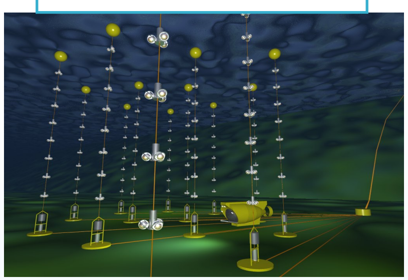
- ANTARES and KM3NeT are ν telescopes made of 3D PMT arrays in the deep sea water well shielded from atmospheric muons.
  - **Prompt SN emission** (20 MeV neutrinos) should produce the increase of PMT rates in the detector. No event reconstruction but high sensitivity in time domain.
  - **Hidden jets** (~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

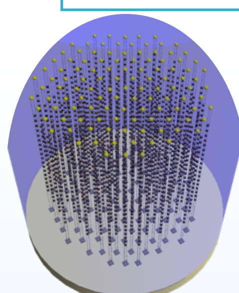
	ANTARES	ORCA (denser)	ARCA (larger)
Eff. Mass	10 Mt	5.7 Mt	1 Gt
Line length	350 m	200 m	650 m
Interline distance	70 m	20 m	90 m
Vertical spacing	14.5 m	9 m	36 m

12 lines
25 sectors/line

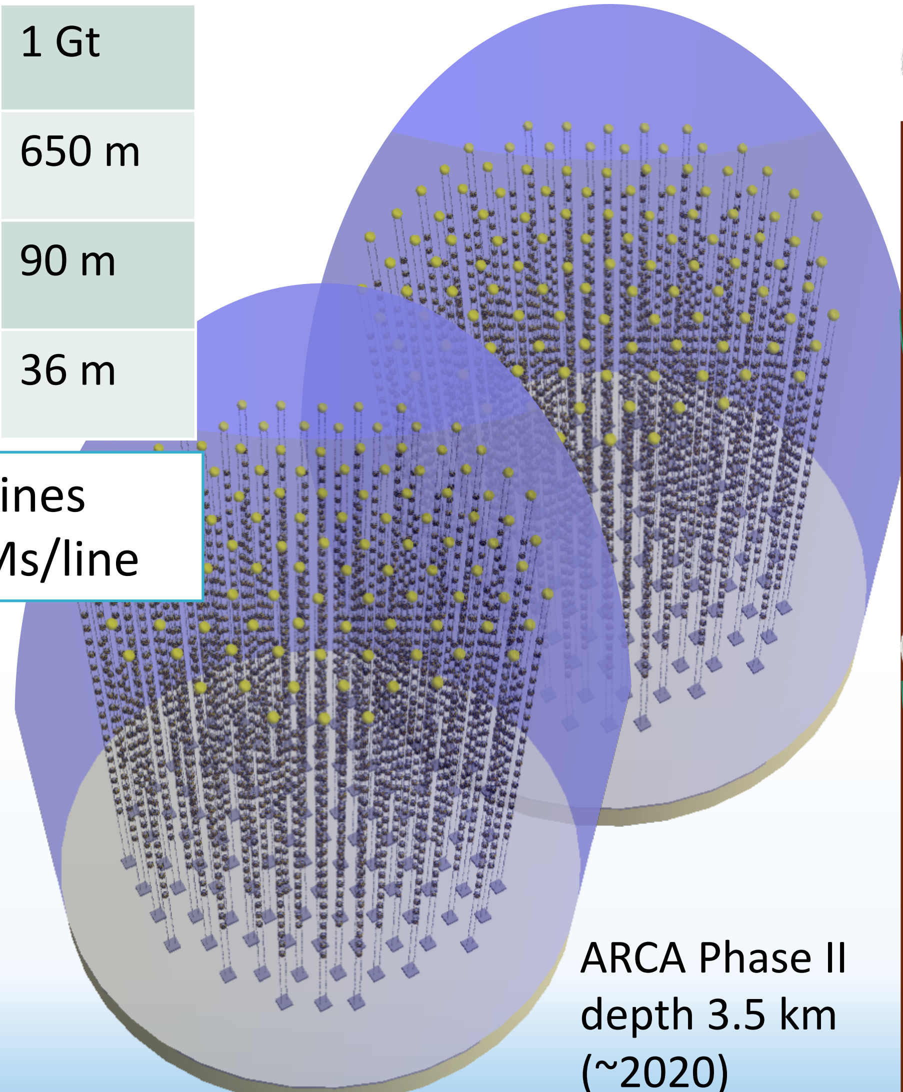


ANTARES
depth 2.5 km
(completed since 2008)

115 lines
18 DOMs/line



ORCA
depth 2.5 km
(~2020)

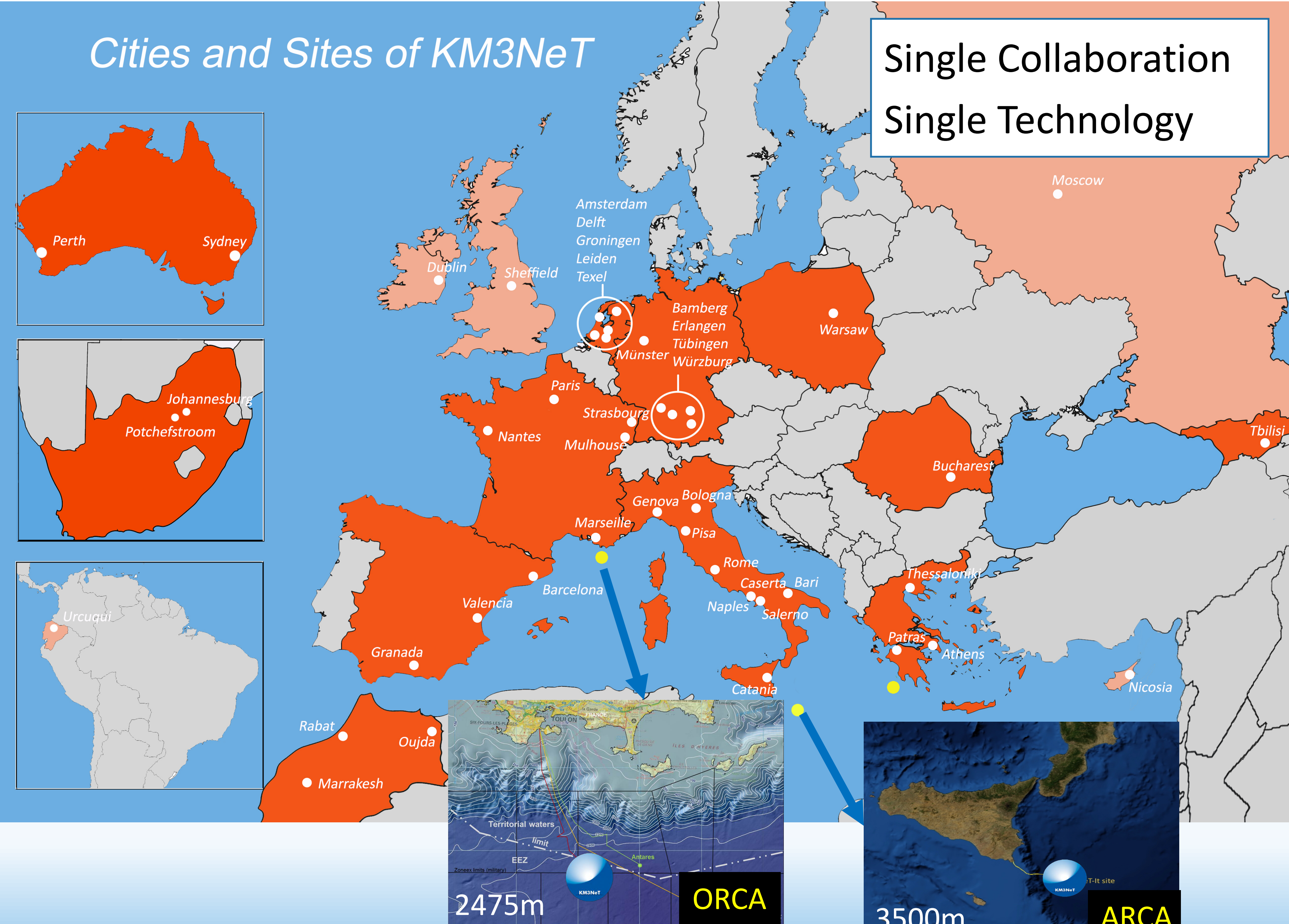


ARCA Phase II
depth 3.5 km
(~2020)

Cities and Sites of KM3NeT

Single Collaboration

Single Technology

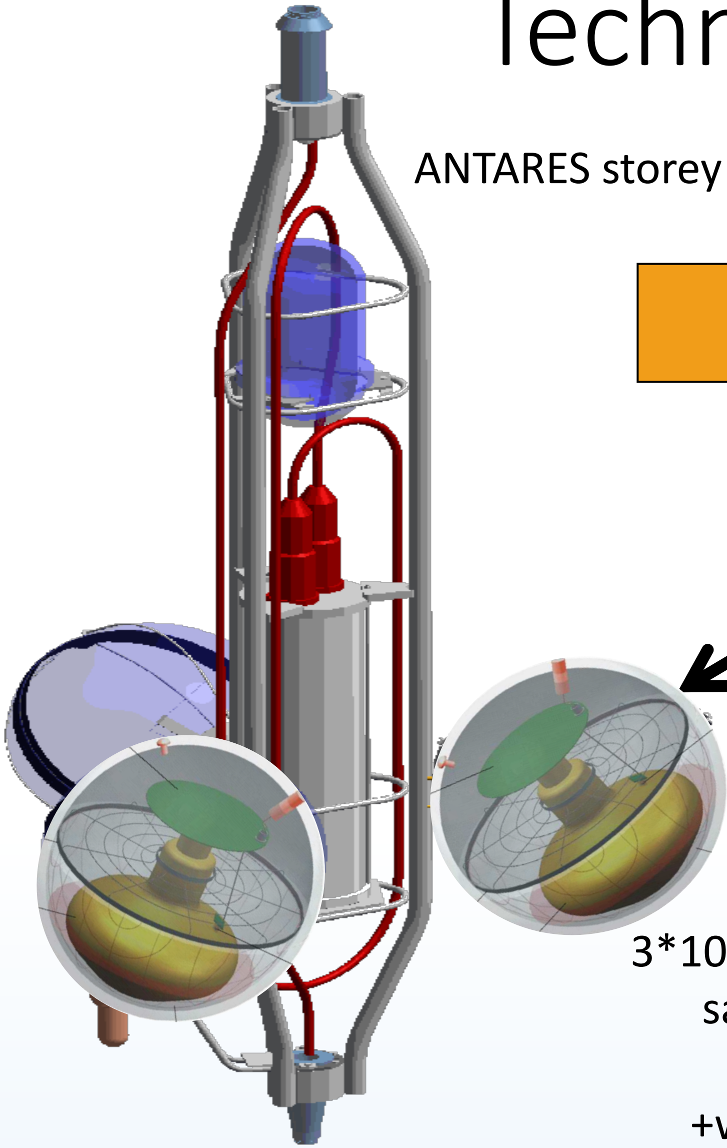


ν mass hierarchy study (GeV ν)

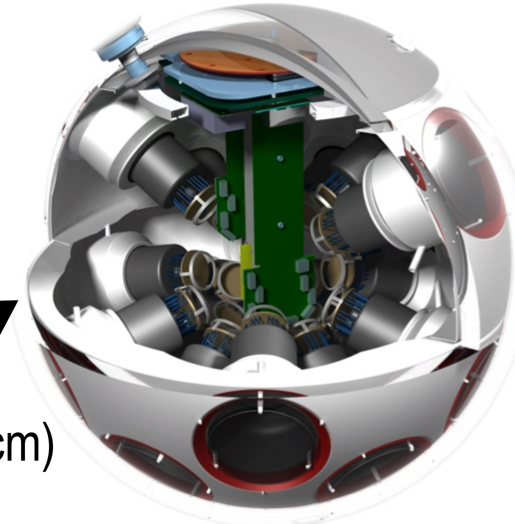
HE ν astronomy (TeV ν)

Technologies

ANTARES storey

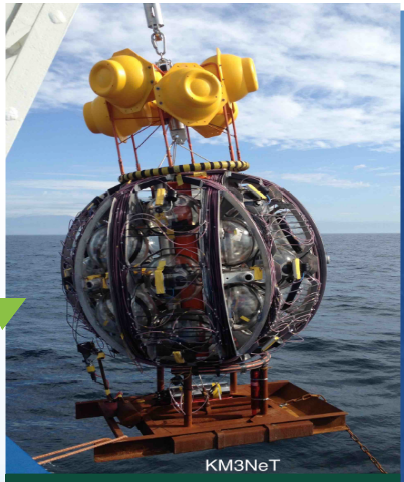


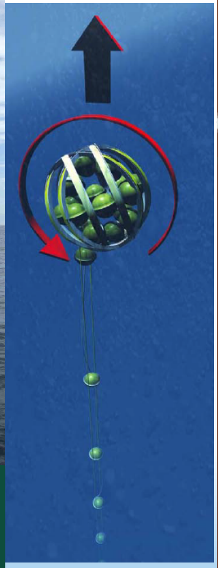
DOM



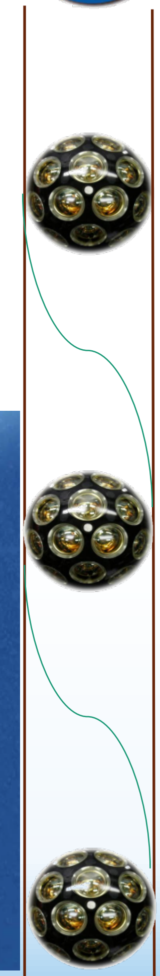
Same size (43cm)

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



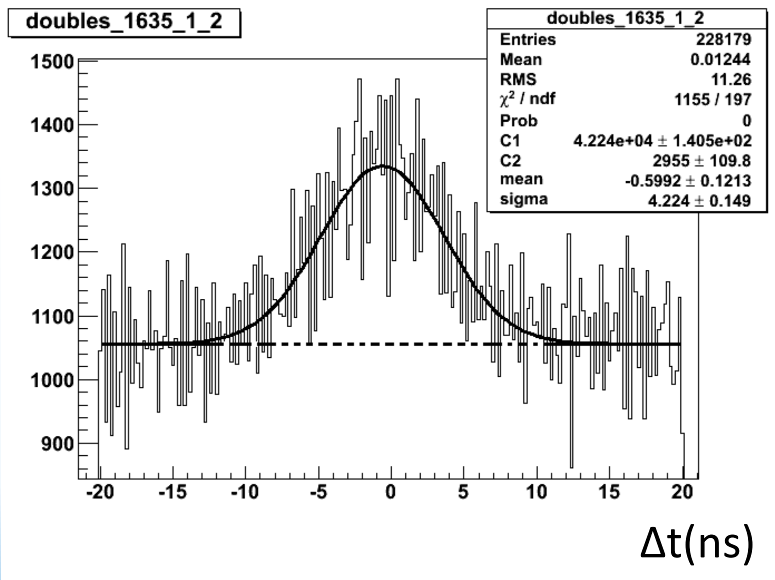


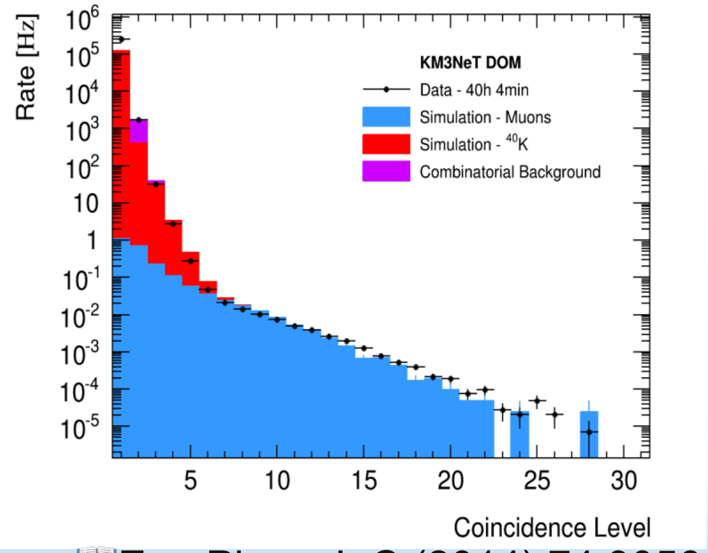
rapid deployment
autonomous unfurling
recoverable



Supernova prompt neutrino detection

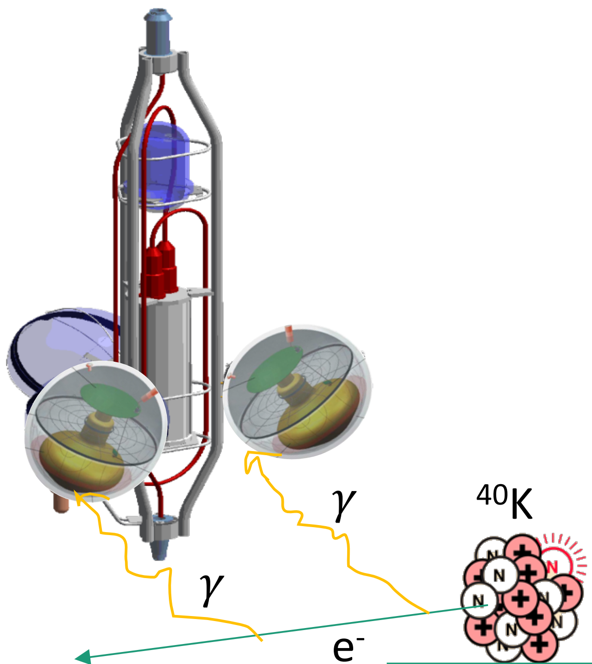
- The main channel – inverse beta decay.
- e^+ of ~10 MeV instantly populate the detector volume.
  - Event reconstruction is not possible.
  - Coherent increase of the light in the detector can be seen.
  - KM3NeT DOM – PMT coincidence level (total p.e. charge) gives an indication about the released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





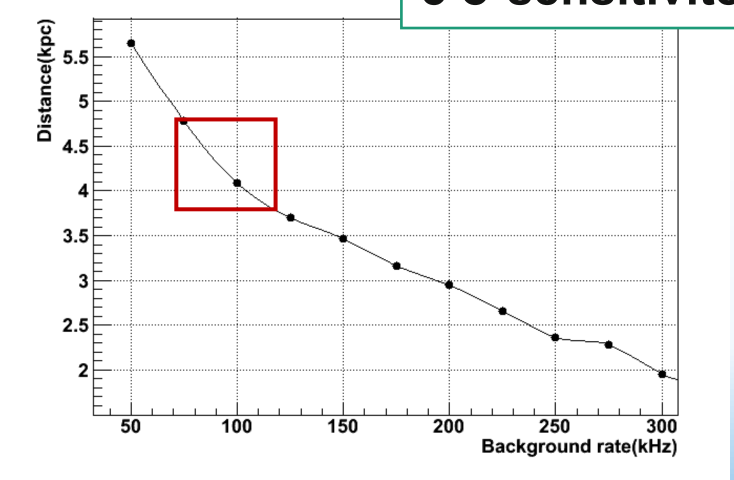
📖Eur. Phys. J. C (2014) 74:3056

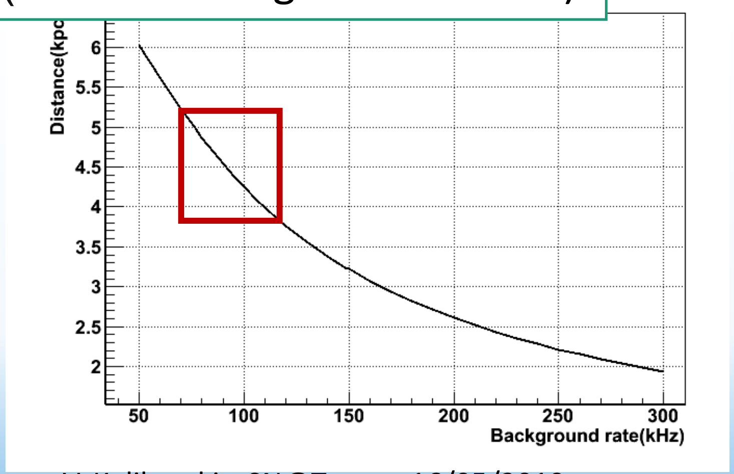
ANTARES



- 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.
  - SN ν flux - model #57 of A. Burrows, APJ 334 (1988) 891.
- Analysis of 100ms around the emission peak.

5 σ sensitivites (📖 Proceedings of ICRC2011)

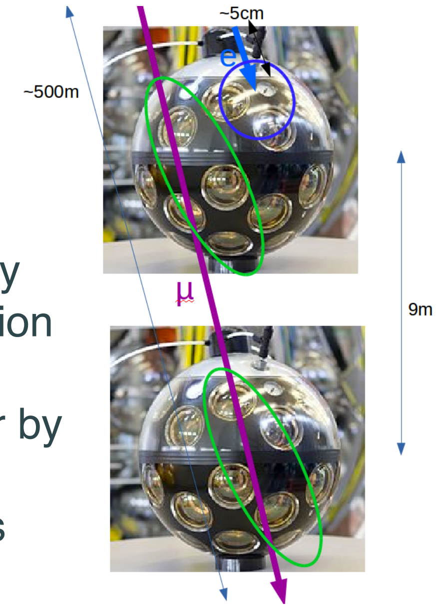


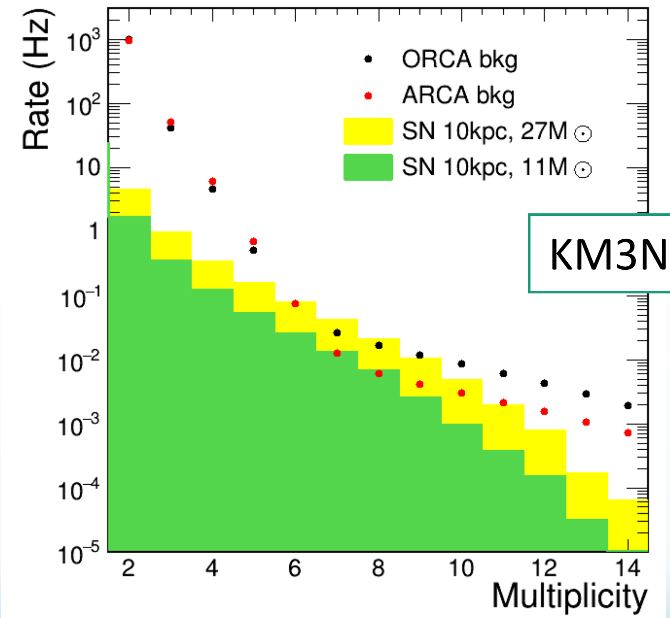


KM3NeT sensitivities (I)

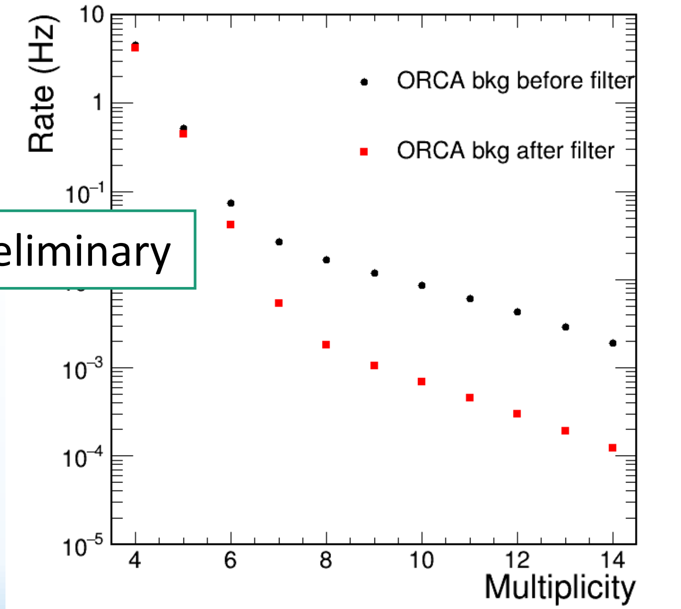
- 3D CCSN flux simulation from MPA Garching Group (only accretion phase considered in this analysis).
  - 97% inverse Beta Decay (IBD), 3% elastic scattering, <1% CC on ^{16}O
- An increase in coincidence rates is observable especially in the multiplicity range 6-10 (used for SN trigger).
  - 40K dominates multiplicity up to 6-7,
  - Atmospheric muons starting from 8.

Muon filter for ORCA geometry either by selection of correlated coincidences or by exploiting the physics triggers





KM3NeT Preliminary

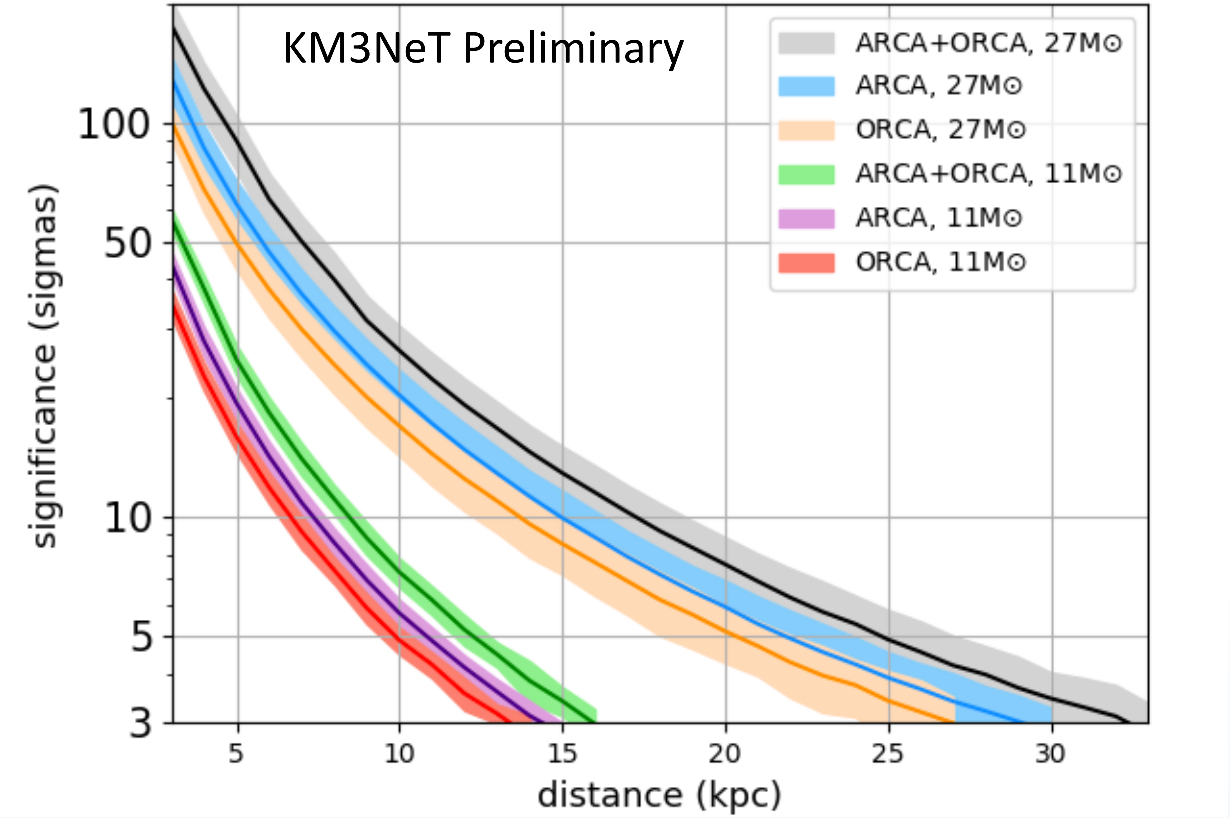


SN rates are average rates over 543ms for 27M and 340ms 10M.

📖 M. Colomer-Molla @ VLVnT 2019

KM3NeT sensitivities (II)

- **Full galaxy** coverage for the **27 M** progenitor and **beyond the galactic center** for the **11 M** progenitor!



M. Colomer-Molla @ VLVnT 2019

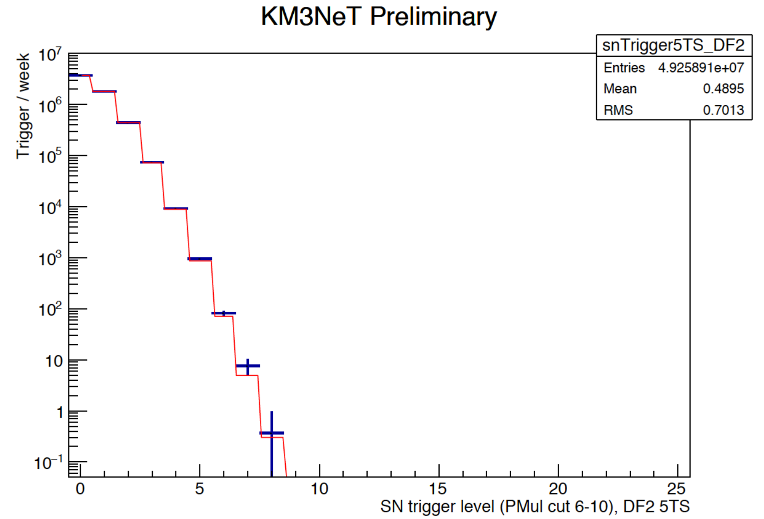
KM3NeT real time search

- A sliding time window of width = 400 ms is updated with a f_s = 10 Hz sampling frequency.
  - Optimum time window from the sensitivity optimisation is 543ms for 27M and 340ms for 10M models.
- This turns the p-value into a false alert rate:

$$R_B(X \geq X_D) = f_s \sum_{X=X_D}^{+\infty} P(\rho_B \cdot \tau, X)$$

- The sampling f_s is optimised in order to:
  - minimise the signal loss due to the time discretisation;
  - avoid unnecessary increase of the number of time-trials.
- Batch analysis of few months of ORCA (1 line deployed) and ARCA data (2 lines deployed) show that the approach is stable and follows very well the Poisson expectation.

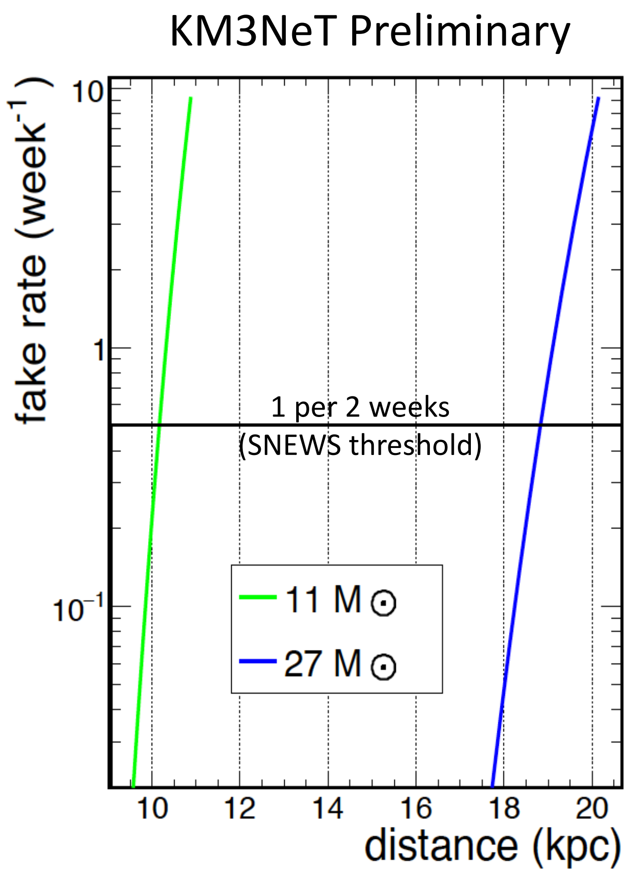
Offline processing of ORCA 1 line data (500 ms window, ~75 days of livetime)



Observation rate vs. trigger level

Joining SNEWS

- Global network combining in real-time alerts from different detectors.
- Online trigger performance for full ORCA block has coverage up to galactic center.
- Time detection of SN arrival at different sites (detectors) can provide direction via triangulation.

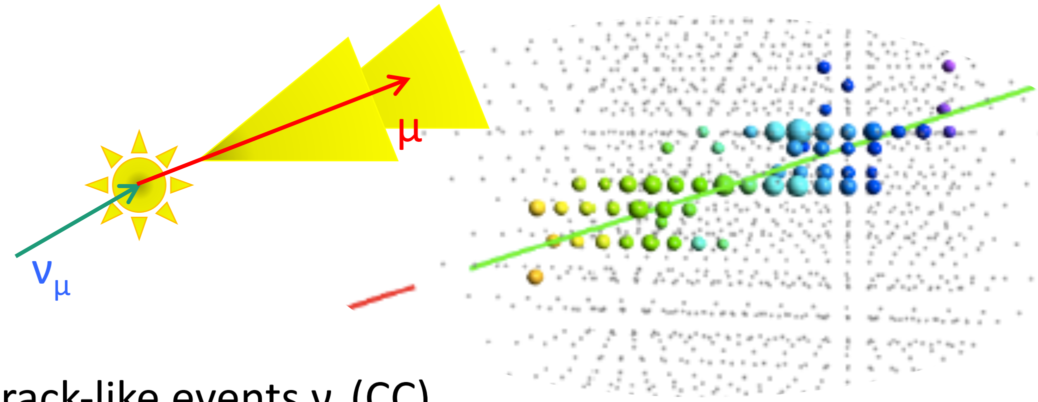


M. Lincetto @ VLVnT 2019

SN light curve studies

- Having CCSN detection at several sites one can estimate the direction of the neutrino flux using arrival time delays.
- Instead of comparing detected neutrino "light" curves with a model to derive arrival times (📖V. Brdar *et al* JCAP 1804 (2018) 025) one could directly compare light curves between experiments to guess lag between them (τ).
  - Model independent (fitting to the model requires that every detector agrees on the common model and what to call arrival time - peak time, time above some threshold etc).
  - Sites using different detection channels (IBD, ES) can be harder to directly compare together.
- Joint sensitivity study between KM3NeT and IceCube is started to test the approach!
  - Number of events is binned with 1-10ms bins (equal for both detectors) - histograms n_i and m_i). One of the histograms (m_i) is shifted by j number of bins to try to match with other histogram (n_i).
  - Bin by bin summed Chi-square test statistic between two histograms is minimized to find $\tau = j\Delta$ (where τ is the arrival lag, Δ is the time bin width):
  - Cross-correlation is tried as well.
- In KM3NeT multiplicities of 2 PMTs seems to be promising for this study (cleaning from bioluminescence, reasonable statistics in 1-10ms bins).
  - This data is also studied for SASI oscillations search!

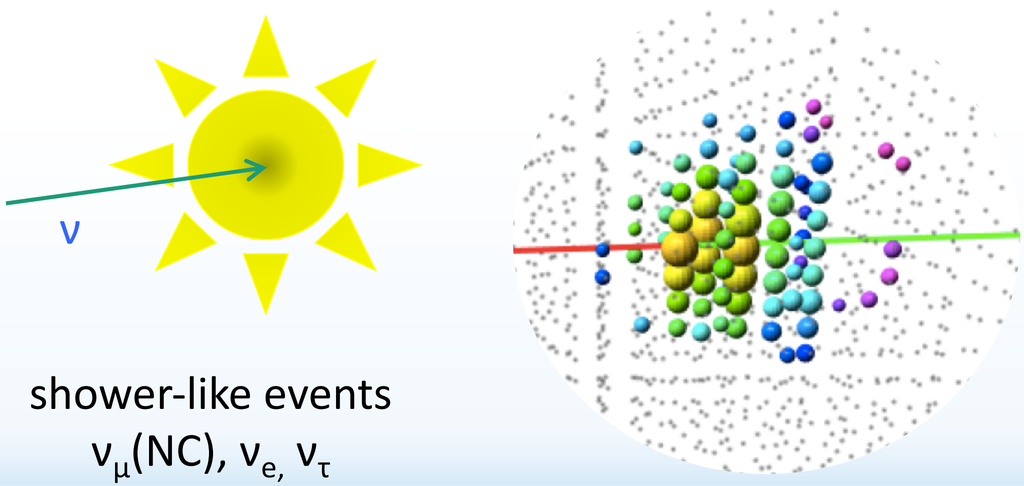
High E_ν: Neutrino events reconstruction



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)



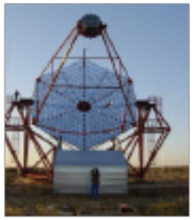
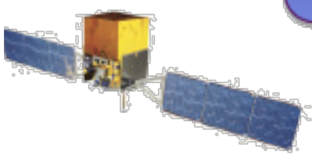
shower-like events
ν_μ(NC), ν_e, ν_τ

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

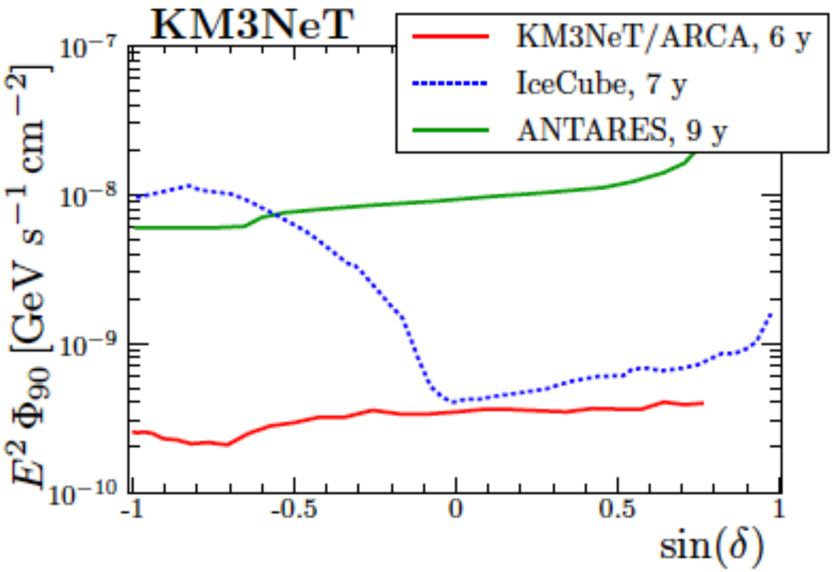

* participation to AMON
Astrophysical Multimessenger Observatory Network

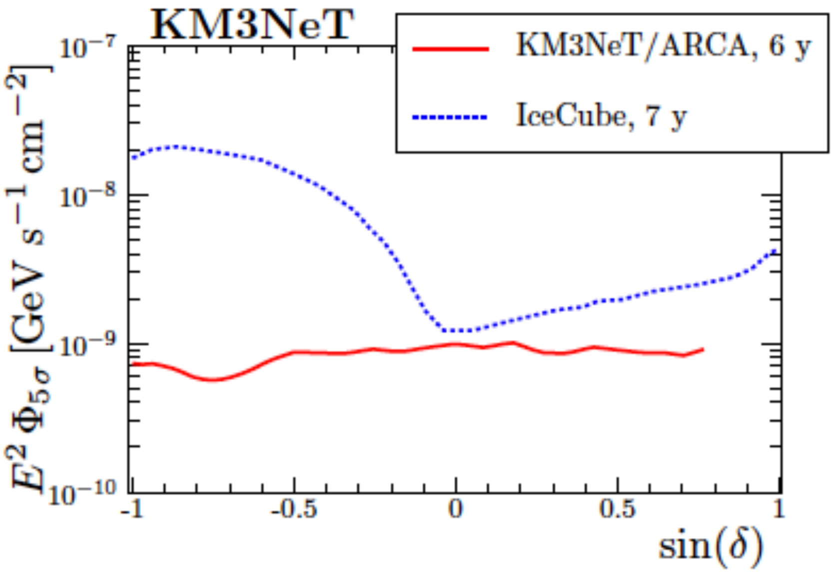
+SNEWS for low E_ν:
receiving alerts for ANTARES
sending with KM3NeT

Asterics
Astronomy ESFRI & Research Infrastructure Cluster

Bringing together the astronomy, astrophysics and particle astrophysics communities.

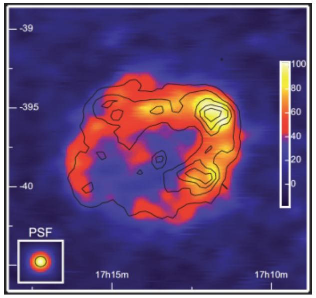
Long term observations (SNR)

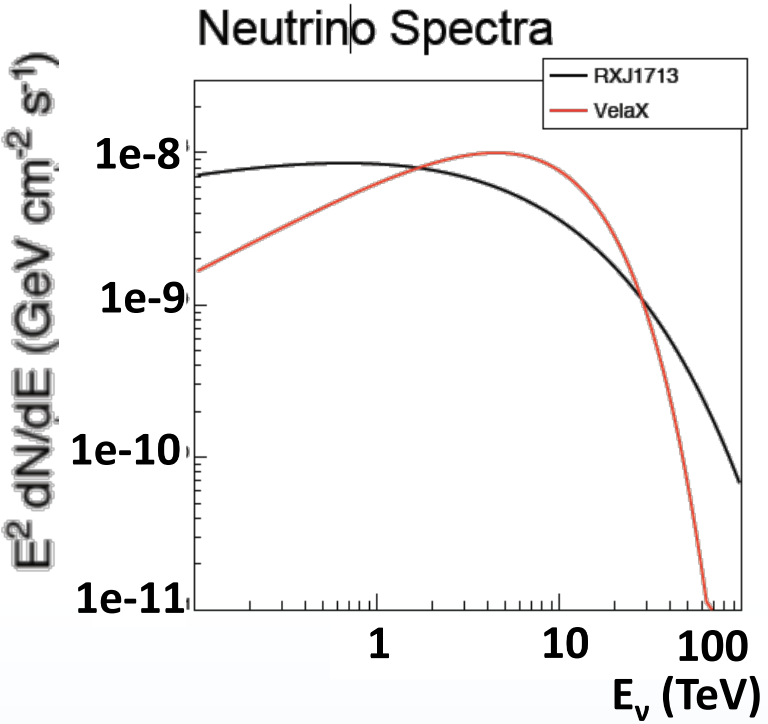


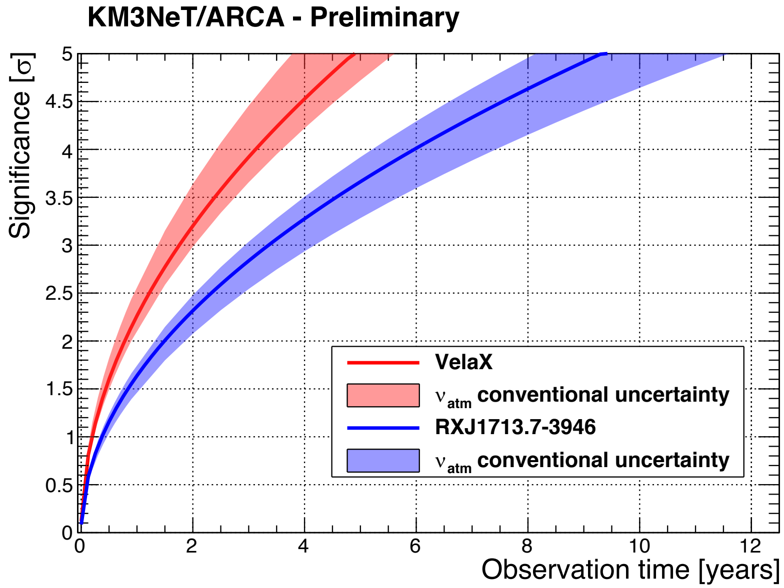


- KM3NeT sensitivity for point-like sources with unbroken E^{-2} spectrum. ANTARES upper limits.
- Shower channel is also promising (especially for N.H.).
- *SNRs are almost point-like sources for the ν telescopes.*

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.

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).
  - ANTARES is still taking the data (after 10 years of operation in the sea).
- 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).
    - Triangulation with SNEWS partners is under study.
    - Possibly, sensitive to SASI and neutrino energy spectrum fit.
  - ORCA: optimised for low energy (GeV) neutrinos (**hidden jets**).
  - ARCA: great capabilities for point-like search (**SNRs**).
  - ARCA and ORCA are currently taking data with one DU each and more lines will be deployed this year.