Core-collapse supernova neutrino detection in KM3NeT

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Core-collapse supernovae

Explosive phenomena that can occur at the end of the life of massive stars. The explosion mechanism is not fully understood, but neutrinos play a fundamental role in it.

99% of gravitational energy released through neutrinos when photons cannot escape the star!

First and only observation as of today: 24 neutrinos detected from SN1987A, future events will bring thousands.

KM3NeT detector

KM3NeT ORCA and ARCA [1] neutrino detectors are 3D arrays of digital optical modules (DOMs), 6210 in total.

A DOM features **31 PMTs in a spherical glass sphere**, with on-board front-end electronics.

18 DOMs are vertically connected to form a **detection unit** (DU).

Optical backgrounds in seawater: radioactive decays, bioluminescence and atmospheric muons.

Simulation of CCSN neutrinos

State-of-the-art 3D simulations of four CCSN progenitors of 40 $M_\odot$, 27 $M_\odot$, 20 $M_\odot$ and 11 $M_\odot$, by the Garching Group [2].

Detailed GEANT4 simulation of the detector response to such flux.

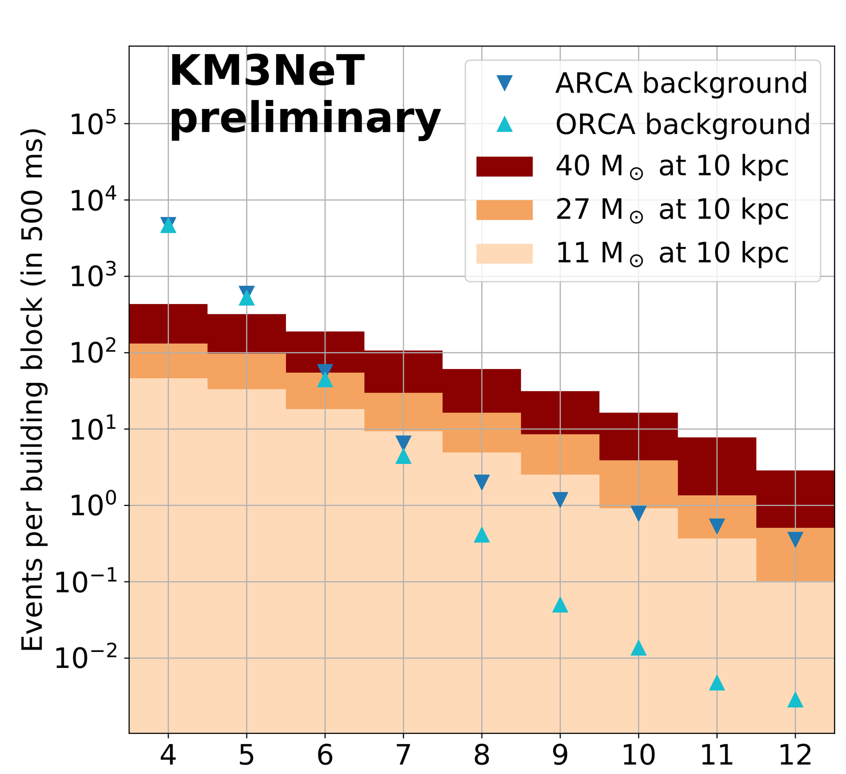
Detection principle

Coincidences between PMTs on KM3NeT DOM are counted as a function of the number of hit PMTs (***multiplicity***);

High multiplicity selection allows to **suppress bioluminescence and radioactive decays**;

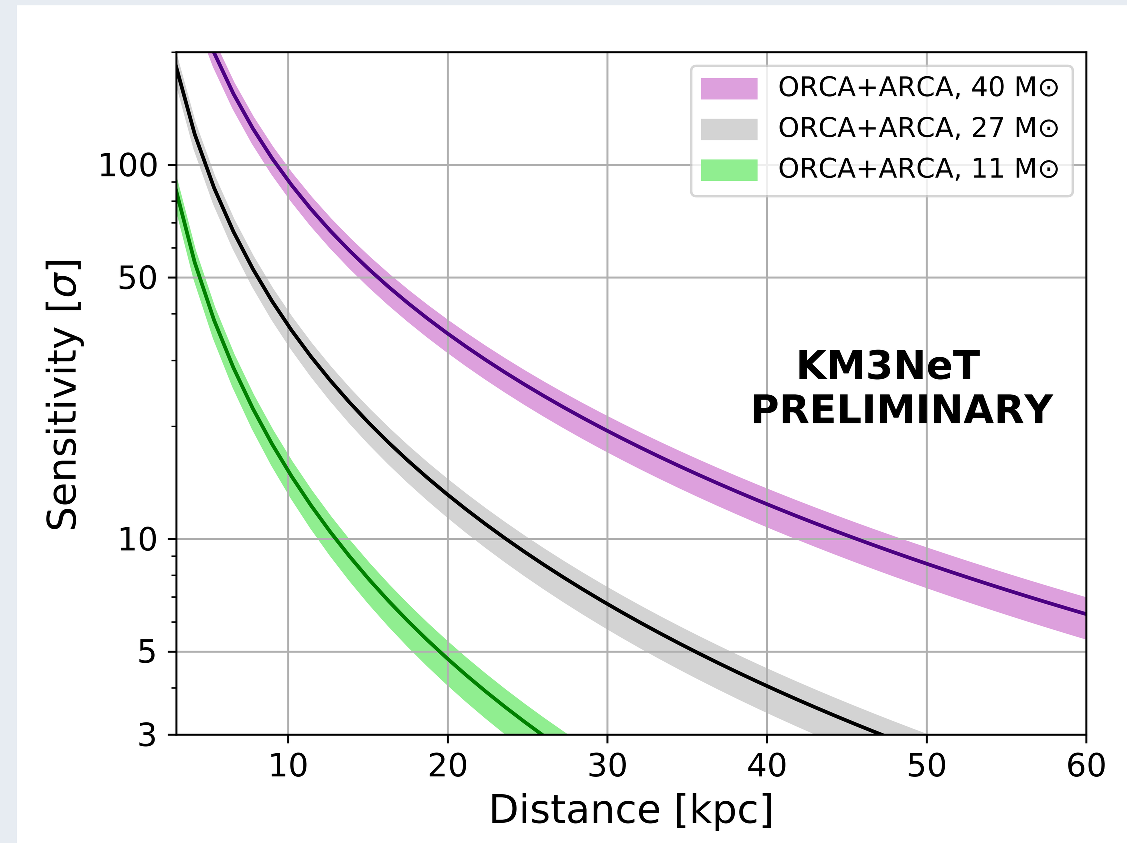
KM3NeT triggers are used to **reject correlated events from atmospheric muons**;

Rates as a function of the multiplicity are compared for signal and background in the figure below:



Detection sensitivity

Expected significance based on **7-11 multiplicity coincidences**, after the filter, in a 500 ms time window.



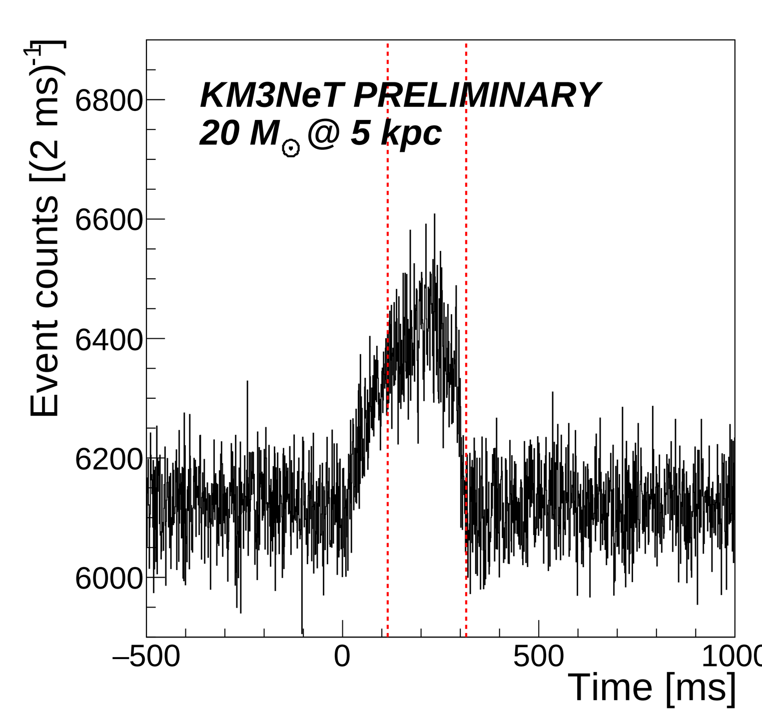
Above 95% of Galactic CCSN progenitors covered with KM3NeT at 5 σ discovery potential! ($\sim$20 kpc)

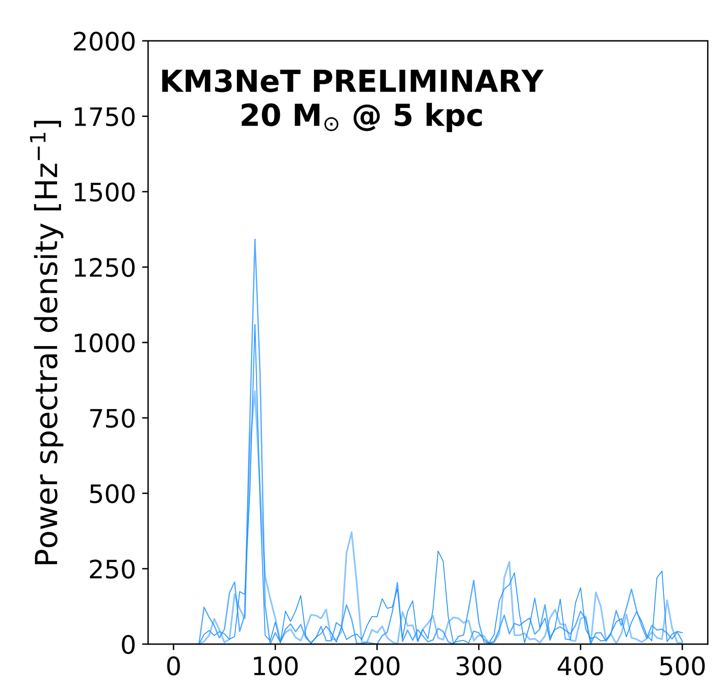
Detection of SASI oscillations in the ν light-curve

Standing Accretion Shock Instability: anisotropic hydrodynamical instabilities predicted by state-of-the art 3D simulations.

SASI would enhance the neutrino heating, favouring the explosion. Observable as **fast oscillations in the neutrino light-curve** with a characteristic frequency $\rightarrow$ **spectral analysis of neutrino data**

*Figures below show the expected light-curve in ARCA (20 $M_\odot$ at 5 kpc) using all coincidences (left), and the **Fourier transform** with a visible peak at **80 Hz** (right).*





Progenitor	d [kpc]	unkown f_{SASI}	known f_{SASI}	Galactic coverage
27 $M_\odot$	3	2.8±0.7σ	4.1±0.9σ	3%
20 $M_\odot$	5	3.2±0.7σ	4.5±0.9σ	10%
40 $M_\odot$	8	3.8±0.7σ	>5σ	35%

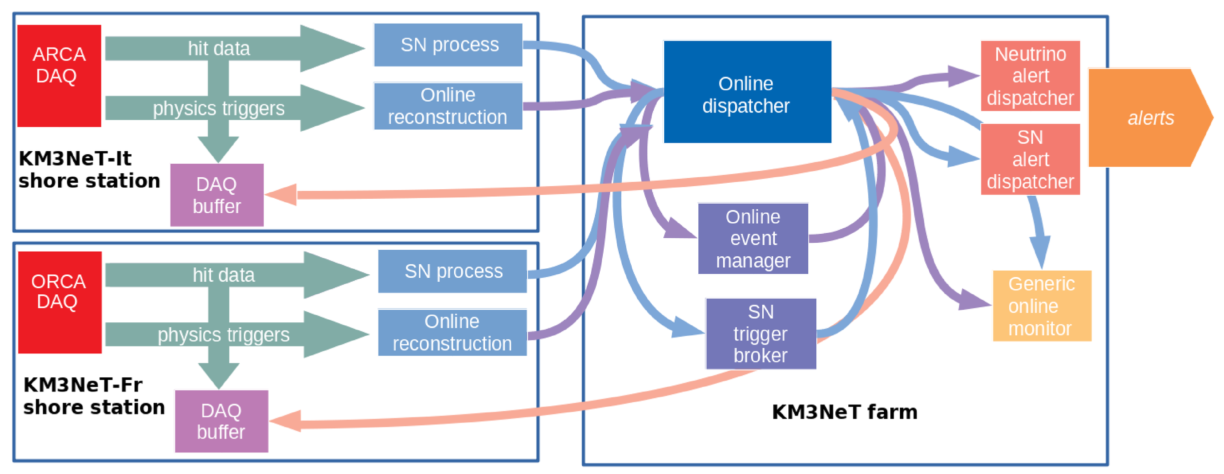
Sensitivity estimated searching for a energy excess in the power spectrum.

Real-time monitoring

Sliding window search: number of coincidences in the selection evaluated every 100 ms over a 500 ms time window.

ARCA and ORCA data are combined in a single trigger, alert generation with latency below 20 s.

Functional diagram of the real-time monitoring system in fig. below.



KM3NeT is now connected to the SNEWS network! [3]

CCSN Alert sending: FAR < 1/8 days.

Currently operational: ORCA 6 DUs can trigger up to 5.4 and 9.5 kpc, correspondingly for the 11 $M_\odot$ and 27 $M_\odot$ progenitor flux.

End of 2020 prediction: ARCA 2 DUs + ORCA 10 DUs will be able to trigger up to 6.6 and 11.8 kpc for the 11 $M_\odot$ and 27 $M_\odot$ progenitor flux (10% to 75% Galactic coverage, respectively).

Follow up of LIGO-Virgo GW alerts

Follow-up of two unmodelled GW signals with 4 ORCA lines: S191110af (*retracted) and S200114f public alerts [4]

CCSN neutrino search starting at the GW trigger time.

No significant excess found for the two alerts followed. Cfr. GCNs #26751(*) and #26249.

- Lower limits on the CCSN distance: 6 – 12 kpc.
- Upper limits on the total energy emitted in neutrinos, assuming $\langle E_\nu \rangle = 15\,\mathrm{MeV}$: $E_\nu^{90\%} \simeq 3 \times 10^{53}$ erg at 10 kpc .

References

[1] KM3NeT Collaboration, *J. of Phys. G 43 (8), 084001* (2016)

[2] I. Tamborra et al., *Phys. Rev. D 90, 045032* (2014)

[3] K. Scholberg, *arXiv:eprint: astro-ph/9911359* (2000)

[4] *https://gracedb.ligo.org/superevents/public/O3/*