Prospects for CCSN alert triggering with KM3NeT

Workshop on core-collapse supernova neutrino detection

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July 04-05, 2018

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KM3NeT design key points

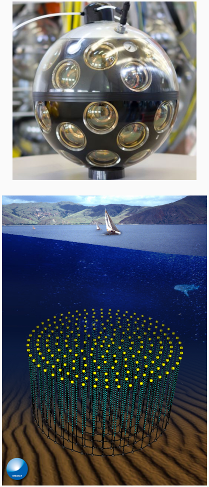

Figure 1: KM3NeT DOM and building block

- 31 PMTs per DOM, 18 DOM per line (detection unit, DU), 115 lines per block;
- Two blocks for the ARCA (IT) and one block for the ORCA (FR) detector;
- local **coincidence** $\equiv$ cluster of hits on the same DOM within 10 ns;
- **multiplicity** $\equiv$ number of hit PMTs in a coincidence.

KM3NeT DAQ system

Overview

- **all data to shore**: every detected hit over 0.3 PE (L0) is recorded with ns time accuracy and sent to the on-shore datafilter;
- the **optical datafilter** builds local coincidences (L1) and produces corresponding data streams (data downsampling is foreseen);
- the **trigger algorithms** process the hit/cluster datas treams and produce triggered events for GeV-TeV scale physics.

Supernova monitoring

- Dedicated **supernova coincidence datastream** including high-multiplicity (≥ 4) coincidences;
- **Sampling of PMT single rates** on sub-ms scale is foreseen to compensate the downsampling of low-level data.

KM3NeT background for the CCSN signal

- **PMT single rates**: 250 kHz per DOM from **^{40}K decays** in sea water (+ **bioluminescence** contribution);
- **Coincidences**: dominated by **^{40}K decays** for low multiplicities and **atmospheric muons** for high-multiplicities.

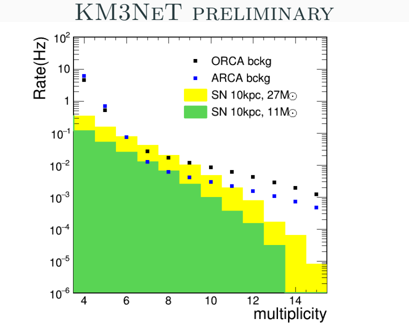

Figure 2: Multiplicity rates for background and signal (Garching model) in KM3NeT.

- Effective volume for **single hit detection** is larger but **correlation of bioluminescence noise** is difficult to constrain without real data from a multi-line detector → study of single rates is undergoing;
- S/N does not benefit from the inclusion of low-level multiplicities → selection of **high-level coincidences (6-10 multiplicity)**.

Background rejection strategies

Bioluminescence

- **Localised bursts** affecting neighbors PMTs $\rightarrow$ channels recording a hit rate over 20 kHz are suppressed (**high-rate-veto**);
- **Diffuse glows** are well-suppressed by the coincidence selection.

^{40}K in seawater

- Constant rate uncorrelated background that affects to **6-fold coincidences**;
- Application of an **angular cut** to the hits allowed in coincidence has a slight reduction effect.

Atmospheric muons

- Cherenkov tracks from muons produce high-multiplicity correlated concidences across DOMs on a μs time scale.

ORCA muon rejection filter

Same approach used both **offline and online**.

- Reject events with at least two $M \geq 4$ coincidences within $1\,\mu$s on different DOMs.
- Introduces a 2% dead time dominated by ^{40}K random coincidences.

KM3NeT PRELIMINARY

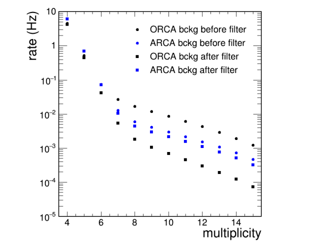

Figure 3: Multiplicity rates before and after filter

Multiplicity	6	7	8	9	10	$\sum_{6-10}$
ORCA rej. eff.	40%	80%	90%	90%	92%	62%
ARCA rej. eff.	12%	26%	35%	35%	35%	17%

Foreseen development (ARCA): use of physics events identified by the trigger to suppress the DOMs in correspondence with muons.

KM3NeT CCSN sensitivity

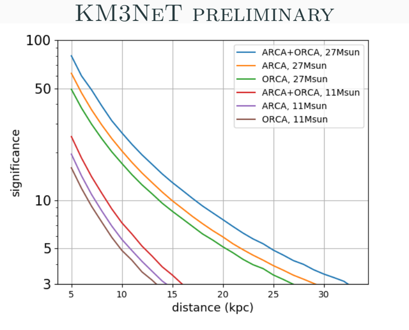

Figure 4: Sensitivity of KM3NeT to a CCSN supernova neutrino burst

- This sensitivity estimation assumes a **known arrival time** of the CCSN neutrino burst.
- The signal is evaluated on a defined time window τ after the exact time of the event.

$$\text{(p-value)} \equiv P(X \geq X_T) = \sum_{X=X_T}^{+\infty} \mathcal{P}(\rho_B \cdot \tau, X)$$

What if we don't know the onset time?

"Bring yourself online!"

Configuration & false rate

- sliding time window $\equiv \tau$
- sampling frequency $\equiv f$

$$R_B(X \geq X_T) = f \sum_{X=X_T}^{+\infty} \mathcal{P}(\rho_B \cdot \tau, X)$$

Robustness

Switch to **DOM counting** instead of coincidence counting (maximum of one coincidence in the SN cut per DOM is accepted in the time window).

Significance?

No longer well-defined as long as the *observation time* T is indefinite.

Fixing T a post-trial significance can be recalculated multiplying the p-value by the resulting **trial factor** fT.

Time window optimization

- **Integral** over time is profitable as long as the signal expectation is above the background expectation;
- In general this is **distance-dependent**;
- In practice the peak of interest (accretion) is **4-500 ms wide**.

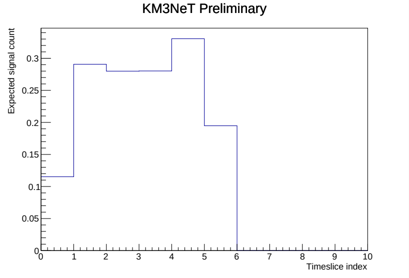

Figure 5: Expected time profile of a CCSN neutrino signal in 1 KM3NeT line, 1 timeslice = 100 ms

Sampling frequency / time binning

First approach

- If **too low**: risk of losing signal events due to the time discretization;
- If **too high**: unnecessary increase of the number of trials;
- **Natural choice** for KM3NeT is the DAQ time slicing (100 ms $\leftrightarrow$ 10 Hz).

Getting smarter

- f can be increased arbitrarily once the coincidence stream has been reconstructed;
- Instead of fixing a sampling frequency, **update the time window with each detected coincidence** $\rightarrow$ statistical model is not trivial, toy MC investigation is needed;
- Use of **bayesian blocks** approach (cfr. IceCube).

Trigger stability

- DOM counting regime is shown to be very stable and perfectly predictable with Poisson statistics;
- Bioluminescence does not impact the trigger in terms or false alerts but produces loss of efficiency due to vetoed channels.

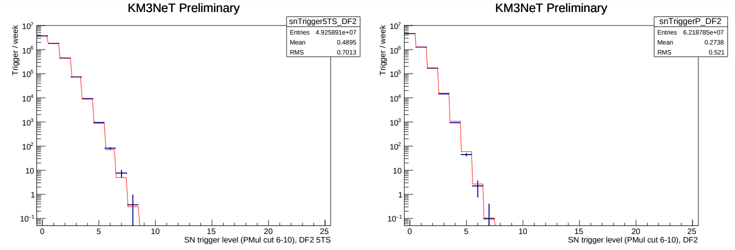

Figure 6: False trigger rate for ORCA 1 line (100 ms time window) and for ARCA 2 lines for (400 ms time window).

False alert rate

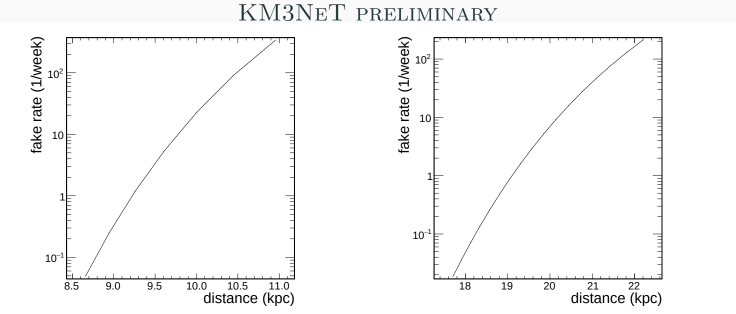

Figure 7: False alert rate expressed in 1/week as a function of the SN distance for a 27 $M_\odot$ progenitor, resp. for ORCA 10 lines (left) and ORCA 115 lines (right).

Under the **SNEWS** requirement of 1/week false alert rate requirement a coverage up to **20 kpc** is reached with 1 ORCA-like KM3NeT building block.

Conclusions

The **offline analysis** for the CCSN detection in KM3NeT can be translated with minor adaptations to a **real-time online approach for the SN triggering**.

The optimization of the time search is still under study and a more sophisticated **time-domain analysis** could bring further improvements.

According to the current estimation, a single KM3NeT block is able to trigger a 27 $M_\odot$ CCSN at **20 kpc within the false alert requirements for SNEWS**.