KM3NeT

Sensitivity estimates for diffuse, point-like and extended neutrino sources with KM3NeT/ARCA

Rasa Muller — rasam@nikhef.nl
Aart Heijboer — aart.heijboer@nikhef.nl
Alfonso Garcia Soto — aagarciasoto@km3net.de
Barbara Caiffi — barbara.caiffi@ge.infn.it
Matteo Sanguineti — Matteo.Sanguineti@ge.infn.it
Vladimir Kulikovsky — Vladimir.Kulikovskiy@ge.infn.it

on behalf of the KM3NeT Collaboration

Nikhef INFN

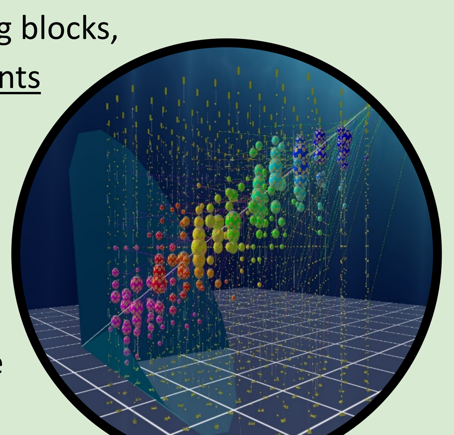
The idea in a nutshell

The **identification of cosmic objects emitting high energy (HE) neutrinos (ν)** could provide new insights about the Universe and its active sources. The **KM3NeT/ARCA detector** will excel in the identification of these neutrino sources thanks to its **precise angular resolution** (< 0.2 degree for E > 10 TeV ν_μ events) after **event selection**. A new likelihood framework is being developed and tested with Monte-Carlo pseudo-experiments to compute the **discovery potential** and the **sensitivity** for **diffuse** and **point-like** cosmic neutrino fluxes for KM3NeT/ARCA. Other flavours (electron and tau neutrinos) will be added to the point source analysis in the near **future**. In addition, analysis steps will be refined and prepared for **real data** analysis.

ν detection KM3NeT/ARCA

Detector design [1]

- KM³ detector at the bottom of the Mediterranean Sea sensitive to GeV – PeV neutrinos. Consisting of 2 building blocks, 115 lines each, with 18 light sensitive elements to detect *"Cherenkov radiation"* caused by -apart from background sources- charged particles from a ν hitting a water molecule



Event topologies

- Track: High E μ traveling trough water before it decays. Provides good pointing resolution
- Shower: Electromagnetic/Hadronic shower (NC and ν_e^{CC} interactions). Provides good energy resolution

Background sources

- Atmospheric neutrinos (prompt & conventional) and muons
- Bioluminescence and K40 decay

Likelihood framework

In the new KM3NeT HE analysis framework, we build our H0 (background only), and H1 (signal + background) models consisting of several components (a point source / a diffuse isotropic flux / background) depending on the analysis to test

With the detector response PDF's as a function of energy and sky direction, we generate Monte Carlo pseudo experiments to analyse the sensitivity and discovery potential of KM3NeT/ARCA to diffuse and point source fluxes

The global likelihood maximised is given by

$$L = \sum_{i \in \text{events}} \sum_{k \in \text{components}} \log\left(\frac{dN_{i,k}}{d\Omega d\log(E_{rec})}\right) - N_{tot}$$

In the statistical analysis we compute relevant sensitivities and discovery potentials

BDT event selection

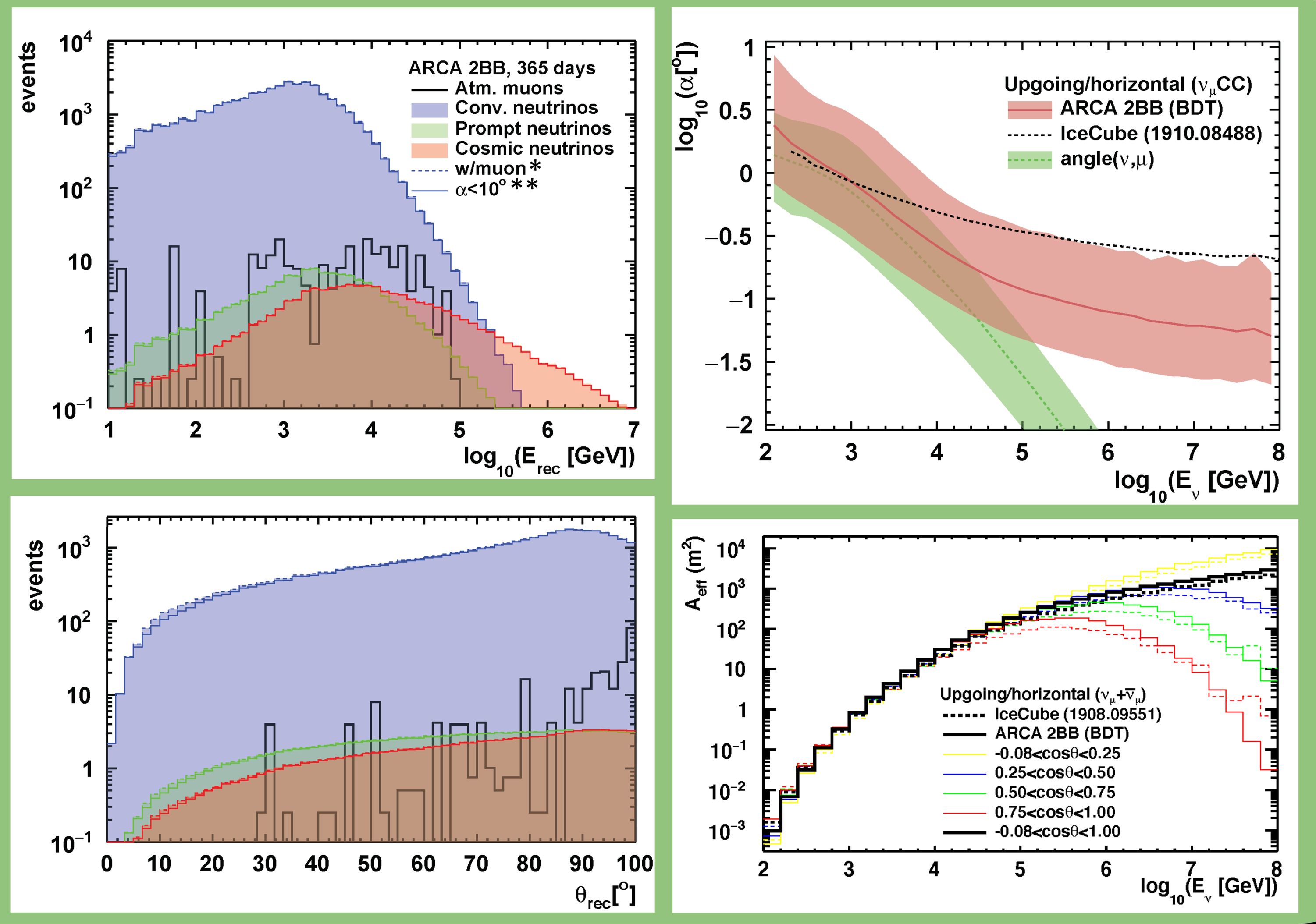
Aim: Provide clean sample of well reconstructed tracks coming from up-going or horizontal ν's interacting inside or in the vicinity of KM3NeT/ARCA115.

Signal definition: Minimal one μ producing light (i.e. photon from $\mu_{E_{max}}$ produces a hit on 2 or more different DOMs *) & reconstruction of good quality (i.e. angle between reconstructed track and $\mu_{E_{max}} < 10°$ **).

Preselection: Track exists, Direction, Rough background rejection, Clear signal selection. All doubtful cases: BDT TMVA ROOT algorithm.

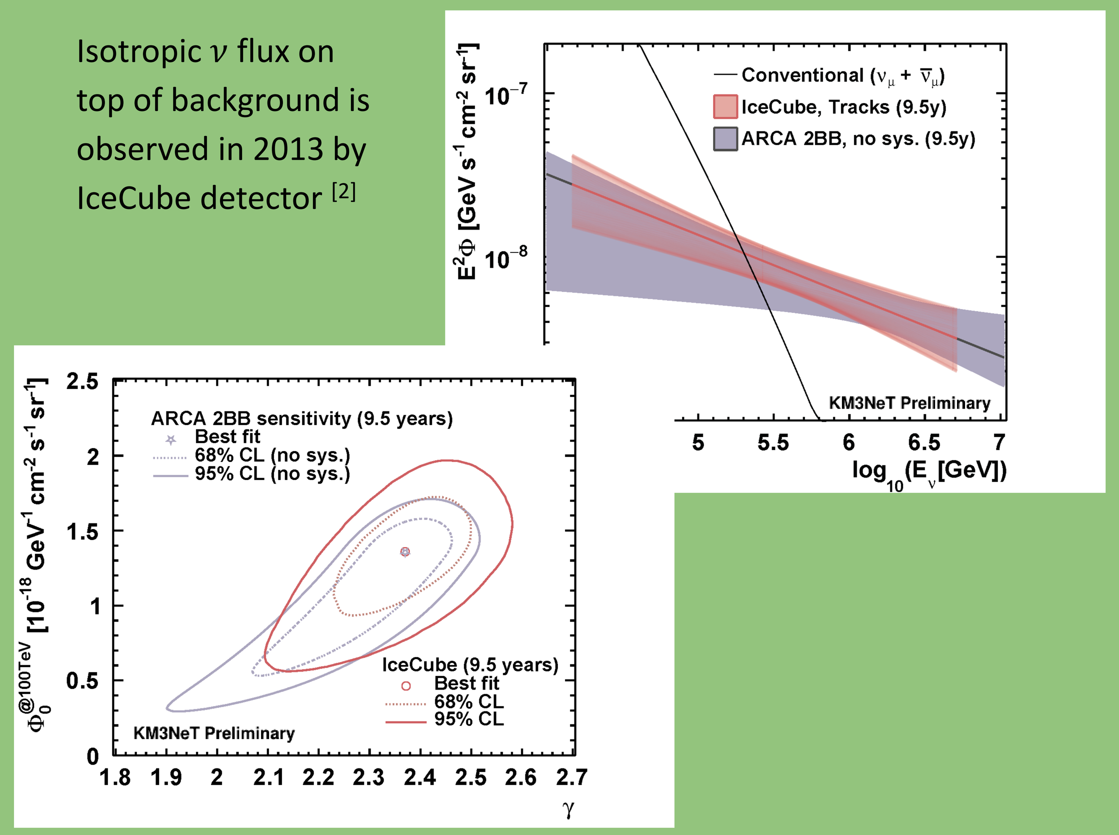
Performance: neutrino purity $= \frac{N_{\text{selected } \nu \text{ evts}}}{N_{\text{selected events}}} = 99.7\%$. Of which $> 99.9\%$ ν_μ

Plots: Energy (top left) and zenith angle (bottom left) distributions for reconstructed up-going or horizontal tracks passing the signal-like or the BDT cut. Angular resolutions (top right) as function of the E_ν for ν_μ^{CC} events. Effective area (bottom right) as function of the E_ν for the selected event sample.



Sensitivity and discovery potential for Φ_{diff} analysis

Isotropic ν flux on top of background is observed in 2013 by IceCube detector [2]



Sensitivity projections for diffuse flux. Preliminary estimations fitting three normalisations (conventional, prompt and astrophysical) and spectral index.

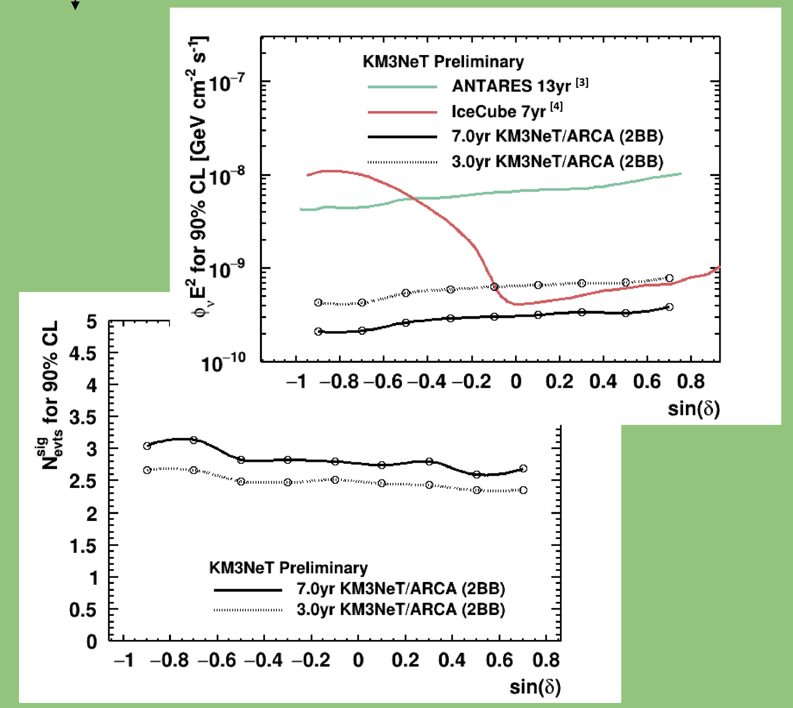
Additional systematics (detector, cosmic ray flux and hadronic models) are not incorporated yet.

Main challenge will be to disentangle prompt and astrophysical contributions.

Sensitivity and discovery potential for neutrino sources

Excess of neutrinos from one (or more) specific direction(s) in the sky may indicate the existence of ν source(s)

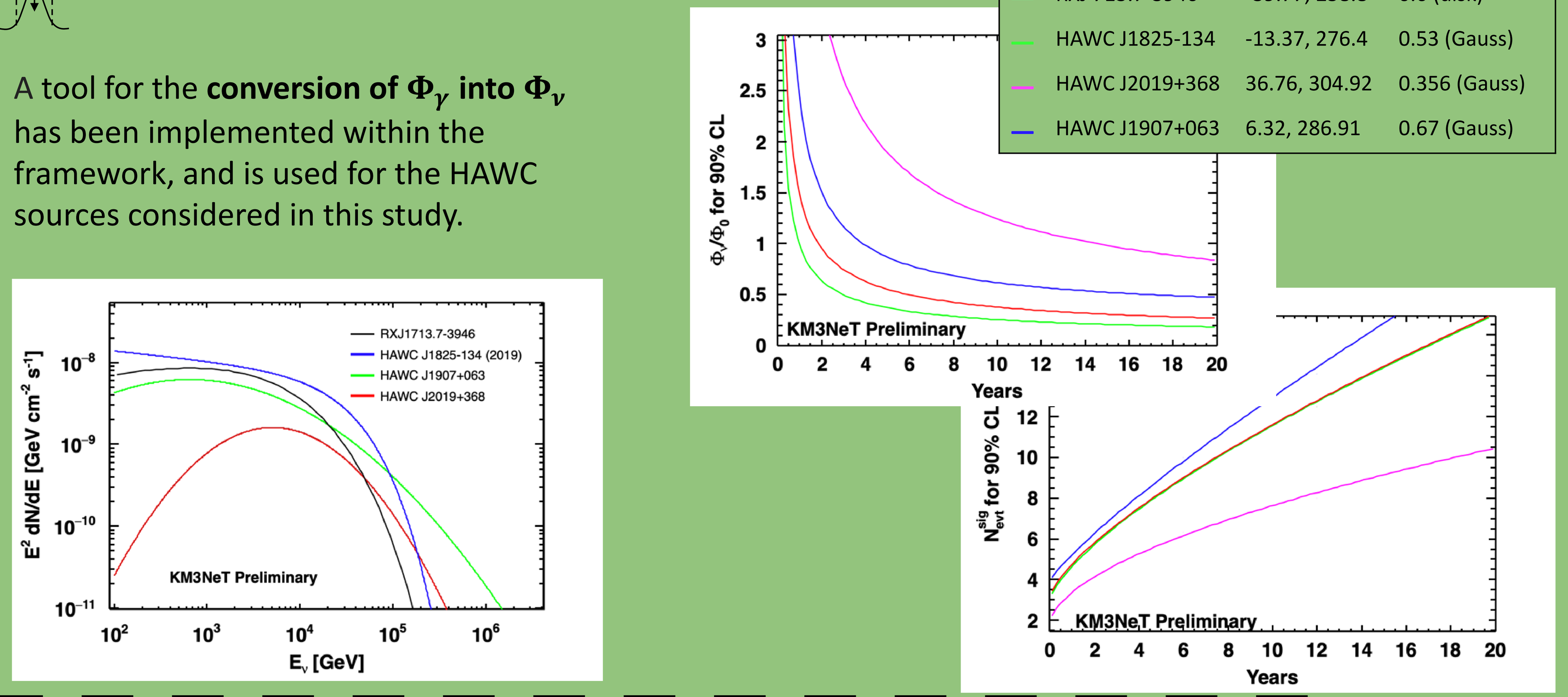
E^{-2} point source



Extended sources

A tool for the **conversion of Φ_γ into Φ_ν** has been implemented within the framework, and is used for the HAWC sources considered in this study.

Source	Decl, RA [°]	Ext [°]
RXJ 713.7-3946	-39.77, 258.8	0.6 (disk)
HAWC J1825-134	-13.37, 276.4	0.53 (Gauss)
HAWC J2019+368	36.76, 304.92	0.356 (Gauss)
HAWC J1907+063	6.32, 286.91	0.67 (Gauss)



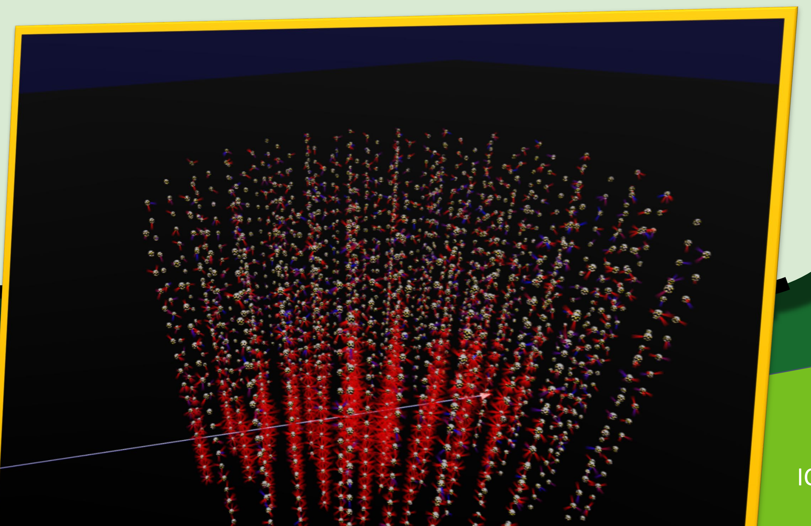
Next steps

1: Expand current MC-based work

- Include ν_τ / vary flavor contributions to flux / showers / time dependent searches
- Fine tune analysis methods / automate steps for future analysis / include systematics

2: Perform an analysis with real data!

- 6 ARCA strings taking data since April 2021! This means real data for:
  - Multi-messenger analysis
  - Follow-up studies



Take Home Message

With the new build analysis framework for KM3NeT we can compute sensitivities and discovery potentials to point sources and diffuse fluxes. Thanks to the good angular resolution for ν_μ events expected for the KM3NeT/ARCA 115 strings, the current set of selection cuts provides strong evidence that KM3NeT/ARCA will perform similar of even better than IceCube. Work is ongoing to expand this framework to do more complex studies unravelling the physics of high energy neutrino sources.

References

[1] KM3NeT Collaboration. (2016). Letter of intent for KM3NeT 2.0. *Journal of Physics G: Nuclear and Particle Physics*, *43*(8), 084001.
[2] IceCube Collaboration. (2013). Evidence for high-energy extraterrestrial neutrinos at the IceCube detector. Science, 342(6161).
[3] See ICRC contribution: poster 1142 by G.Illuminati on behalf of the ANTARES collaboration, https://indico.desy.de/event/27991/contributions/101388.
[4] IceCube Collaboration. (2017). Astroph. J. 835, 151.

July-2021
ICRC conference