LHAASO J1825-1326 , Unknown, 276.45, -13.45, 0 | LHAASO J1839-0545 , Unknown, 279.95, -5.75, 0 | LHAASO J1843-0338 , Unknown, 280.75, -3.65, 0 | LHAASO J1849-0003 , Unknown, 282.35, -0.05, 0 | LHAASO J1908+0621 , Unknown, 287.05, 6.35, 0 | LHAASO J1929+1745 , Unknown, 292.25, 17.75, 0 | LHAASO J1956+2845 , Unknown, 299.05, 28.75, 0 | LHAASO J2018+3651 , Unknown, 304.75, 36.85, 0 | LHAASO J2032+4102 , Unknown, 308.05, 41.05, 0 | LHAASO J2108+5157 , Dark?, 317.15, 51.95, 0 | MG3 J225517+2409, blazar/BLL, 343.82, 24.19, 0 | MGRO J2019+37, Unknown, 305, 38, 0.75 | NGC 1068, SBG, 40.67, -0.01, 0 | OT081, BLL, 267.89, 9.65, 0 | PKS 1424+240, BLL, 216.76, 23.8, 0 | PKS B0735+178, blazar, 114.53, 17.71, 0 | PKS B1253-055, blazar, 194.05, -5.79, 0 |

PKS B1502-106, blazar, 226.1, -10.49, 0 | PKS B1730-130, blazar, 263.26, -13.08, 0 | PKS B1741-038, radio blazar, 266, -3.83, 0 | PKS B2145+067, blazar, 327.02, 6.96, 0 | PKS0215+015, blazar, 34.45, 1.75, 0 | PKS0537-441, BLL, 84.71, -44.08, 0 | PKS0727-11, Quasar, 112.58, -11.7, 0 | PKS1454-354, BLL, 224.36, -35.67, 0 | PKS2005-489, BLL, 302.37, -48.82, 0 | QSO2022-077, BLL, 306.4, -7.6, 0 | RGBJ2243+203, BLL, 340.98, 20.35, 0 | RXJ1713.7-3946, SNR, 258.25, -39.75, 0.65 | TXS 0506+056, BLL, 77.35, 5.7, 0 | TXS0310+032, blazar of uncertain type, 48.3, 2.5, 0 | VelaX, PWN, 128.75, -45.6, 0.42

ZHWC J1949+244, Unknown, 297.42, 24.46, 1 | 3C403, radio galaxy, 298.07, 2.51, 0 | AT2019dsg, tidal disruption event, 314.26, 14.2, 0 | AT2019fdr, tidal disruption event, 257.28, 26.86, 0 | CentaurusA, radio galaxy, 201.36, -43.02, 0 | Galactic center, Galactic center, 266.42, -29.01, 0 | HESSJ0632+057, binary, 98.24, 5.81, 0 | HESSJ1356-645, PWN, 209, -64.5, 0.2 | HESSJ1641-463, Unknown, 250.26, -46.3, 0 | HESSJ1741-302, Unknown, 265.25, -30.2, 0 | HESSJ1828-099, Unknown, 277.24, -9.99, 0 | hotspot in the Southern hemisphere, Unknown, 350.2, -56.5, 0 | J0242+1101, blazar, 40.62, 11.02, 0 | LHAASO J0534+2202, PWN, 83.55, 22.05, 0 |

KM3NeT Nikhef INFN

Search for cosmic neutrino point sources and extended sources with 6 lines of KM3NeT/ARCA

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The analysis 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** has taken 92 days of data with a 6 string detector configuration between May 2021 and September 2021. After the **event selection** the **detector response** is determined and used for the **binned likelihood analysis** in order to look for a neutrino excess from 46 listed **candidate sources**. There were no strong neutrino emitters found. The lowest p-value (0.0202) was found for the radio galaxy **Centaurus A**, but this is in line with the background expectation. In the near **future** new lines will be deployed and the analysis methods will be improved in performance and speed.

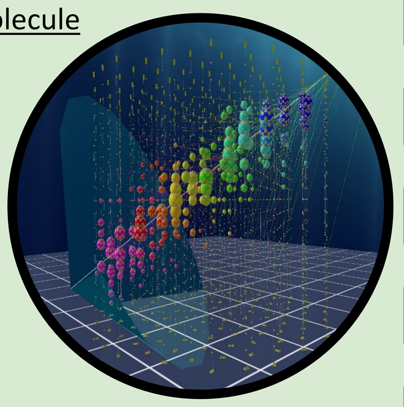
ν detection KM3NeT/ARCA

Detector [1]

- KM3 detector at the bottom of the Mediterranean Sea sensitive to GeV – PeV neutrinos. It will consist of two so called 'building blocks', 115 vertical 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

Dataset

- For this analysis 92 days of data between May 2021 and September 2021 with the first 6 lines of KM3NeT/ARCA are analysed



Event topologies

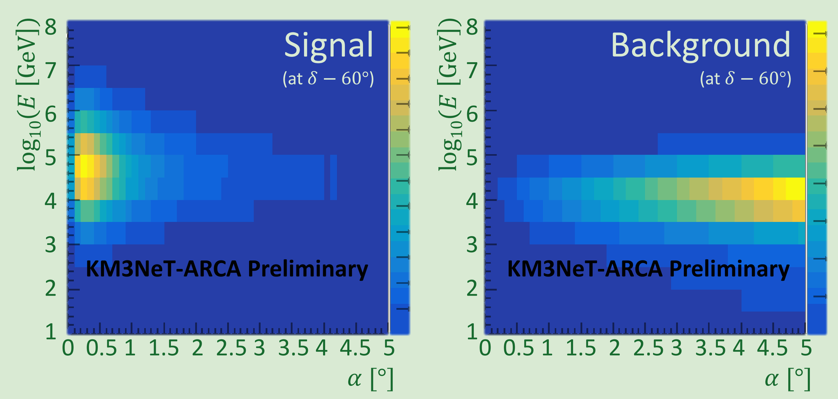
- Track: High energy μ from ν_μ^{CC} interactions, ν_τ^{CC} τ-decays or directly from the atmosphere, traveling trough water before it decays. Provides good pointing resolution
- Shower: Electromagnetic/Hadronic shower from NC and ν_e^{CC} interactions. Provides good energy resolution

Background sources

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

Analysis method

- Binned likelihood in the angular distance of the event to a source: α [°] {0 - 5} and the energy of the event: $\log_{10}(E\ [\text{GeV}])$ {1 - 8}
- H0 (background only), and H1 (signal + background) models are built from the signal and background components. Monte Carlo simulations are used for the signal modelling, and scrambled data is used for the background modelling
- The signal strength is kept as a free parameter



- The log-likelihood is the Poisson probability of the bin-contents (i):

$$\log(L) = \sum_i^{N_{bins}} N_i \log(B_i + \mu S_i) - B_i - \mu S_i$$

Where N_i is the number of events in data in bin i, and μ is the signal strength, which effectively parameterises the flux intensity
- From these log likelihoods, the test statistic is calculated as:

$$\lambda = \log(L(\mu = \hat{\mu})) - \log(L(\mu = 0))$$

Event selection

Aim:

- Provide sample of well reconstructed tracks coming from up-going or horizontal ν's interacting inside or in the vicinity of KM3NeT/ARCA6
- Since the analysis method does not require a-priori optimisation of the signal to background ratio, but will perform best with as much signal as possible, the event-selection criteria are quite loose in order to keep the signal efficiency high

Signal definition:

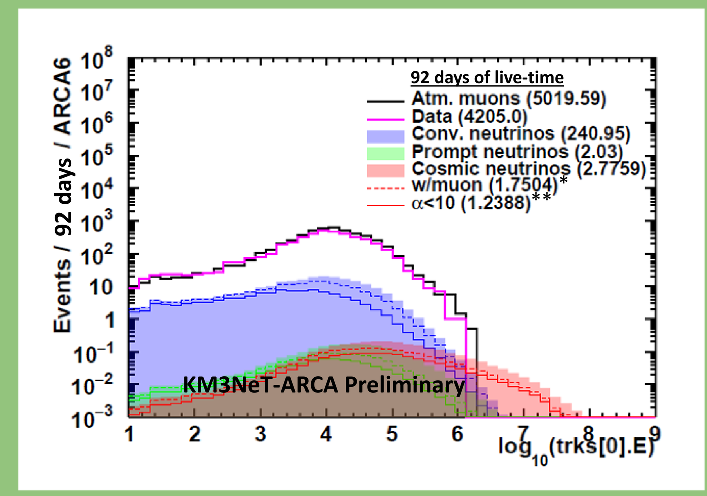
- An event with:
  - Minimal one μ producing light (i.e. photons from $\mu_{E_{max}}$ produce hits on 2 or more different DOMs (* see plot legend)
  - Reconstruction of good quality (i.e. angle between reconstructed track and $\mu_{E_{max}} < 10°$ (** see plot legend)

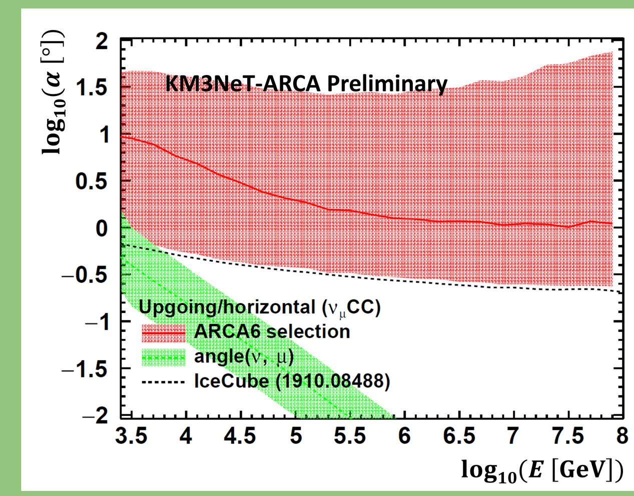
Selection:

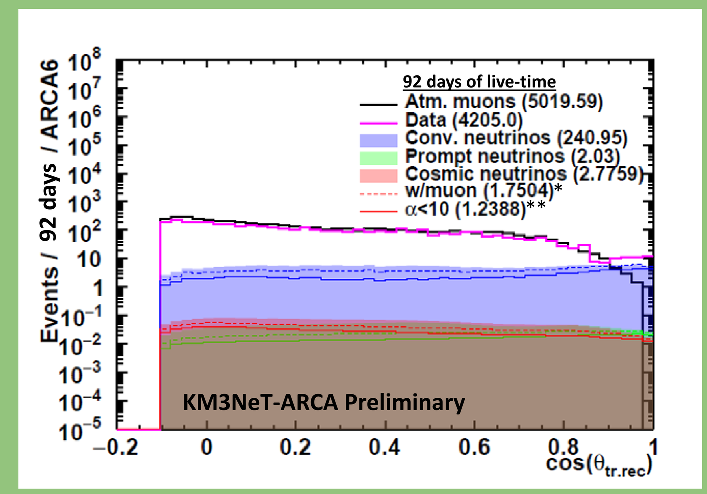
- Track exists, noise discarded, direction horizontal/up-going
- After track selection the muon contamination is 95.3%

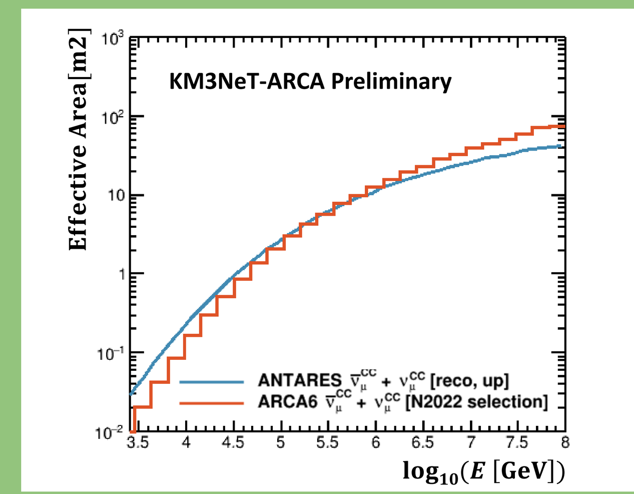
Plots:

Energy (top left) and zenith angle (bottom left) distributions for reconstructed up-going or horizontal tracks passing the event selection. 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





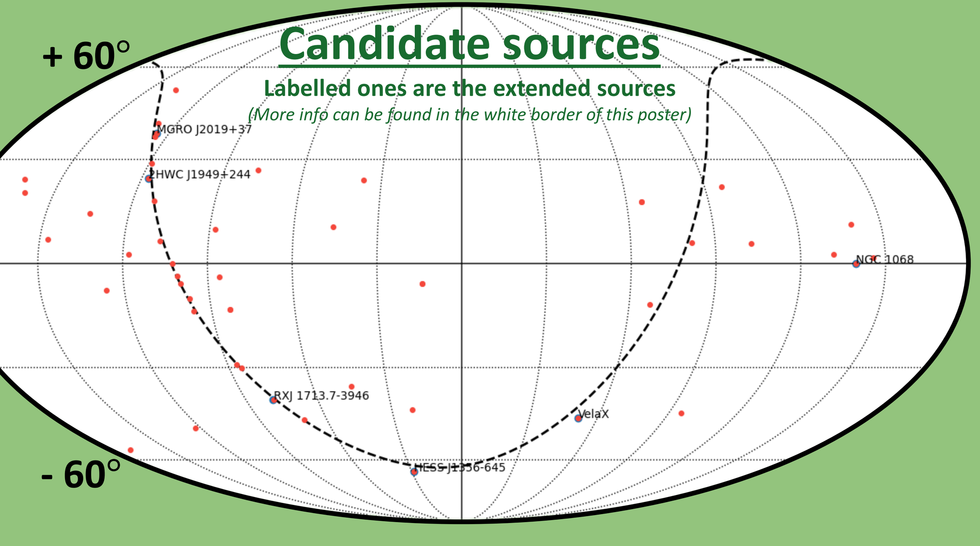




Catalog search

The sources

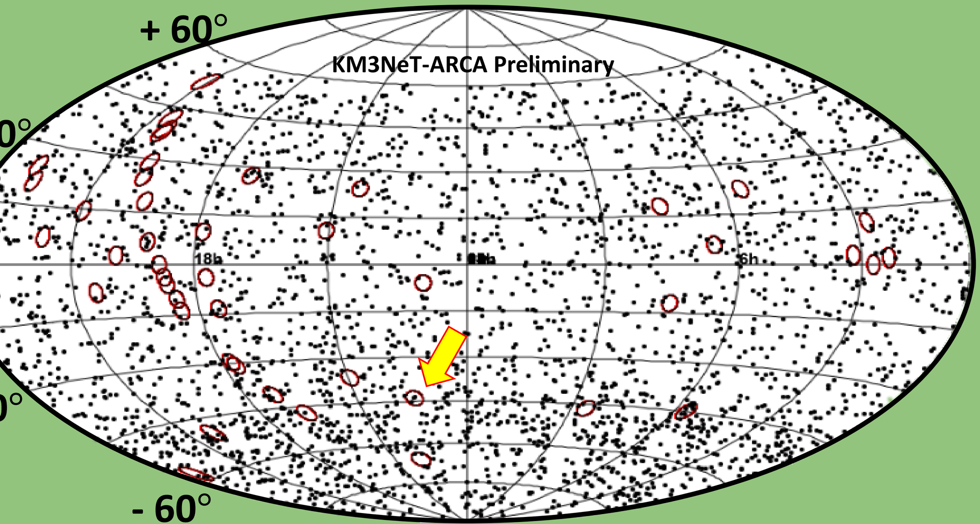
- The analysis will probe 46 selected candidate sources selected for various reasons [5 – 15] *(details on "Name, Source type, RA, δ, Size [°]" of each source can be found in white border of this poster in alphabetical order starting from bottom left)*
- An E^{-2} spectrum is tested for each source
- 6 sources are known to be spatially extended in the sky. The detector point spread function is modified with a Gaussian or disk-like smearing around the source centre, to account for the change in angular distribution of the events compared to a pointed position in the sky

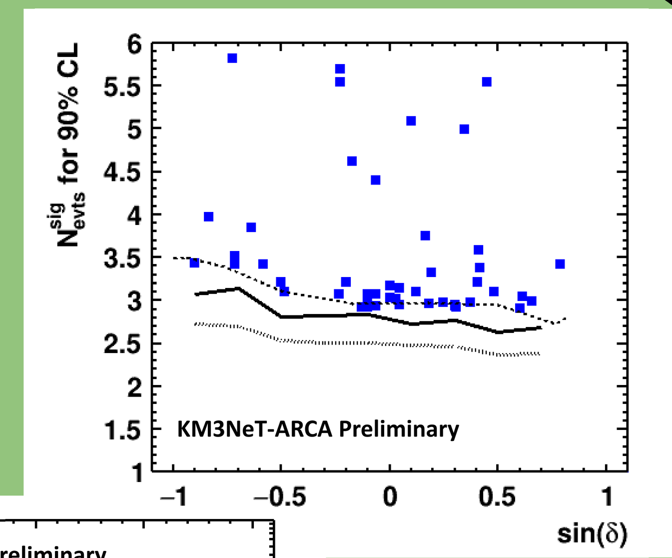


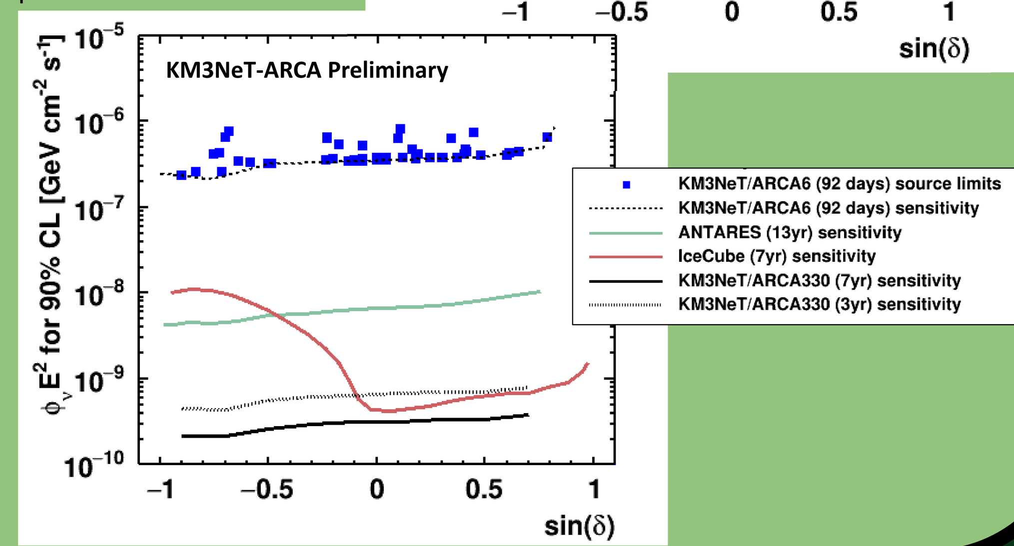
Result

Source with the smallest p-value

- A skymap of the un-blinded data is shown below. With a cone of 2.5 degees indicated around each candidate source
- The smallest p-value (0.0201755) is found for the radio galaxy Centaurus A at RA = 201.36, δ = -43.02, for which 2.60 signal events were fitted. This source is indicated by the yellow arrow. The observed limit for this source is found for 8.67 signal events, and the corresponding flux normalisation for an E^{-2} flux is: $7.31 \cdot 10^{-7}\ \text{GeV}^{-1}\ \text{cm}^{-1}\ \text{s}^{-1}$
- With a candidate list of ~50 sources, finding one source with a p-value of ~2% is in line with the background expectation
- Plots on the right show the observed limits on the number of events (top), and on the flux (bottom), in comparison with sensitivities presented at ICRC 2021
- This study shows that there were no strong neutrino emitters in the studied period of May 2021 – September 2021







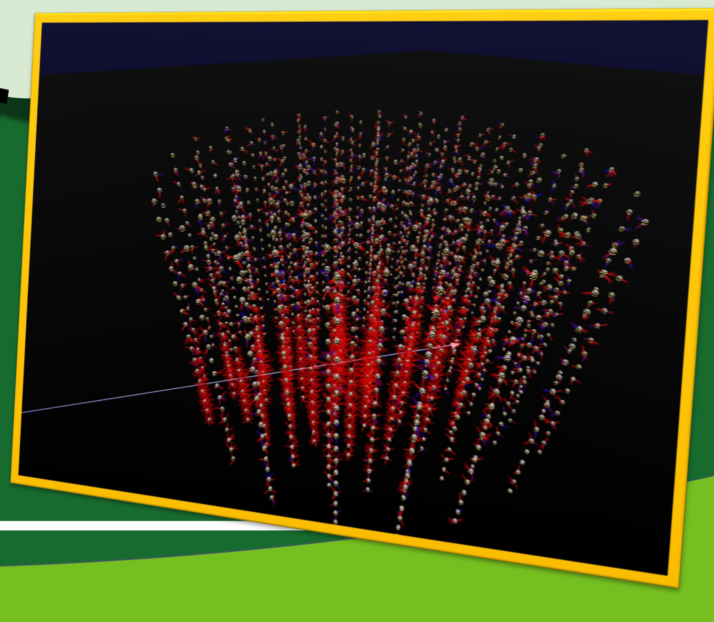
Next steps

1: Perform an analysis with more data!

- Include ARCA8 data
- Deploy more lines (to be foreseen this summer!)
- Perform combined analysis with ANTARES

2: Expand current Monte-Carlo based work

- Include all flavours
- Include shower channel
- Perform a stacked analysis
- Improve track reconstruction for small detector configuration
- Fine tune analysis methods:
  - Automate steps for future analysis



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[3] See ICRC contribution: poster 1142 by G.Illuminati on behalf of the ANTARES collaboration, https://indico.desy.de/event/27991/contributions/101388.
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[11] https://www.nature.com/articles/s41586-021-03498-z & https://pos.sissa.it/395/1161/pdf | [12] IC211208A, GVD211208A, Baksan | [13] IC220205B |
[14] IC220225A | [15] IC220304A

Take Home Message

The first ever point source analysis with 6 lines of KM3NeT/ARCA is done, searching with 92 days of data. Neutrino emission is searched among 40 known point sources plus 6 extended sources. No strong neutrino emitters were observed between May 2021 and September 2021. The lowest p-value (0.0202) was found for the radio galaxy Centaurus A, but this is in line with the background expectation given the 46 sources we have looked for. Nevertheless this study shows that our analysis framework is in place, and working. While our detector is taking more data, work is ongoing to expand the framework in order to improve our performance and do more extended studies.

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