Combined KM3NeT/ARCA and ANTARES searches for point-like neutrino emission

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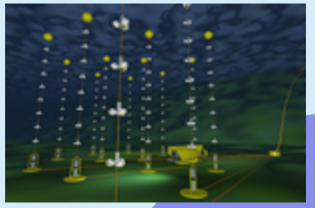
Combined point-like search motivations

- ANTARES detector switched off in February 2022 after 15 years of data taking.
  - This analysis exploits 2007-2020 data.
- KM3NeT collaboration installs next generation of neutrino detectors in the deep sea.
  - The data from about 1 year of ARCA6-8 is used in this analysis. Similar detector volume as ANTARES
  - KM3NeT/ARCA operates now with 28 lines and the detector will continue to grow.

KM3NeT/ARCA and ANTARES

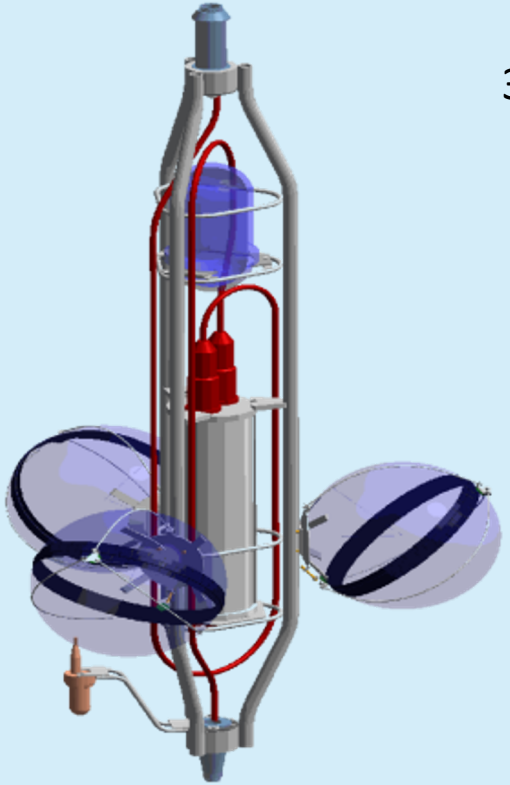
	ANTARES	ARCA
Effective Mass	10 Mt	1 Gt
Line length	350 m	650 m
Interline distance	70 m	90 m
Vertical spacing	14.5 m	36 m



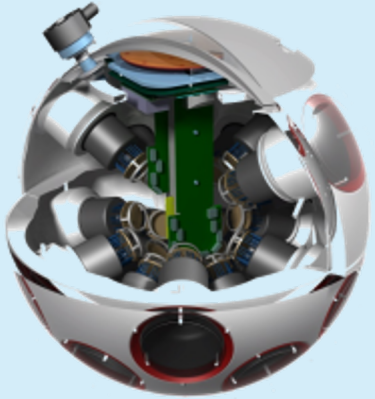
- Two detectors in the Mediterranean sea.
- Each detector is based on a 3D array of Optical modules. Modules are installed on flexible lines.

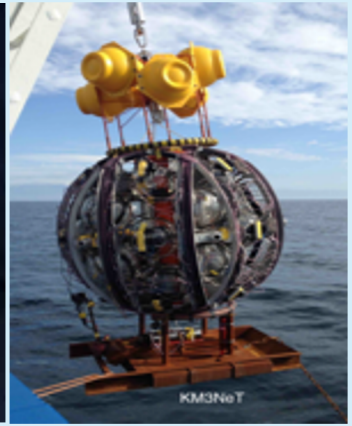
KM3NeT/ARCA
TeV-PeV ν astronomy

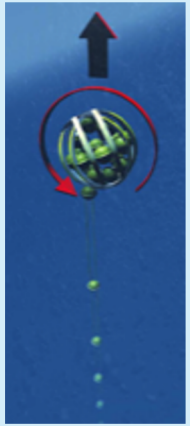
Technologies

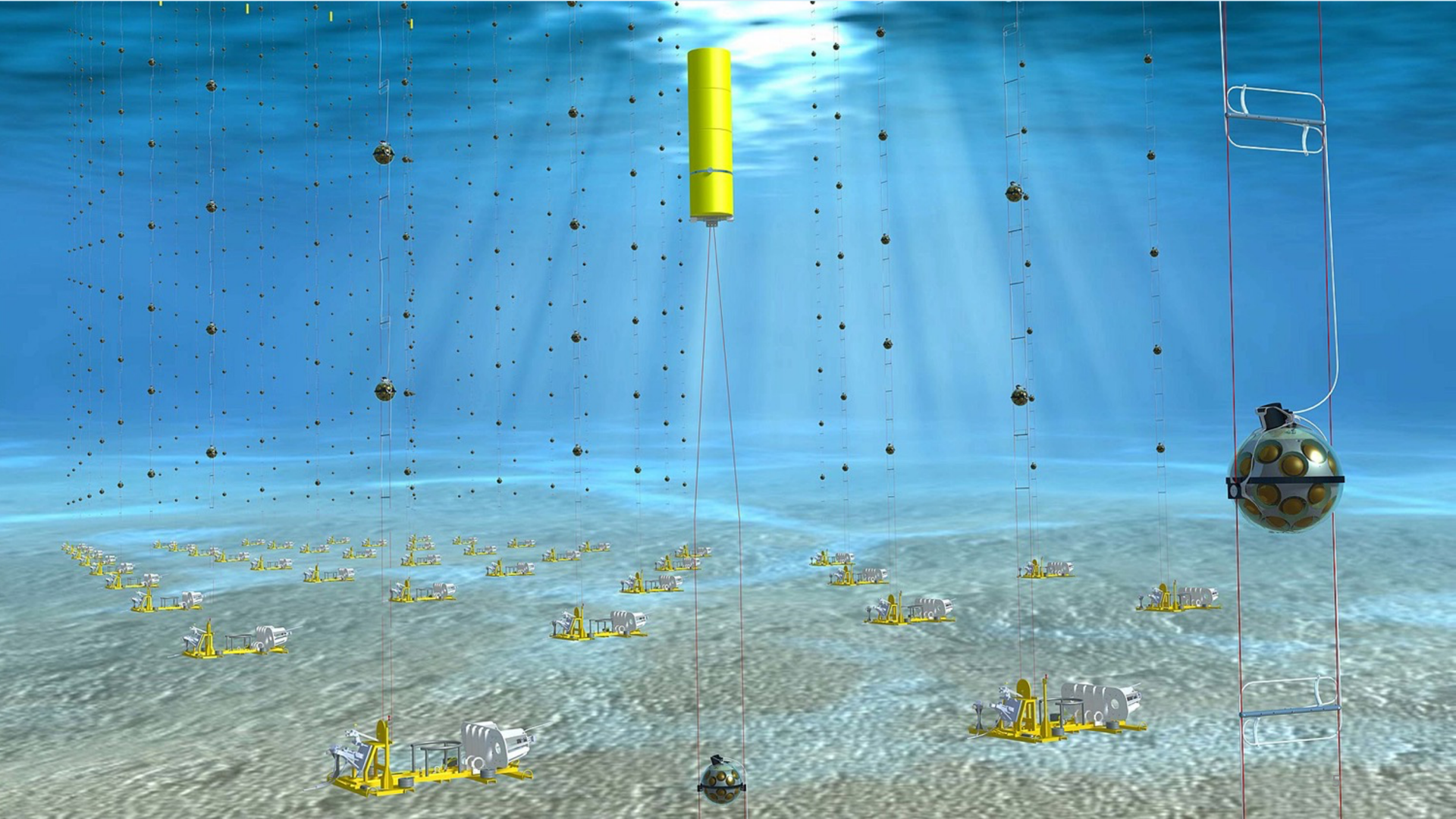


3*10” PMTs -> 31*3” PMTs
same sensitive area
+ compactness
+ wider angle of view
+ directional information
+ digital photon counting
+ cost reduction

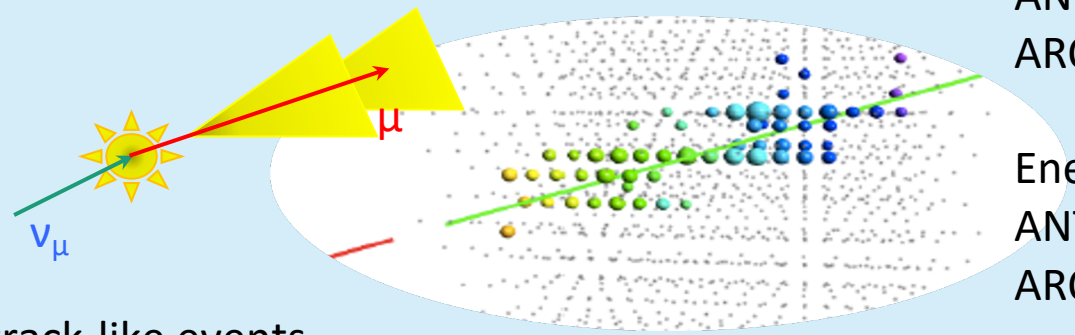








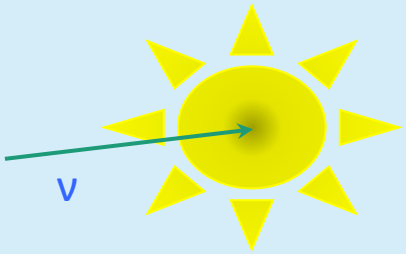
Event types

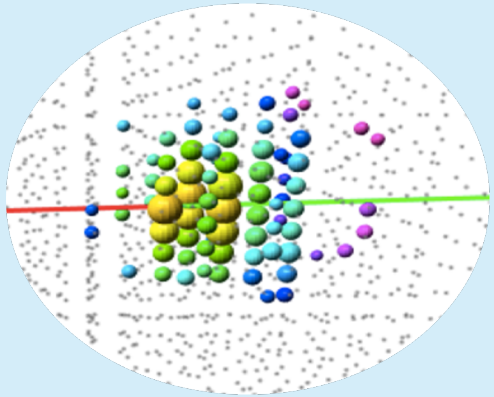


track-like events
ν_μ(CC)

Angular resolution:
ANTARES: <0.4° (E>10 TeV)
ARCA: <0.2° (E>10 TeV)

Energy resolution:
ANTARES: <0.5 (log E_μ)
ARCA: <27% (E_μ)



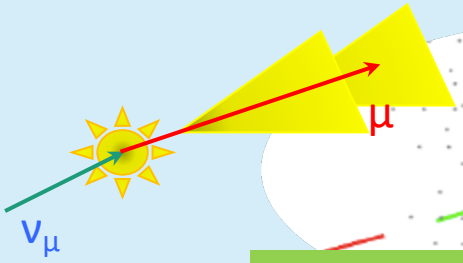


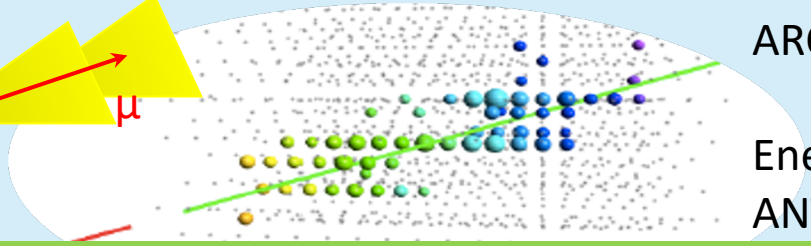
shower-like events
ν_μ(NC), ν_e, ν_τ

Angular resolution:
ANTARES: ~3° (E>10 TeV)
ARCA: ~2° (E>10 TeV)

Energy resolution (E_ν):
ANTARES: ~25%
ARCA: <5%

Event types





track-like even
ν_μ(CC)

Angular resolution:
ANTARES: <0.4° (E>10 TeV)
ARCA: <0.2° (E>10 TeV)

Energy resolution:
ANTARES: <0.5 (log E_μ)
)

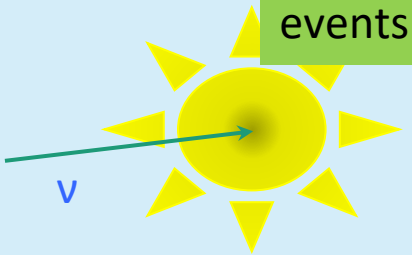
mospheric muons!

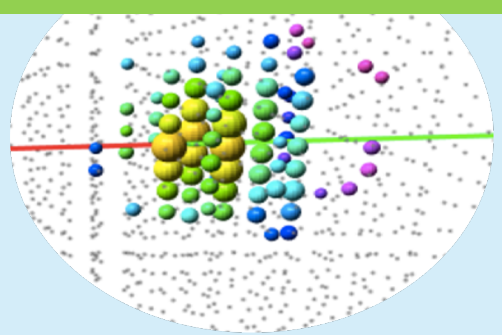
n:
ANTARES: ~3° (E>10 TeV)
ARCA: ~2° (E>10 TeV)

Energy resolution (E_ν):
ANTARES: ~25%
ARCA: <5%

Developed framework can merge statistics of events of both types from both detectors.

The sensitivities presented today refer to track-like events only.

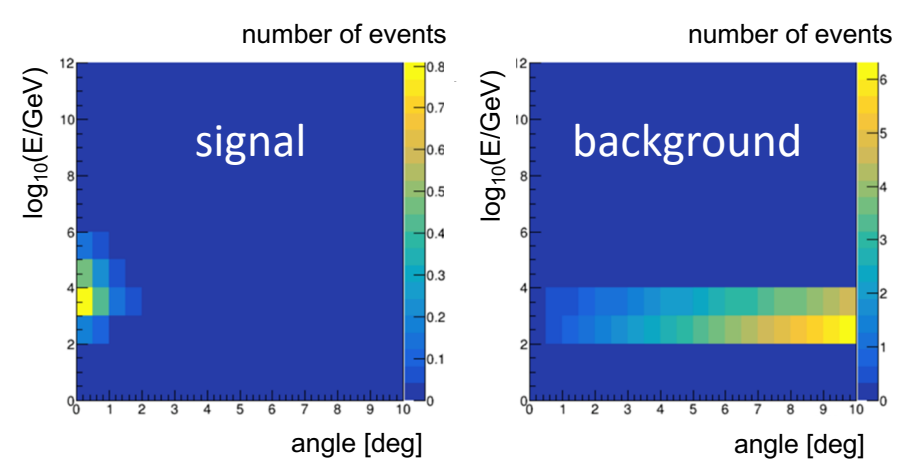




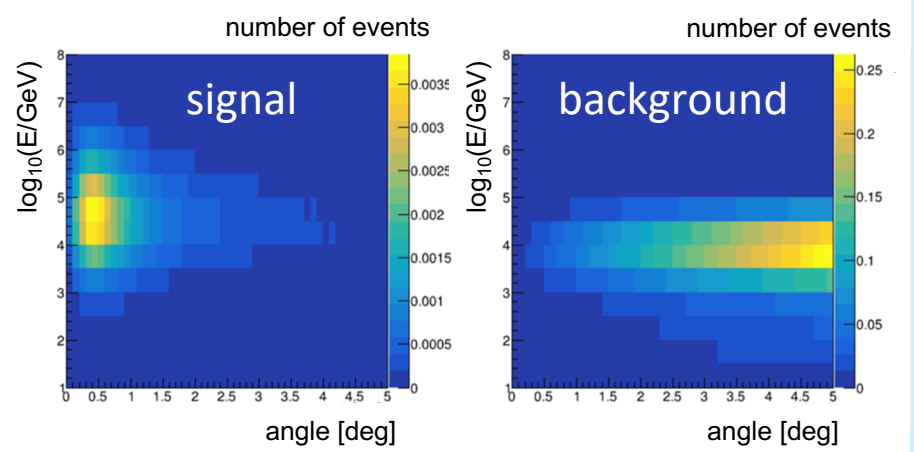
shower-like events
ν_μ(NC), ν_e, ν_τ

Binned analysis

ANTARES 2007-2020
preliminary



KM3NeT/ARCA8 (210 days)
preliminary



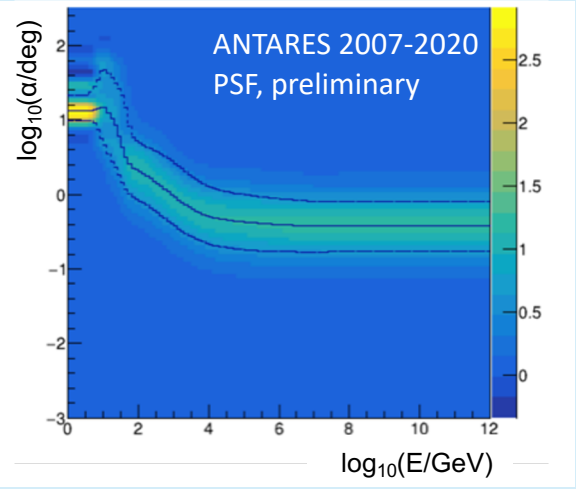
- Data set: detector period with a particular event selection (track/showers etc).
  - Data sets do not overlap (no common events).
- For each data set:
  - Signal expectation (**MC**) *S*,
  - Background expectation (MC, **data sampling**) *B*,
  - Data/pseudo-experiment *N*,
  - Histogram binnings are customizable for each set.

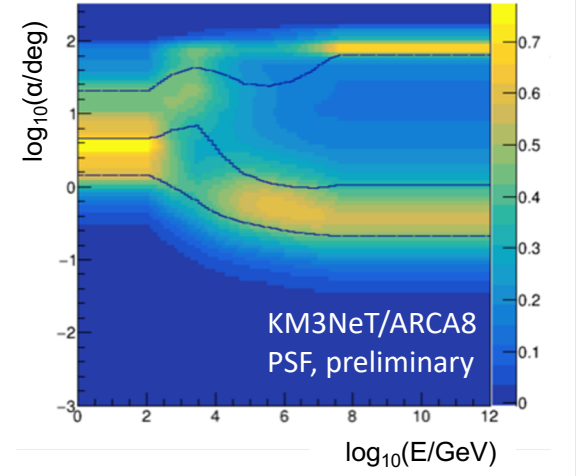
$$\log L = \sum_{\text{bins}} N_i \log(B_i + \mu S_i) - (B_i + \mu S_i)$$

- μ signal strength (for a given default flux)
- Sum over bins of all data sets

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

Signal simulation





Signal is simulated using detector properties (from MC):

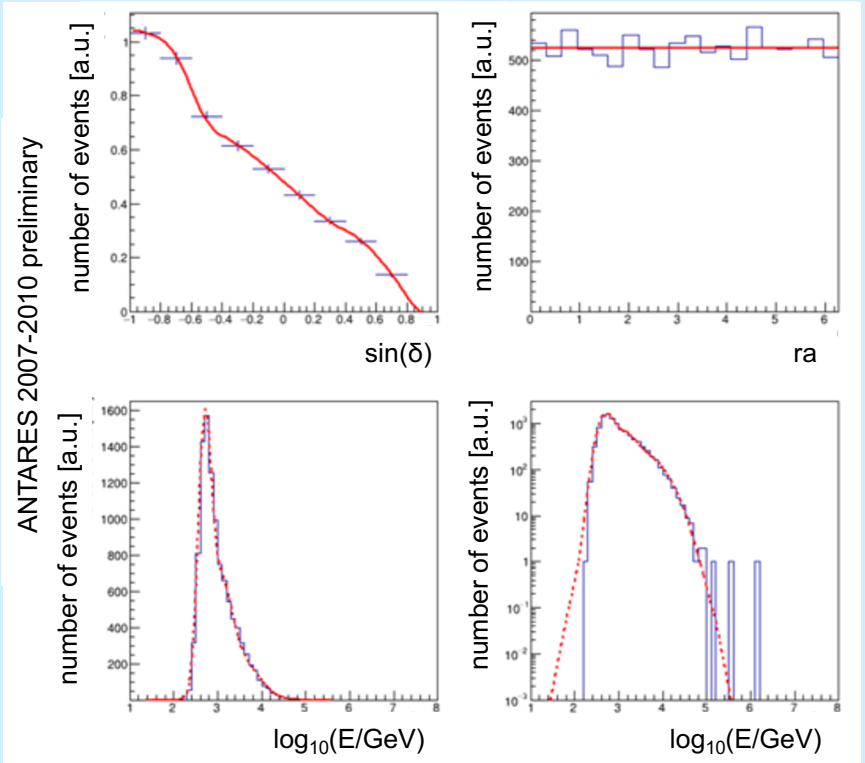
- **effective area**, dependent on true neutrino energy and zenith/declination. It serves as a measure for the detector sensitivities to neutrinos at different energies and incoming angles;
- **neutrino energy resolution** estimated as the fraction of the events with a given reconstructed neutrino energy for a given bin of true neutrino energy and zenith/declination;
- **point spread function** estimated as the fraction of the events with a reconstructed angular distance from the true source centre for a given bin of true neutrino energy.
  - Can be further smeared with source extension (if known).

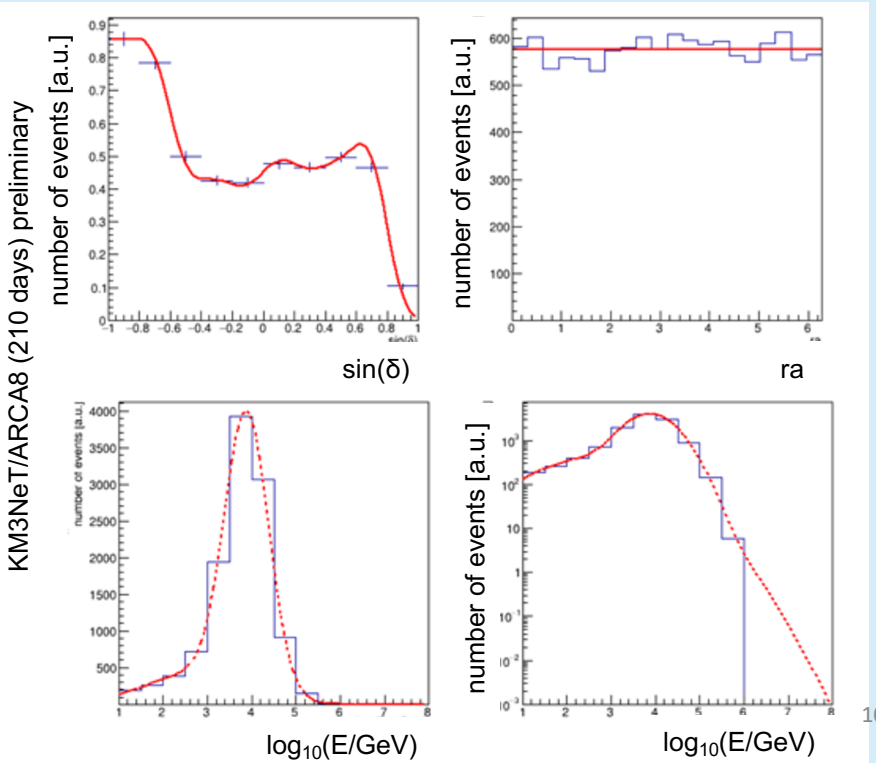
Background and pseudo-experiments

- Background is factorised by data fits in reconstructed declination and energy.

$$B = n * F(DEC) * F(E)$$

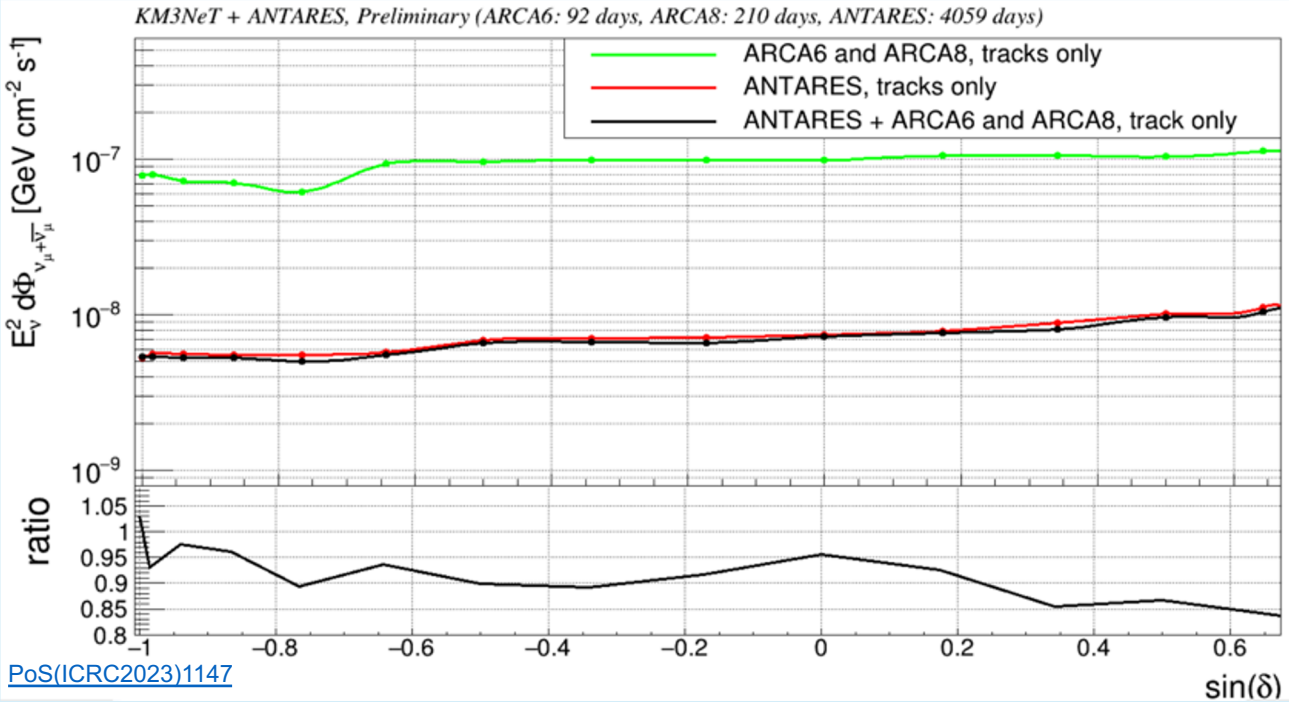
- Pseudo-experiments are generated as Poisson with mean μS+B (for each bin).





Sensitivities

- Median Neyman upper limit for pseudo-experiments with no signal.



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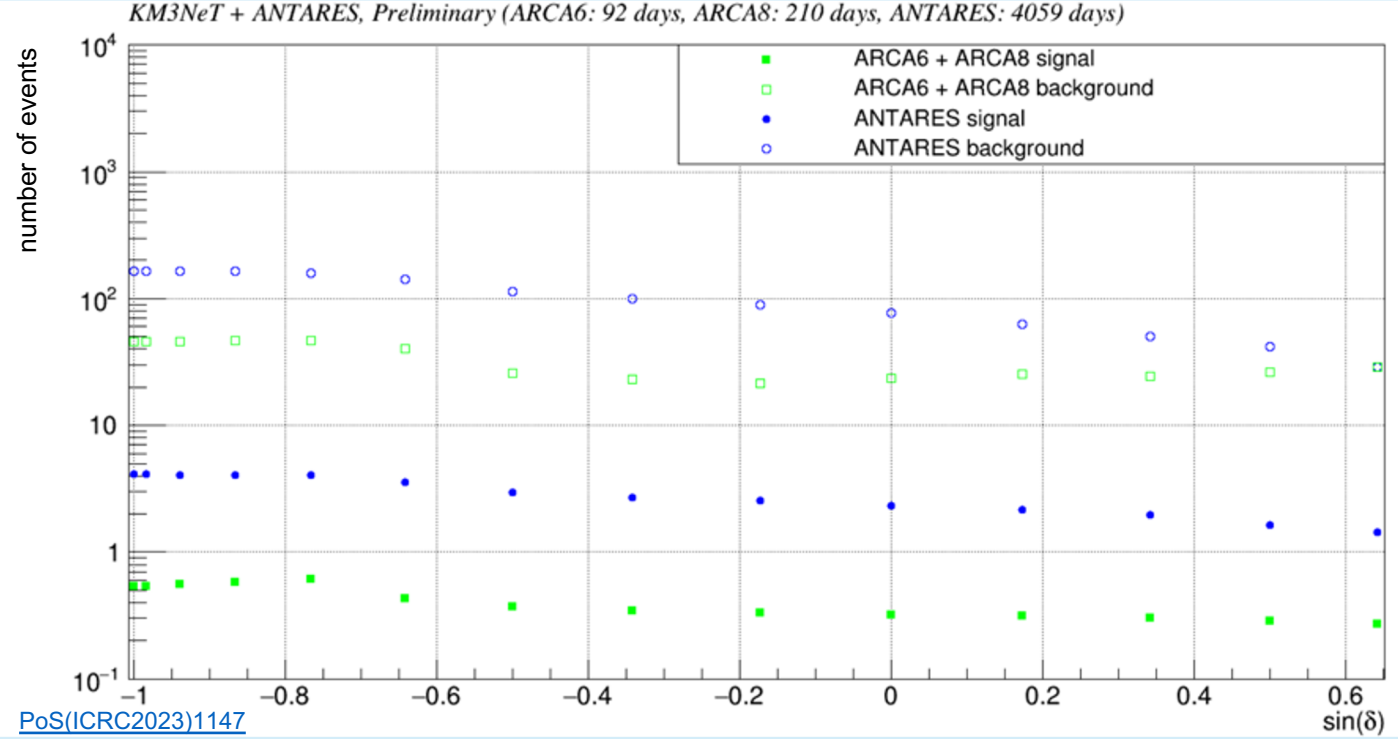
- Sensitivity of the analysed KM3NeT/ARCA data sets is order of magnitude worse than the ANTARES data set.
  - Sensitivity gain of combined analysis is ~10%.
  - This will rapidly change for the upcoming data sets (ANTARES 2007-2022, 1 year of KM3NeT/ARCA21..)

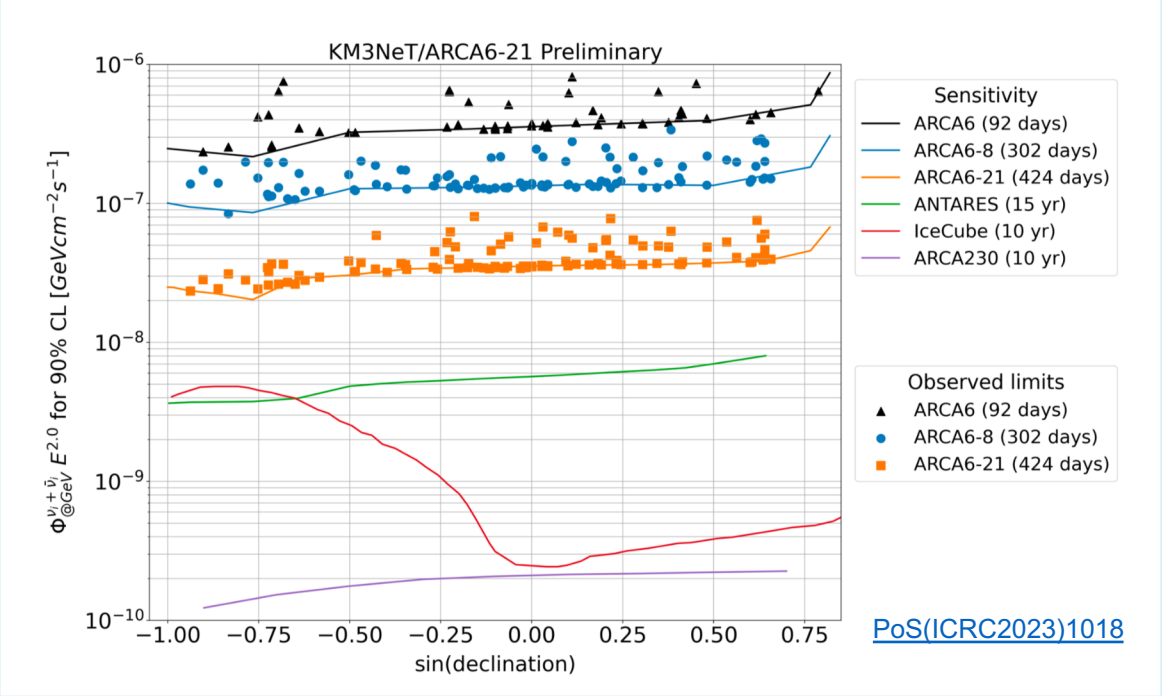
Number of events



- Both detectors work with similar signal/noise regimes.
  - KM3NeT/ARCA has now more background contamination and worse PSF sensitivity. This will rapidly evolve with more strings deployed (better reconstruction performance, more statistics and thus more stringent event selection).

Search for cosmic neutrino point sources with 6-21 lines of KM3NeT/ARCA

- Sensitivity studies performed also for ARCA6 - ARCA8 - ARCA21 up to December 2021
- Total livetime: 424 days



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Summary and Perspectives

- **In this work, the framework for joint analysis has been demonstrated. Its features:**
  - Binned analysis with different data sets: different detectors (ANTARES, ARCA..), different event selection (track-like, shower-like...),
  - Inclusion of source morphology (extension with Gaussian, disk, etc..)

- **Using ARCA6/8 helps to improve ANTARES standalone analysis by ~10%.**

  $\Longrightarrow$ The framework is ready to use the new data sets (ANTARES 2007-2022, ARCA6-21, ORCA6-18...).

- **In the next few years, KM3NeT/ARCA statistics will reach the ANTARES one and overcome it.**

  $\Longrightarrow$ Perfect time for combined searches.

Requested info:

- Abstract: Neutrino telescopes are the instruments for the detection of high energy cosmic neutrinos. The ANTARES detector operated offshore Toulon (France) for 16 years until 2022, while KM3NeT-ARCA infrastructure is under construction in Southern Italy. The ANTARES telescope was composed of 12 strings, each equipped with 75 optical modules. Each optical module contained one 10” photomultiplier tube to detect the faint light produced by neutrinos interacting in the surrounding water. Similarly, the KM3NeT-ARCA detector will count 230 strings of 18 optical modules, each containing 31 3” photomultipliers. In recent years, there has been a growing interest in studying potential sources of neutrinos, as these sources can provide valuable information about the most extreme phenomena in the Universe. This contribution will showcase the analysis of the combined data sample from ANTARES and the first two years of KM3NeT-ARCA to detect high energy cosmic neutrinos from point-like sources.
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- Eventual Organization: KM3NeT Collaboration
- Key-word and topic of your presentation: cosmic neutrino, KM3NeT, ANTARES, point-like sources.