

Search for Point-like Sources with ANTARES & KM3NeT/ARCA

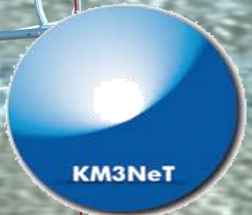
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on behalf of the ANTARES and the KM3NeT collaborations



ICHEP, 19 July 2024



Outlook

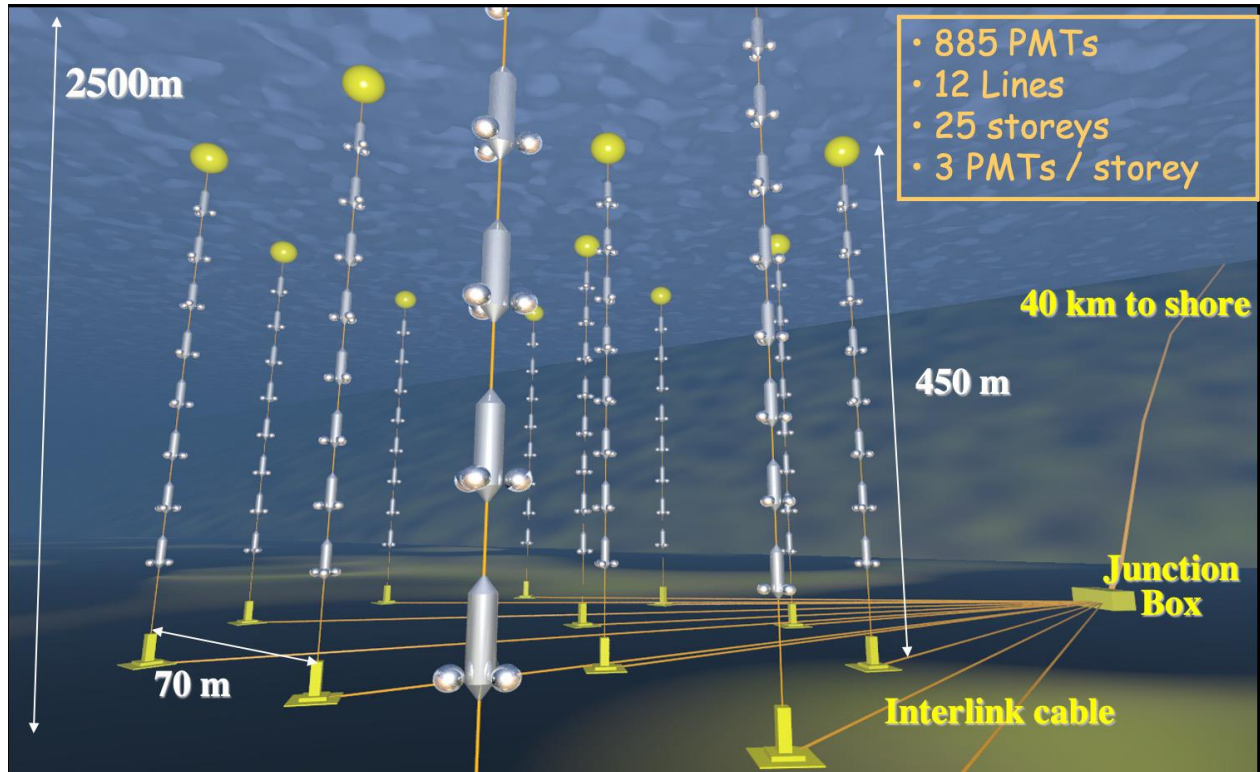
Datasets:

- Full ANTARES dataset (2007-2022), completed with 163 candidate sources,
- KM3NeT/ARCA datasets: dataset (12 May 2021 – 20 December 2022) from 6 detection units (DUs) up to 21 DUs, completed with 101 candidate sources,
 - This set should improve ANTARES results by 10% already,
- Joint analysis is prepared ~100 sources are selected (not unblinded yet).

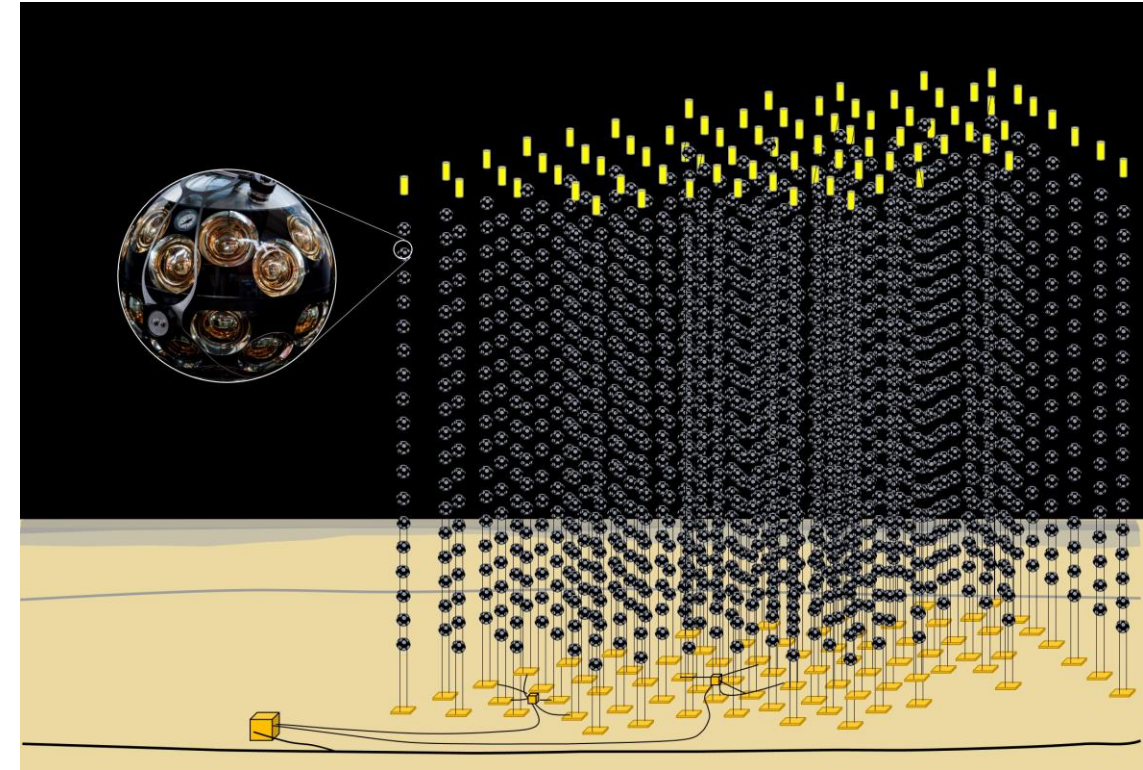
Analysis framework:

- **Binned likelihood framework**, already used for KM3NeT/ARCA analysis, modified to include ANTARES and **KDE approach for background model**.

Detectors: ANTARES and KM3NeT/ARCA



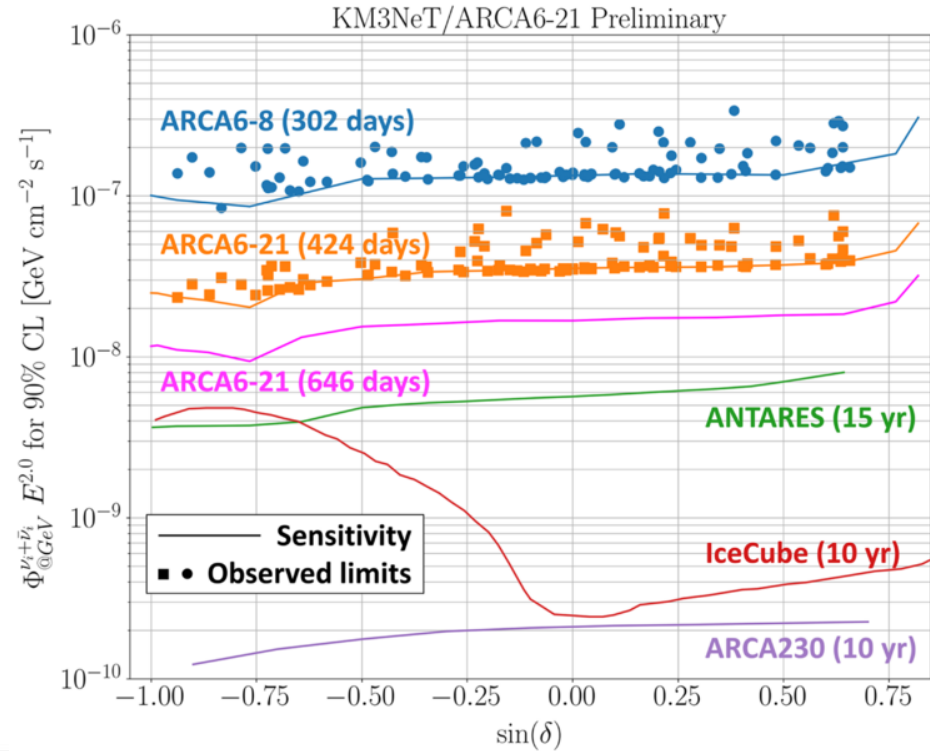
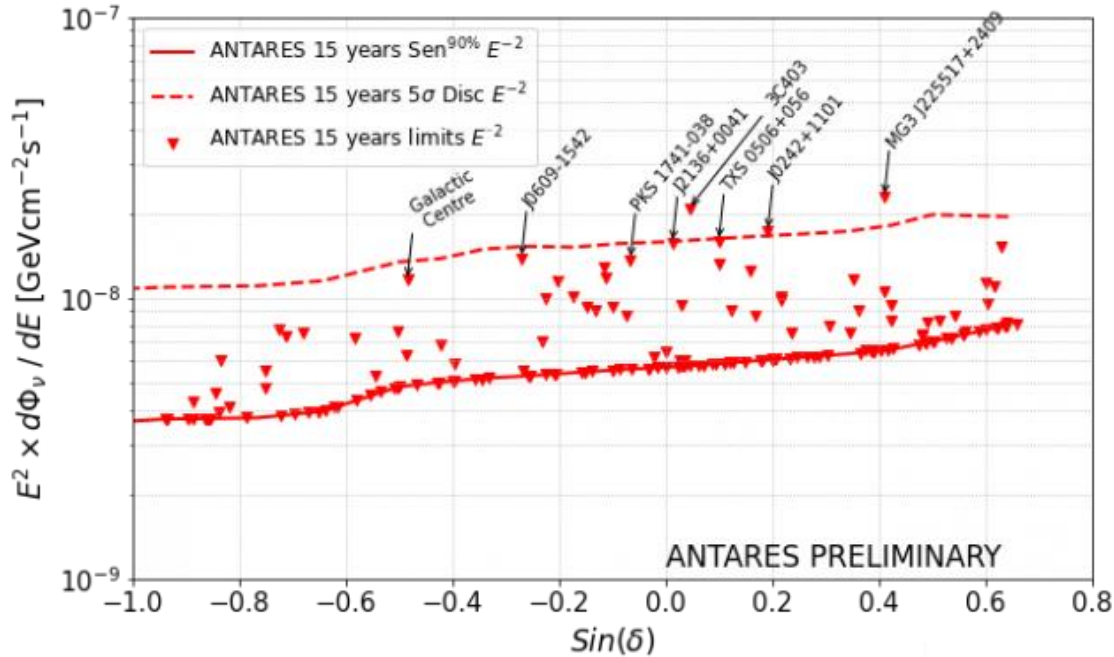
ANTARES was a neutrino detector that operated for more than **15 years** off the coast of Toulon (France), from 2008 to 2022. It consisted of **12 lines**, each equipped with 25 storeys with 3 PMTs.



KM3NeT/ARCA (Astroparticle Research with Cosmics in the Abyss) is a neutrino telescope under construction off the coast of Sicily (Capo Passero), data taking **started in 2015**, currently composed by **28 lines out of the 115** of the first complete building block.

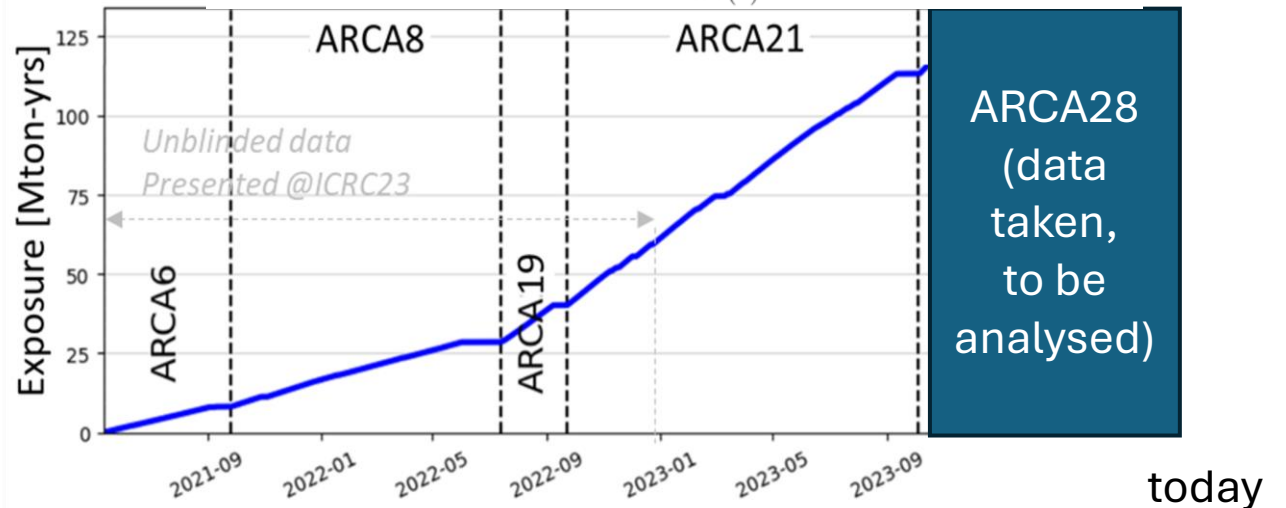
Unblinded datasets

S. Alves et al @ Neutrino 2024



M. Spurio et al @ Neutrino 2024

- ANTARES:
 - 163 candidates , two >3 sigma pre-trial:
 - MG3 J225517+2409, 3.4 σ (1.6 σ post),
 - 3C403, 3.4 σ .
 - Final update and legacy paper is in progress.
- ARCA6-21(424 days) unblinded (ICRC2023). Completing ARCA21 dataset analysis is in progress.
 - ARCA will reach ANTARES sensitivity in few years – the best moment for joint analysis.



Binned likelihood

Data vs Background + Signal histogram test:

- α (angular distance of the reconstructed event from the source center)
- $\log_{10}(E_{rec})$ (event energy estimation)

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

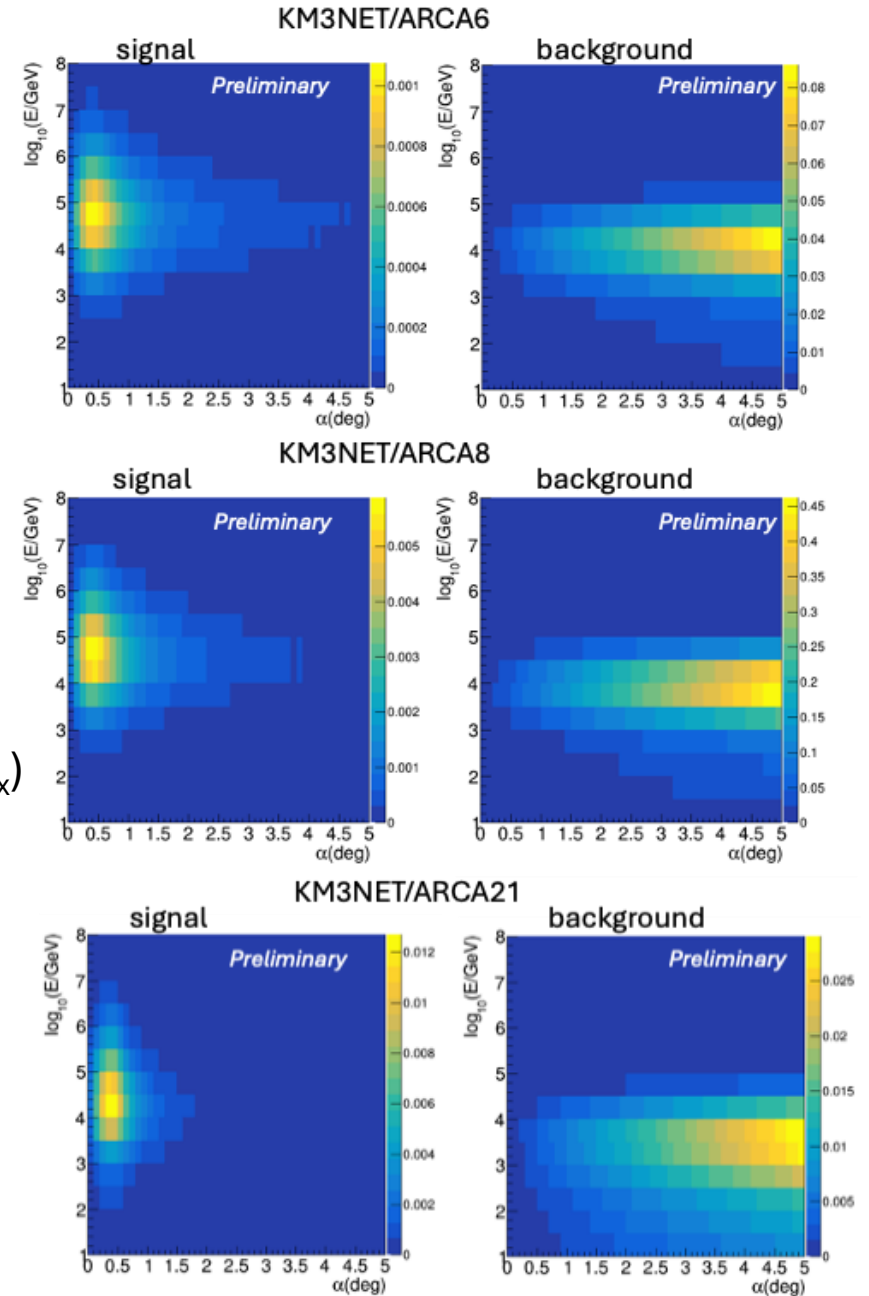
Test statistics
$$\lambda = \log L(\mu = \hat{\mu}) - \log L(\mu = 0)$$

$$S_i = \sum_{E_{true}} \text{rate}(\text{decl}, E_{true}) * f_{\alpha}(E_{true}, \alpha_{min}, \alpha_{max}) f_E(E_{true}, \text{decl}, E_{rec, min}, E_{rec, max})$$

effective area x flux (E^{-2}) angular resolution energy resolution

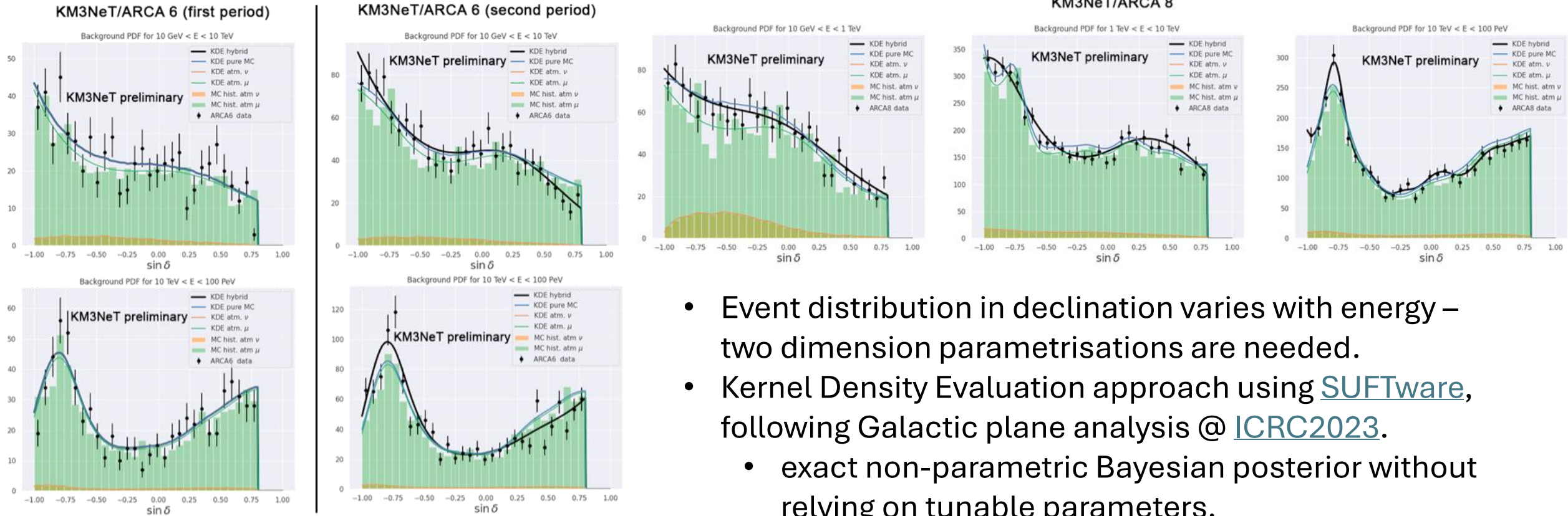
$$B_i = \text{rate}(\text{decl}, E_{rec}) \begin{cases} n \times F(\sin\delta) \times F(\log E_{rec}) \\ n \times KDE(\sin\delta, \log E_{rec}) \end{cases}$$

Background expectation, data-driven, scrambled in RA, reconstructed energy and declination: independent factorization if low statistics, 2D functions following KDE approach if enough statistics



distributions are for $\sin(\text{decl})=0$

Background model: KDE functions

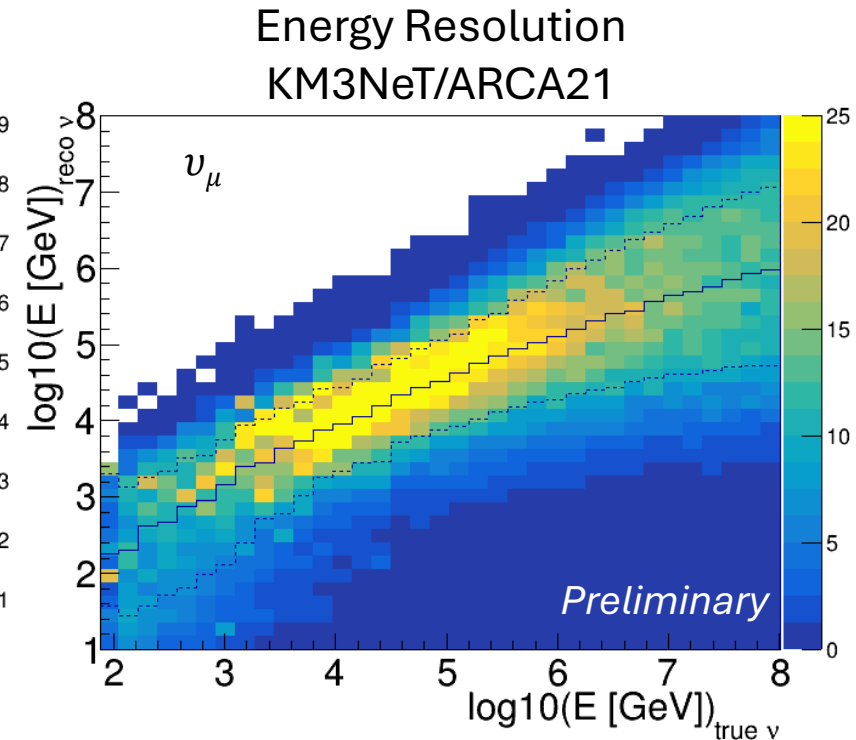
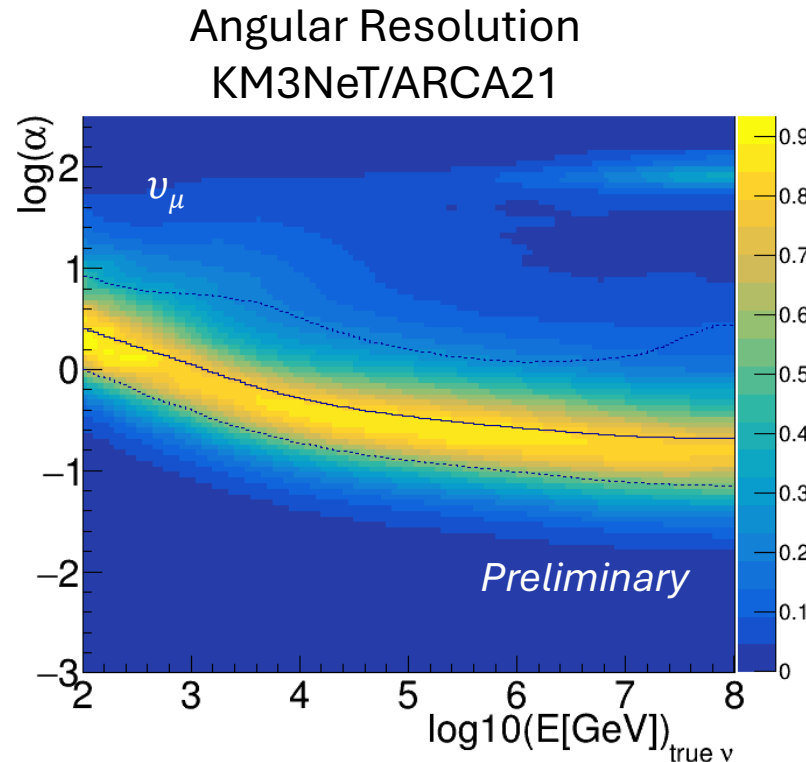
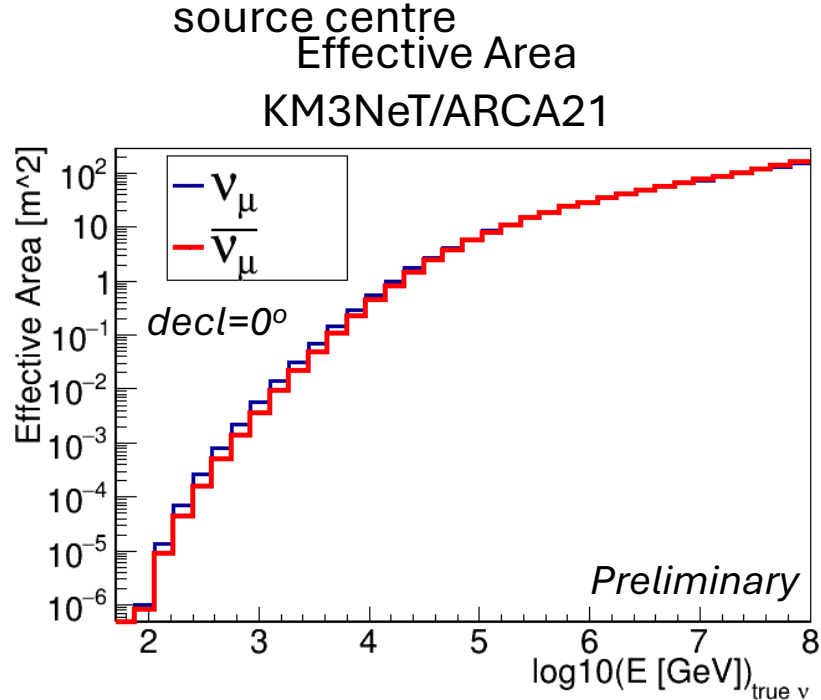


- Event distribution in declination varies with energy – two dimension parametrisations are needed.
- Kernel Density Evaluation approach using [SUFTware](#), following Galactic plane analysis @ [ICRC2023](#).
 - exact non-parametric Bayesian posterior without relying on tunable parameters.
- Splitting dataset in energy on bins with at least 1000 events (in data or MC). Fitting data (if 1000 events are available) or MC.

Signal

From MC (IRFs)

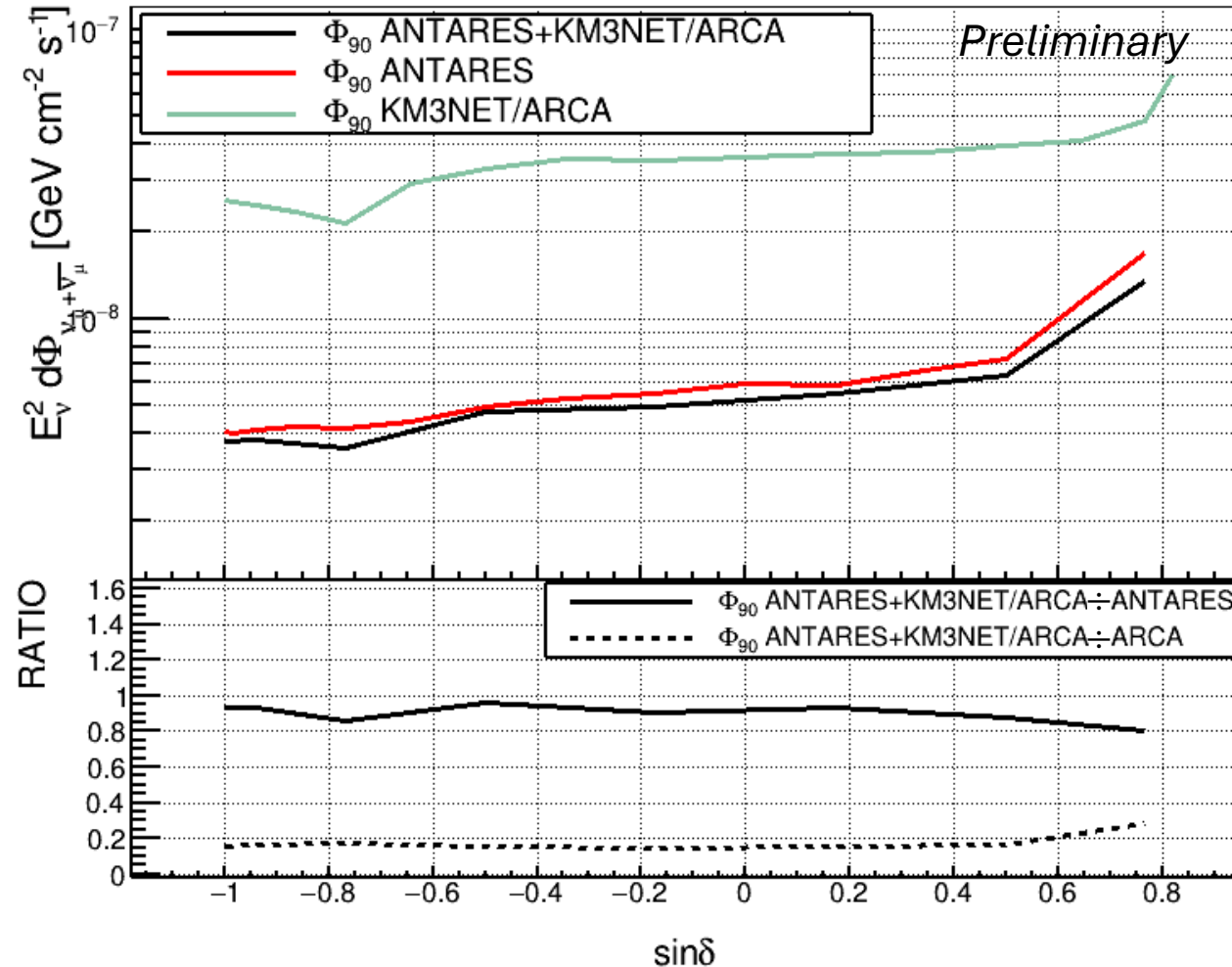
- Effective area vs E_ν^{true} and zenith^{true}/declination^{true}
- Energy resolution: event fraction vs E_ν^{true} , E_ν^{reco} and zenith^{true}/declination^{true}
- PSF (Point Spread Function): event fraction vs E_ν^{true} and α (distance of the reco evt direction to the true source centre)



IRFs produced considering :

- numuCC, anumuCC and muons surviving track selection for ARCA6/8
- All the flavor neutrinos + muons surviving track selection for ARCA19/21
- all the flavour neutrinos surviving track selection for ANTARES tracks
- all the flavour neutrinos surviving shower selection for ANTARES showers

Combined KM3NeT/ARCA+ANTARES



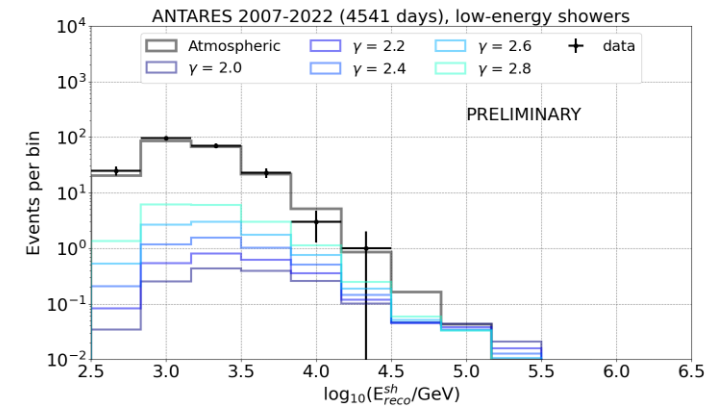
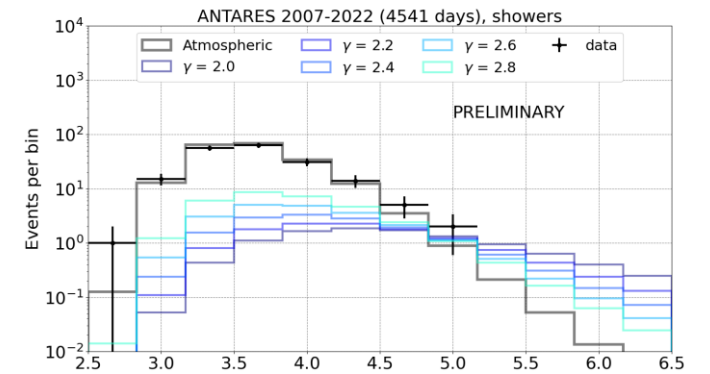
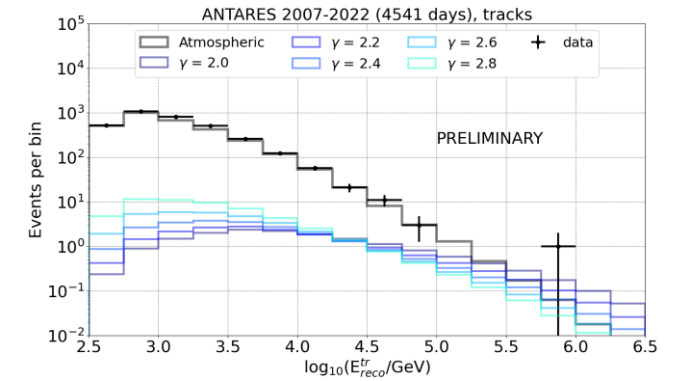
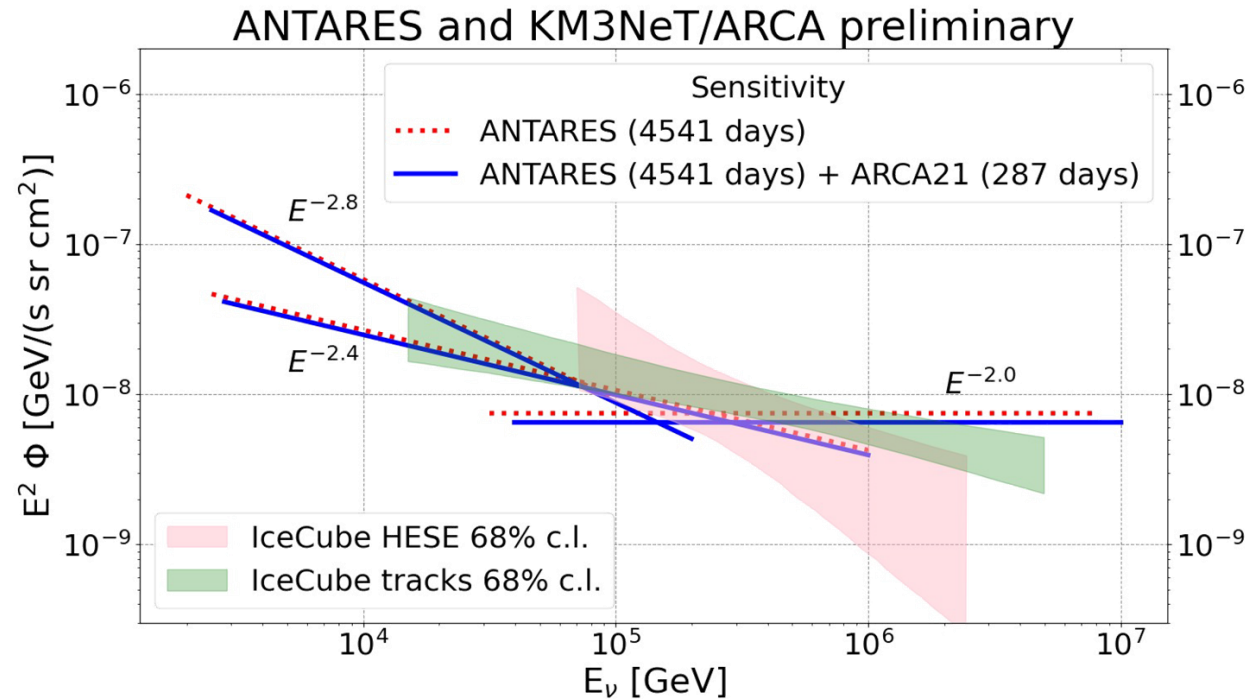
Bottom: Ratio of combined sensitivity over ANTARES and over KM3NeT/ARCA shows:

- By adding ARCA 6/8/19/21 to ANTARES dataset, the sensitivity improves by 10%,
- ARCA6-21 (424 days) dataset sensitivity is ~20% of the joint analysis.

Diffuse flux analysis

- ANTARES and of the ARCA tracks data samples (not unblinded yet),
 - ANTARES 15 years: tracks, showers, and low-energy showers (unblinded),
 - ARCA21 (287 days) tracks.
- Three power-law spectrums tested.

$$\mathcal{L} \left(N_i, S_i^{(\gamma)}, B_i, \phi_{\text{astro}} \right) = \prod_k \prod_{i=1}^{N_{\text{bins}}^k} \mathcal{P}(N_i, B_i + \phi_{\text{astro}} S_i^{(\gamma)})$$



L.Fusco @ Neutrino2024

Conclusions

- ANTARES stopped data taking in 2022, KM3NeT/ARCA is taking data nowadays with bigger effective volume compared to the ANTARES one, however its statistics is still smaller,
- Starting from the binned likelihood framework used for the ARCA 6/8/19/21 analysis, the framework combining ARCA and ANTARES was developed and tested,
- Extensive cross-checks with the official ANTARES analysis are ongoing,
- Data unblinding of the full ARCA19/21 period and of the first joint ANTARES+ARCA analysis are expected in the next months.



ANTARES and KM3NeT/ARCA Point Source Search
V. Kulikovskiy

