Probing heavy dark matter with the KM3-230213A event

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(on behalf of KM3NeT Coll.)

Identification of Dark Matter 2026

Zaragoza

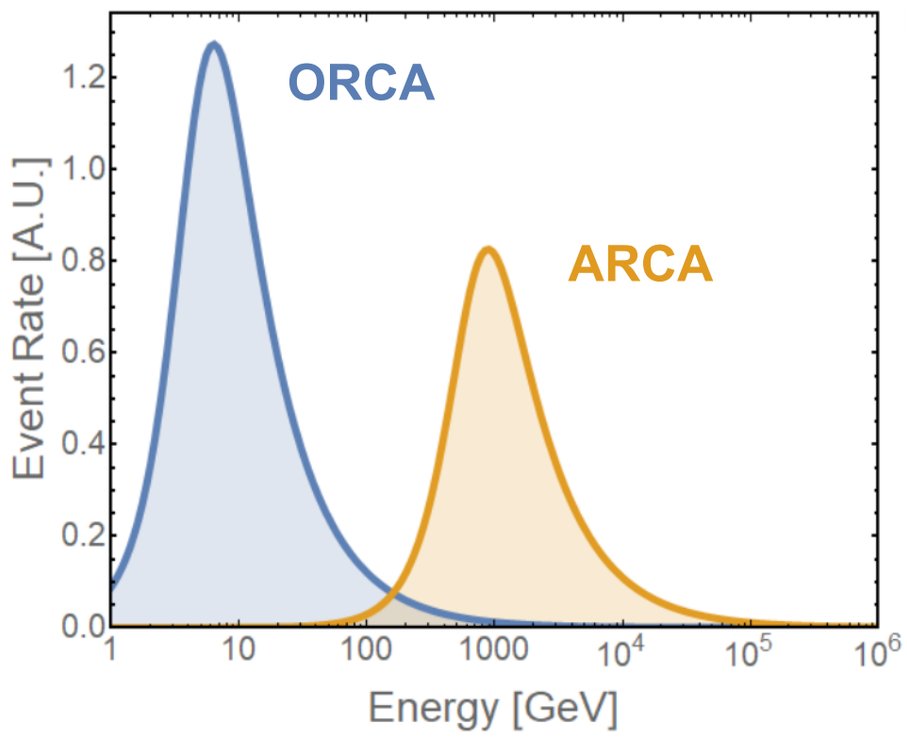
KM3NeT – Mediterranean Cherenkov detectors

Oscillation Research with Cosmics in the Abyss
ORCA

- Main goal -> NMO and oscillation parameters
- Dense instrumentation for few GeV atmospheric neutrinos
- 40km off southern French coast near Toulon
- Sea floor depth of the ORCA site ~2450m
- 115 Detection Units

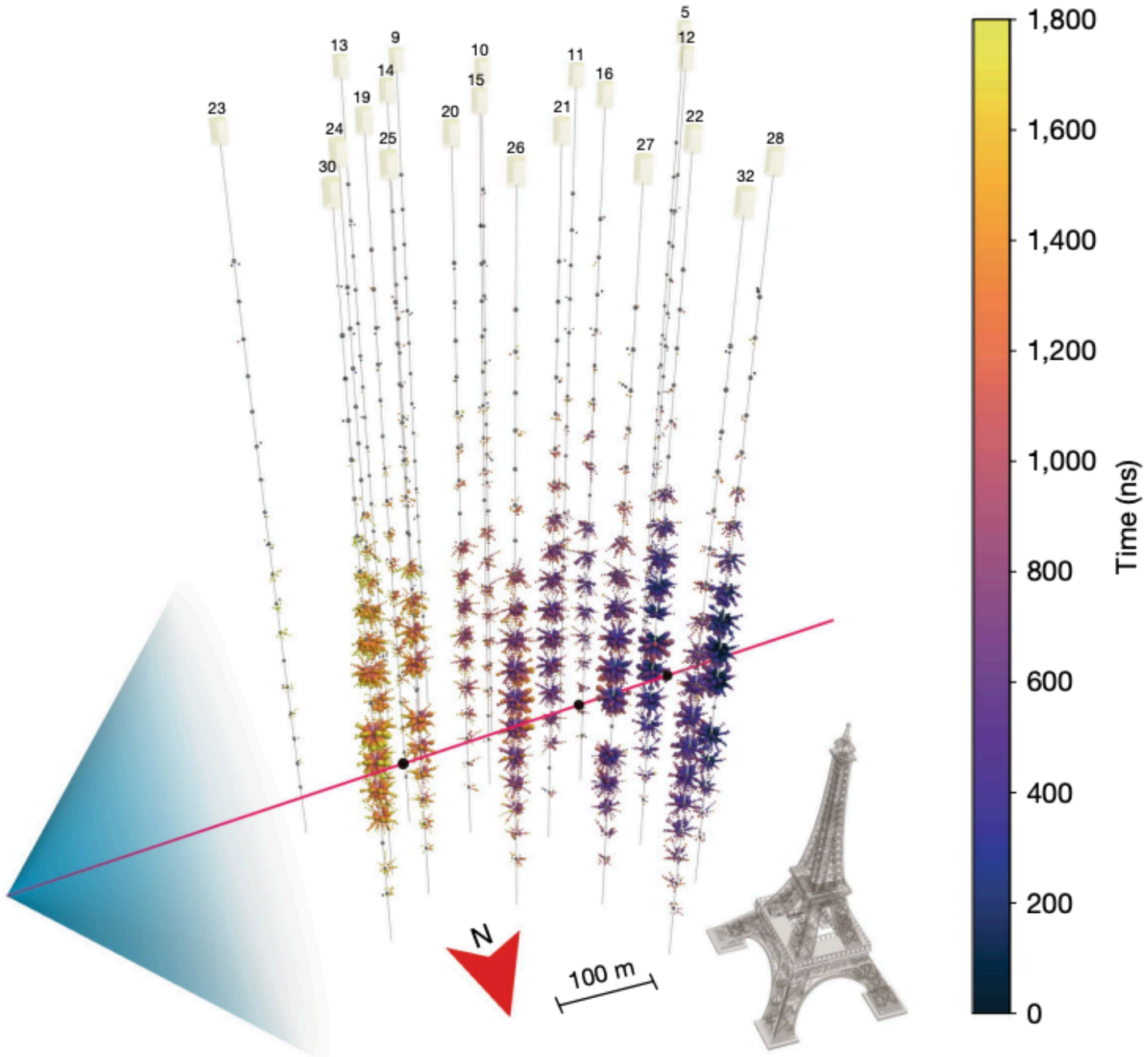
Astroparticle Research with Cosmics in the Abyss
ARCA

- Main goal -> High-energetic astrophysical neutrinos
- Sparse instrumentation covering 1km^3 instrumented volume
- 120 km off Sicily
- Sea floor depth of the ARCA site ~3500m
- 2x115 Detection Units



February 13 2023 (01:16:47 UTC)

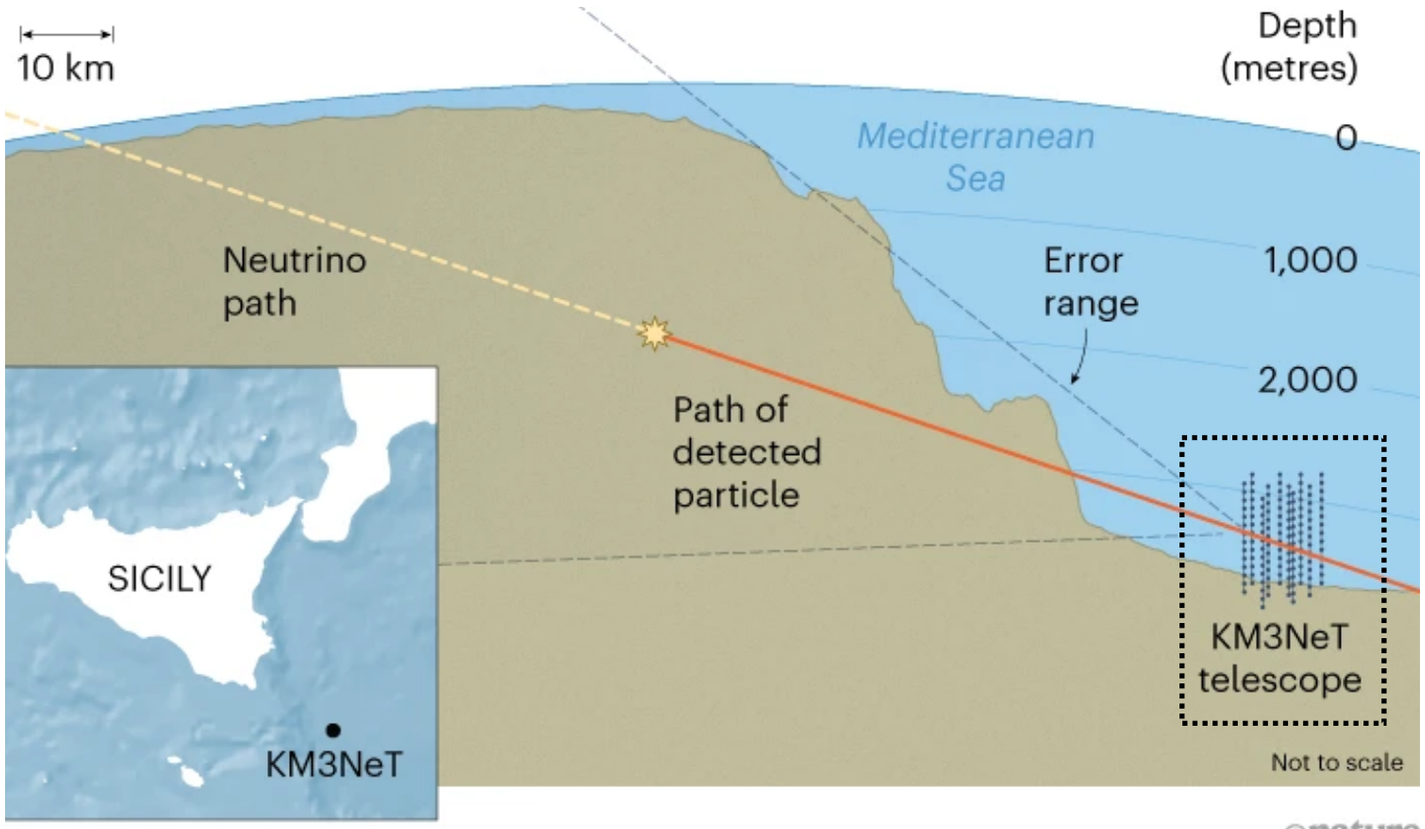
- Bright track-like pattern observed in KM3NeT-ARCA-> named **KM3-20230213A**



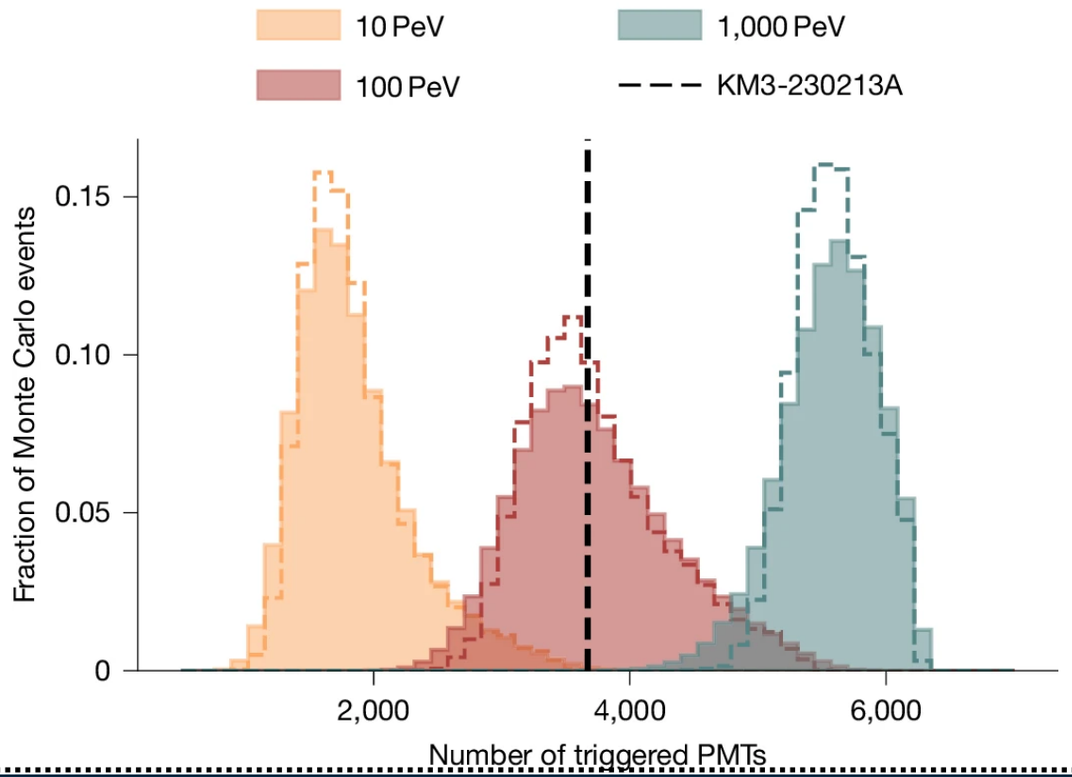
Published in Feb 2025

KM3-230213A

- Event compatible with a very high energy muon crossing horizontally.
- Best explanation -> **very high energy neutrino**

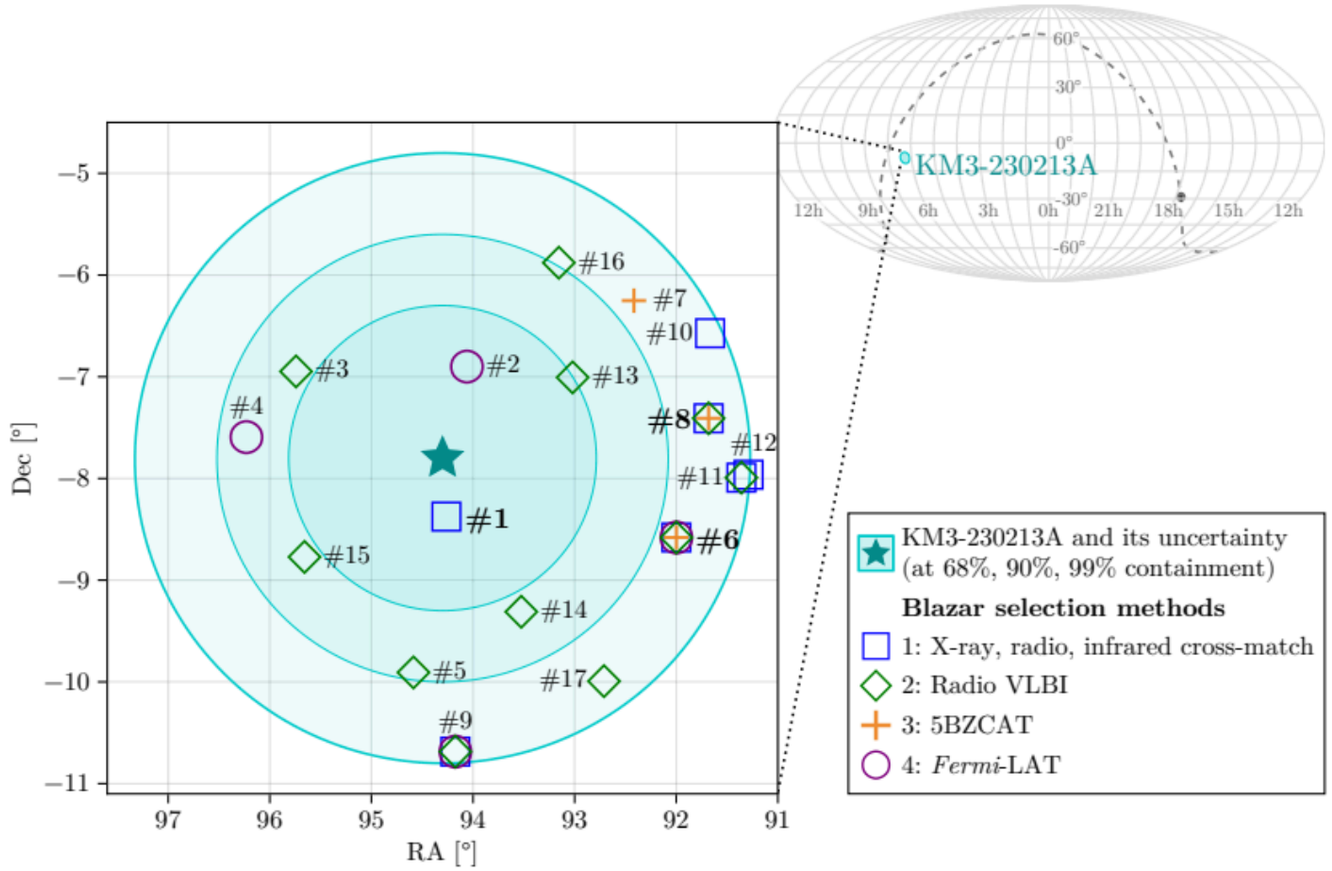


Muon Energy / PeV = 120 (+110/-60)



What is the origin of KM3-20230213A?

- It must be astrophysical (atmospheric production is heavily suppressed in PeV regime).
- Looking at the direction of the sky where the neutrino came from (~1.5 degree uncertainty).
  - Multiple blazars in that direction -> no clear correlation with multiwavelength emission
  - No obvious source in the galaxy

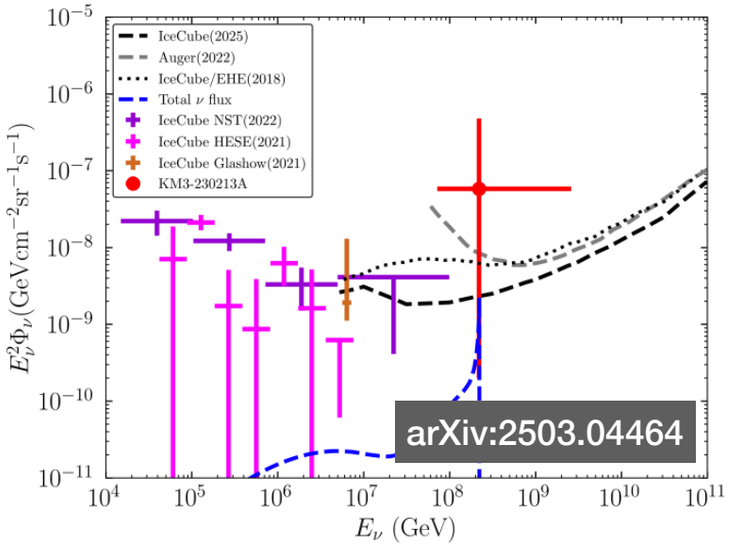


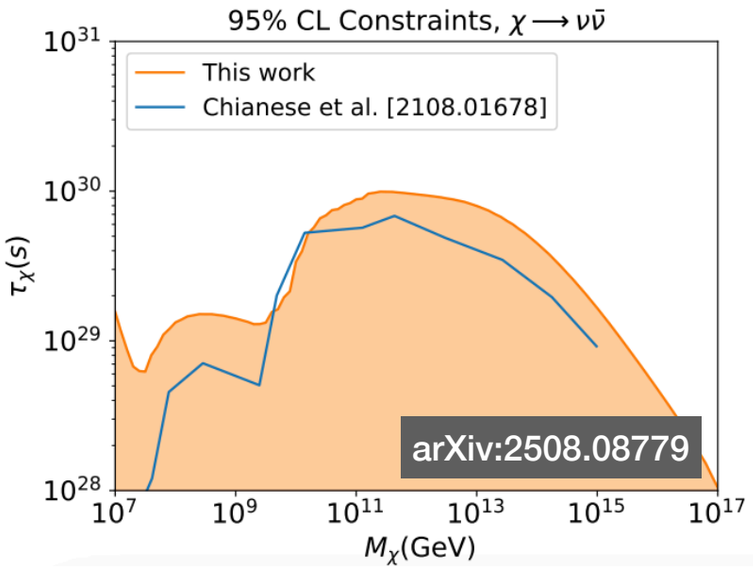
arXiv:2502.08484

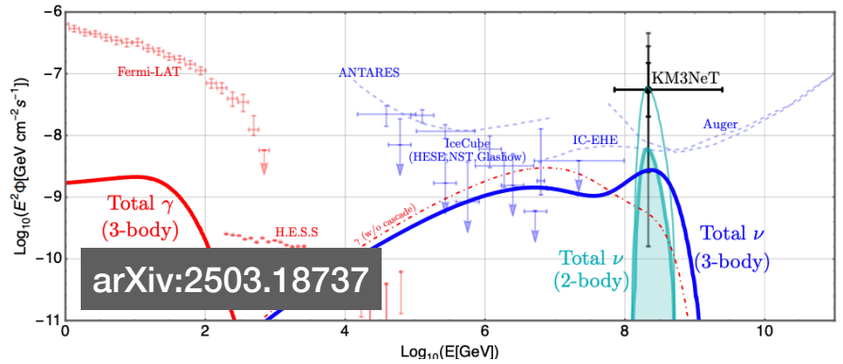
arXiv:2502.08387

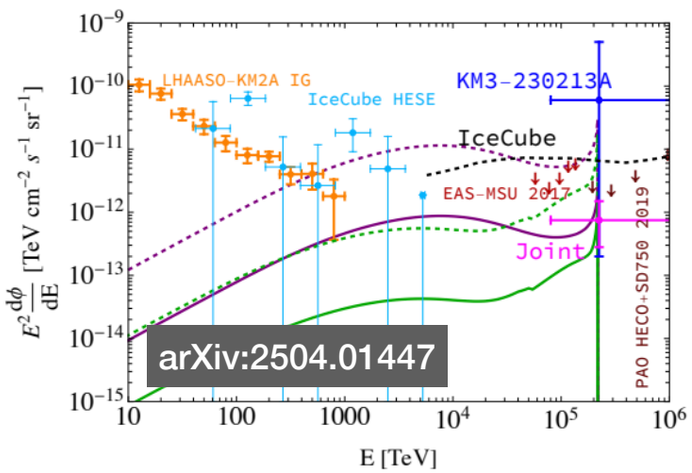
Dark matter interpretation

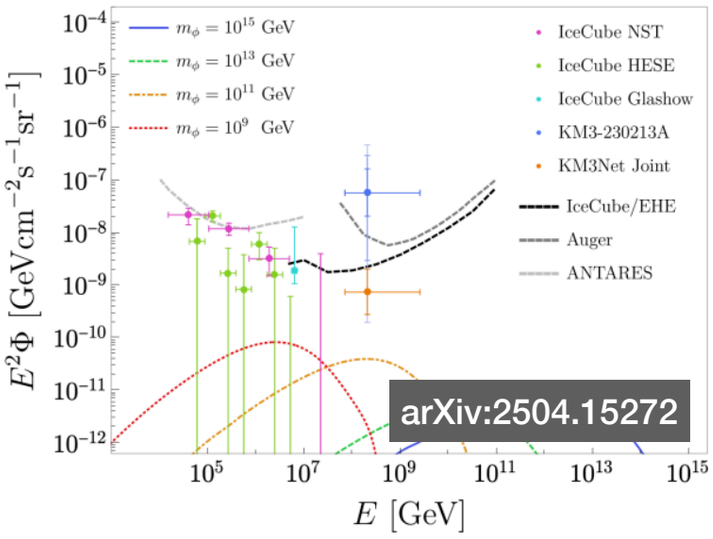
- Several phenomenological works interpreting the event as a product of the decay of a heavy DM particle into SM particles.

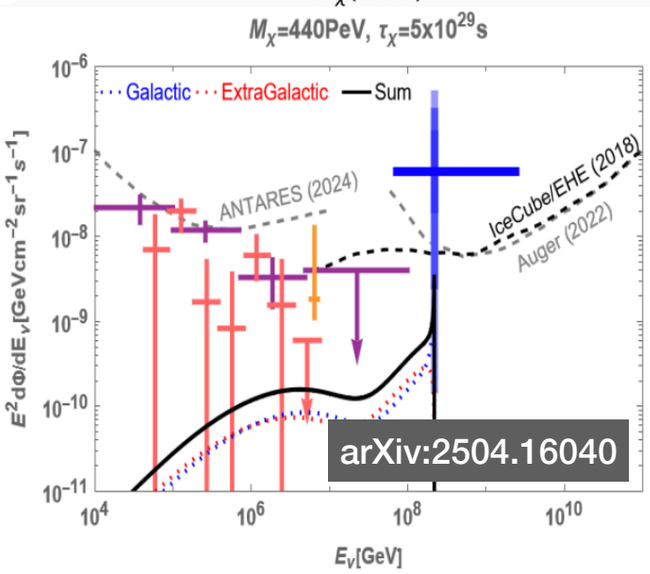


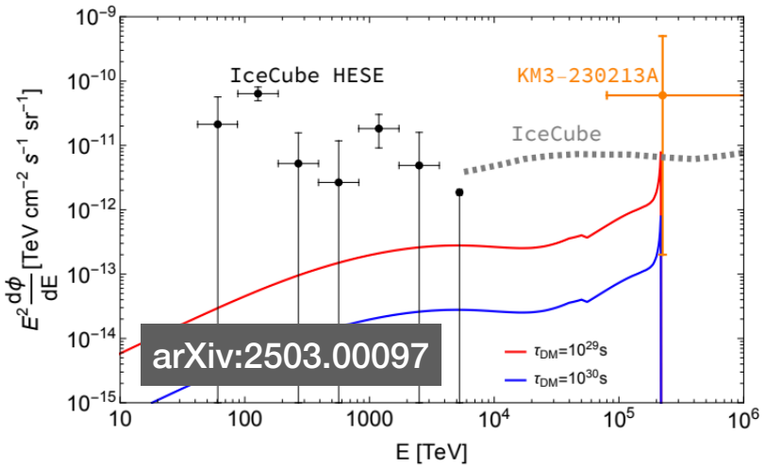






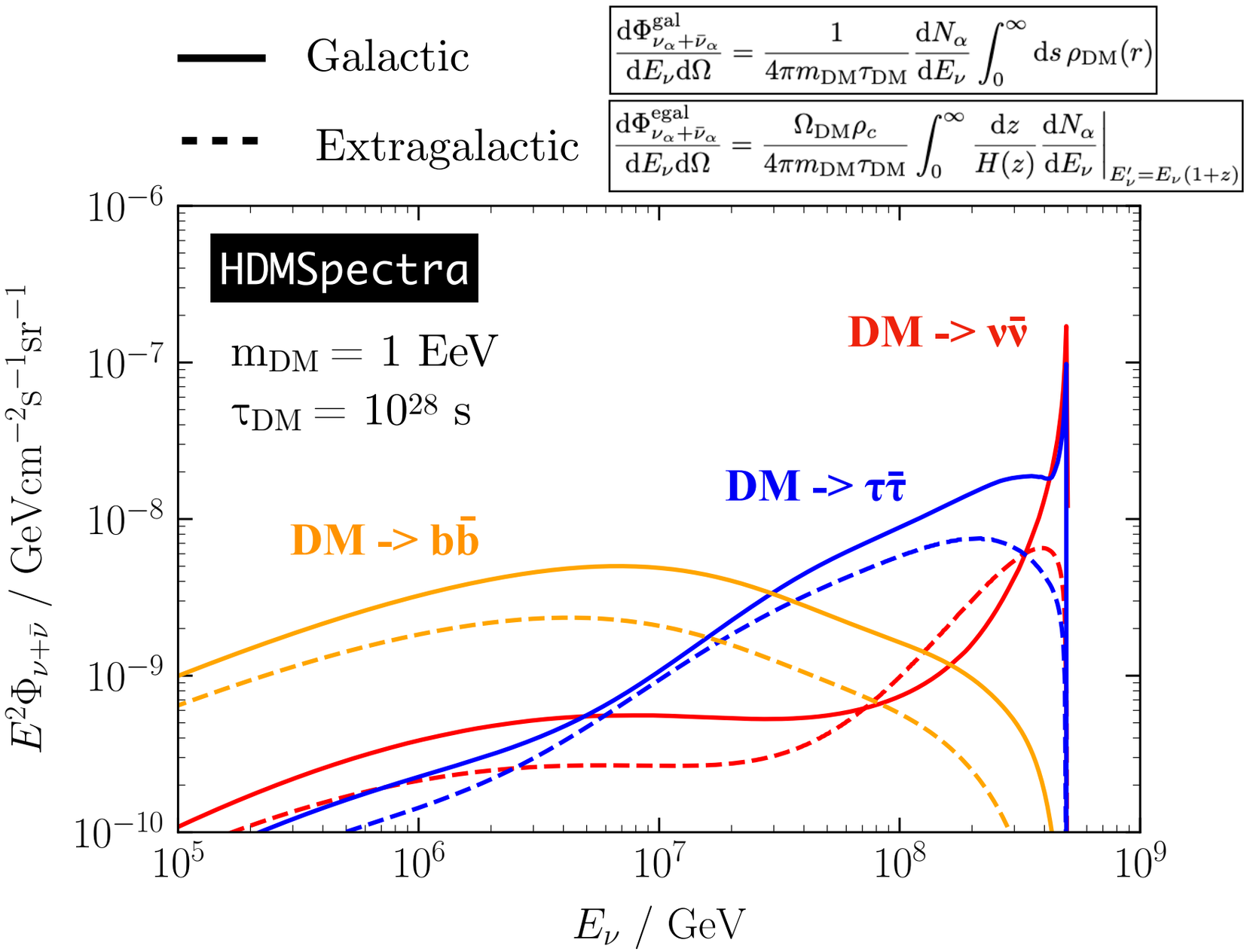






Dark matter interpretation

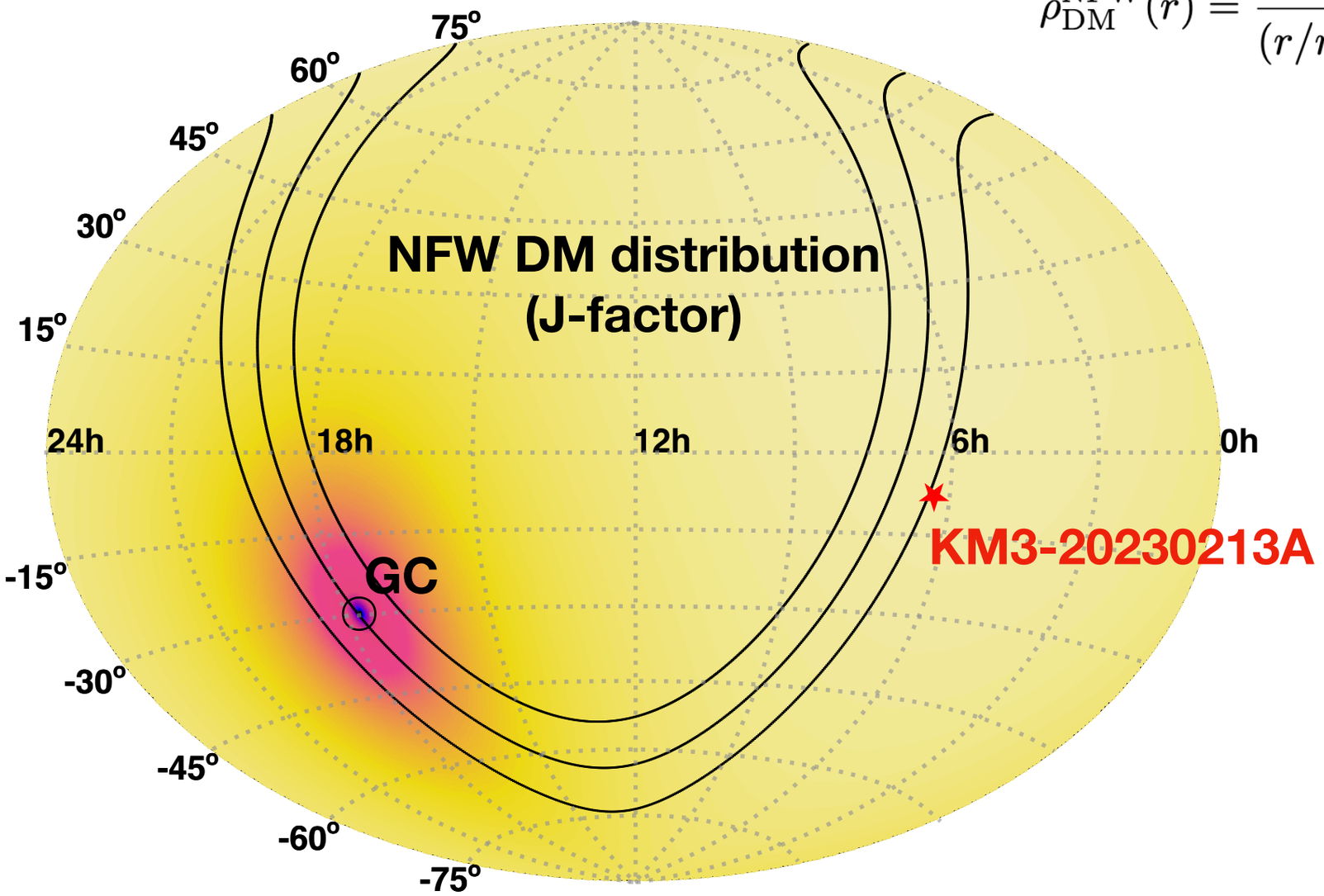
- Caveat of phenomenological analyses:
  - KM3NeT reported a neutrino flux assuming a E^{-2} spectrum
  - Energy spectrum of particles produced in DM decay often follows a peaked behavior



Dark matter interpretation

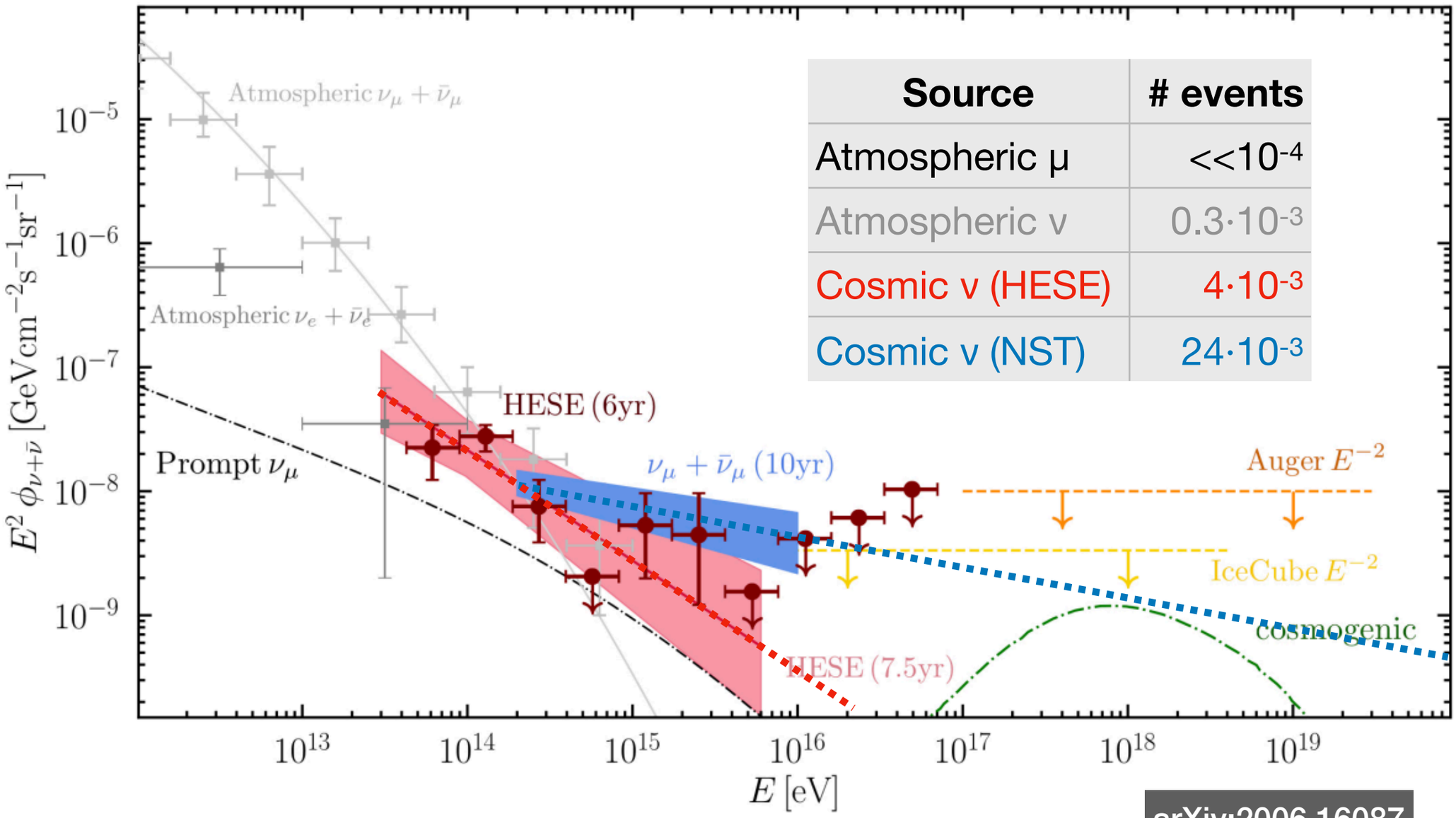
- Phenomenological analysis only studied the energy response
- Given the direction of KM3-20230213A, can we say something about the galactic vs extragalactic origin?

$$\rho_{\mathrm{DM}}^{\mathrm{NFW}}(r) = \frac{\rho_s}{(r/r_s)\,(1+r/r_s)^2}$$



Background estimation

- Estimate how many events with a bright track-like signature in ARCA21 (286 days of lifetime).



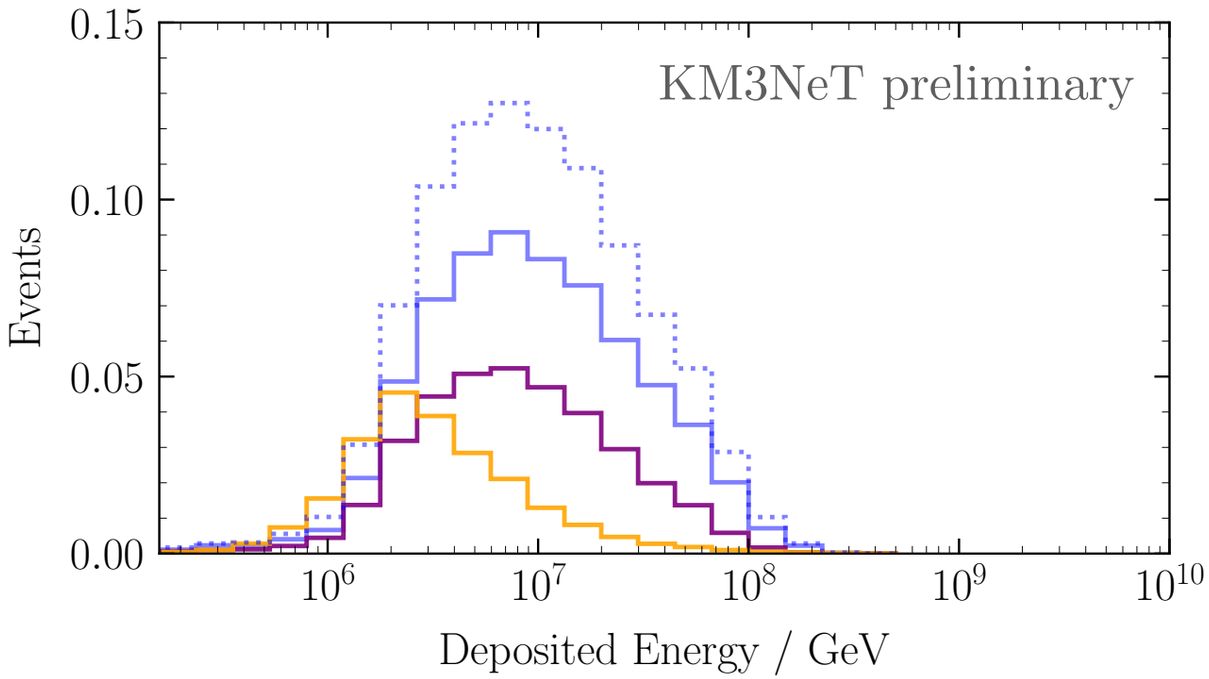
Source	# events
Atmospheric μ	<<10^{-4}
Atmospheric ν	$0.3 \cdot 10^{-3}$
Cosmic ν (HESE)	$4 \cdot 10^{-3}$
Cosmic ν (NST)	$24 \cdot 10^{-3}$

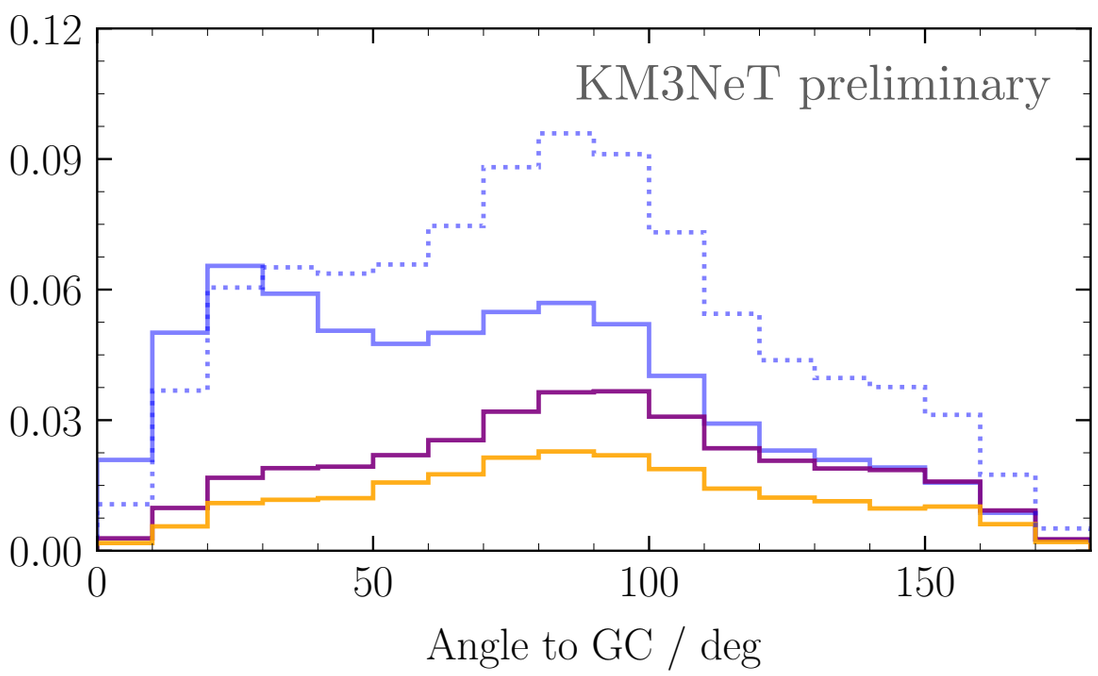
arXiv:2006.16087

How simulations look like?

- Two proxies are used in this analysis:
  - Deposited energy in the detector
  - Angle with respect to Galactic Center

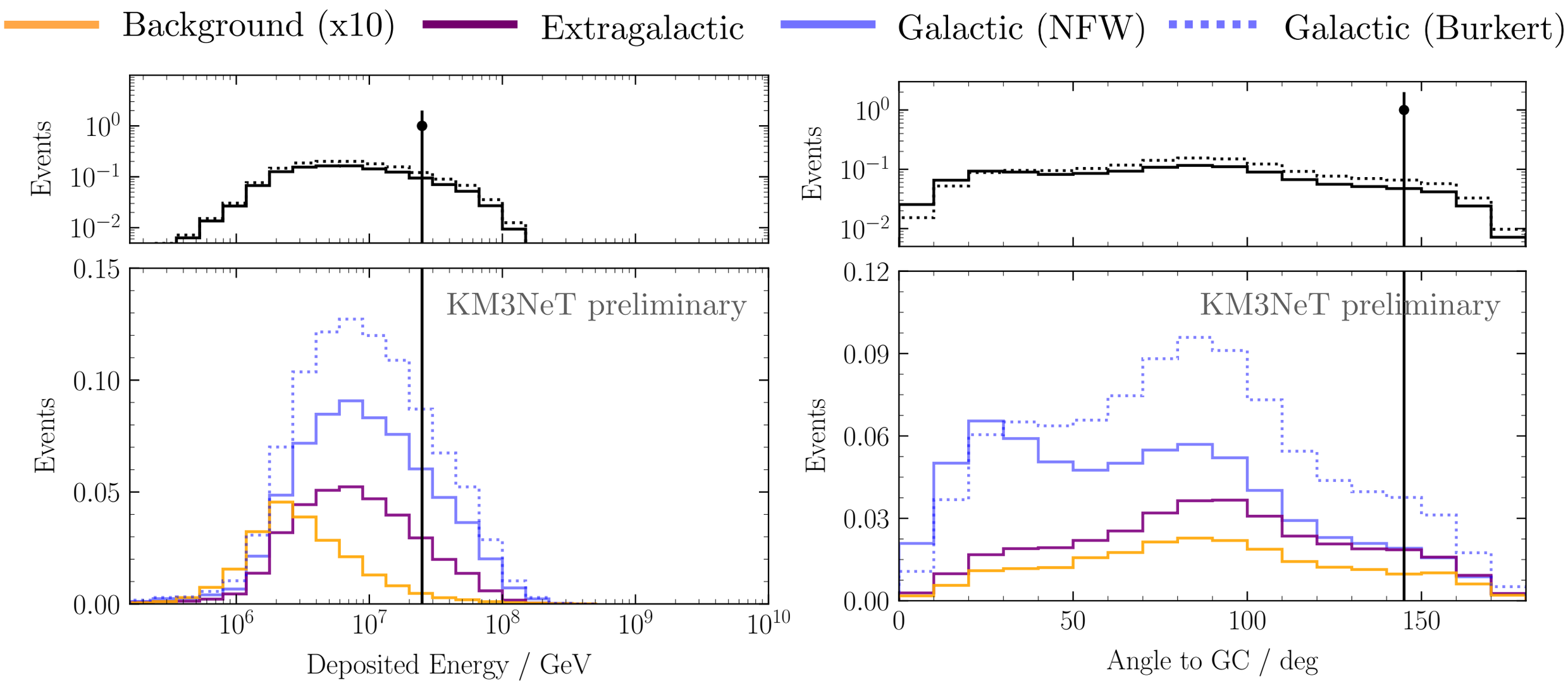
DM -> $\tau\bar{\tau}$ / m_{DM} = 1 EeV / τ_{DM} = $7 \cdot 10^{26}$ s





How data look like?

- In data only one event survives (KM3-20230213A)
  - Observed in a region of sky where galactic and extragalactic contribution are at similar level

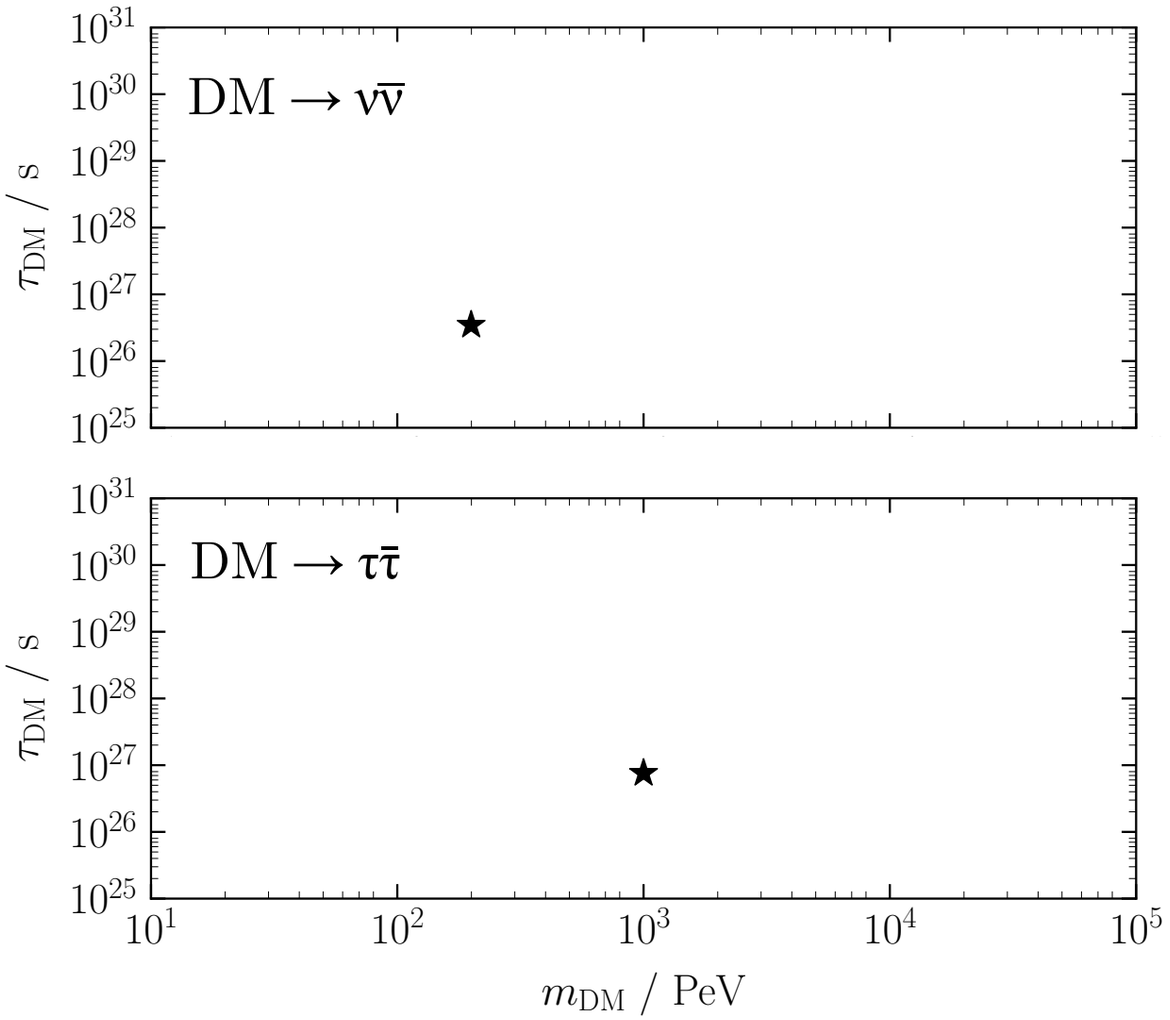


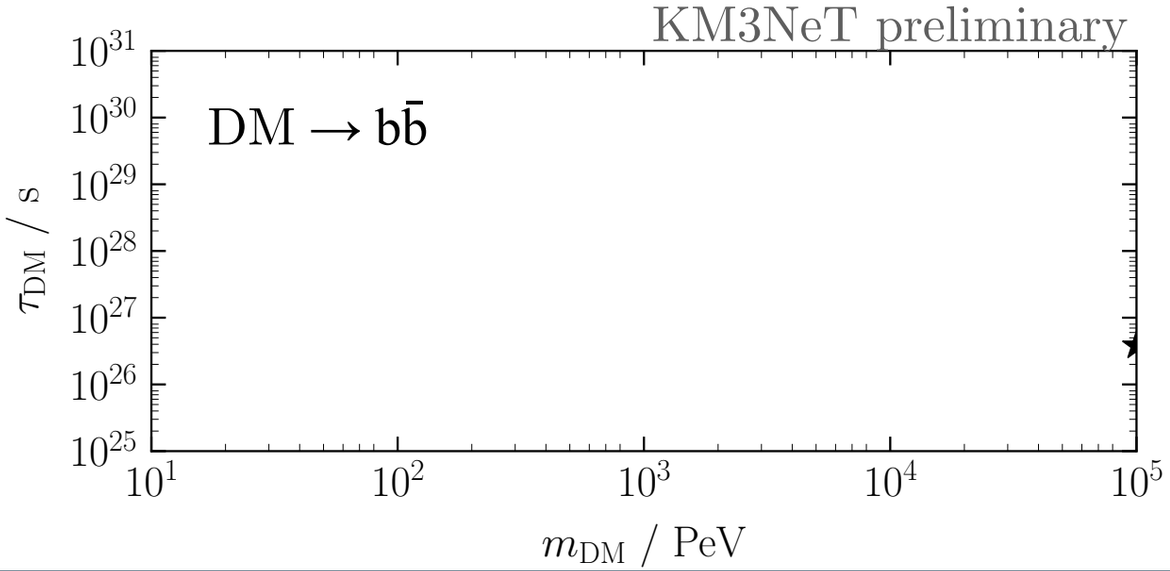
Results

- Binned likelihood analysis:
  - Three cosmic background hypotheses (HESE, NST, no astro)
  - Three decay scenarios

Best fits

Channel	m_{DM} / EeV	τ_{DM} / 10^{26}s
DM->$\nu\bar{\nu}$	0.2	4
DM->$\tau\bar{\tau}$	1	7
DM->$b\bar{b}$	100	4





Results

- Binned likelihood analysis:
  - Three cosmic background hypotheses (HESE, NST, no astro)
  - Three decay scenarios
- Feldman-Cousin preferred regions for each case
  - Lower mass bounds in the ~100PeV regime
  - Upper mass can not be constrain due to energy tails of DM spectra

Best fits

Channel	m_{DM} / EeV	τ_{DM} / 10^{26}s
DM->$\nu\bar{\nu}$	0.2	4
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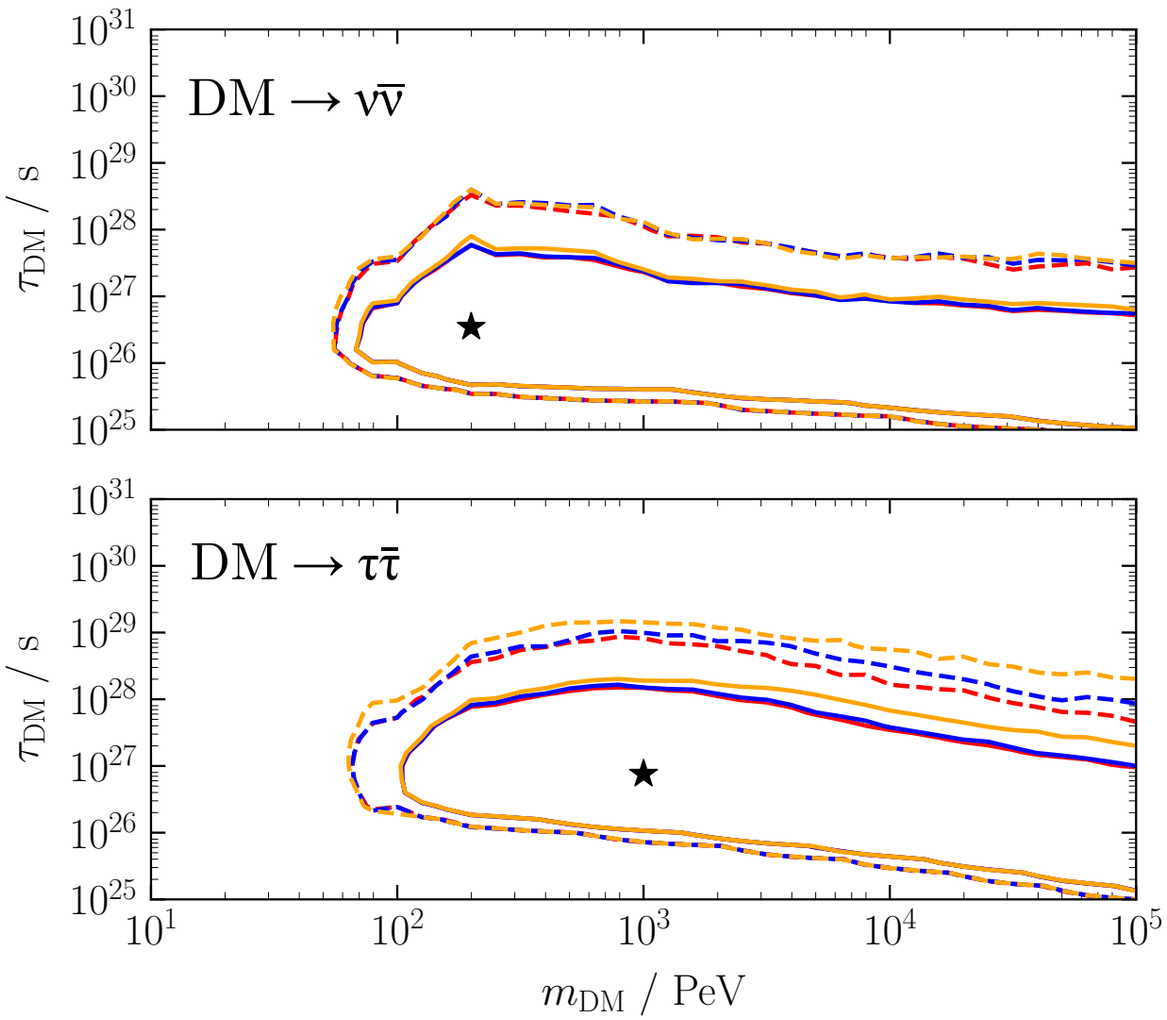
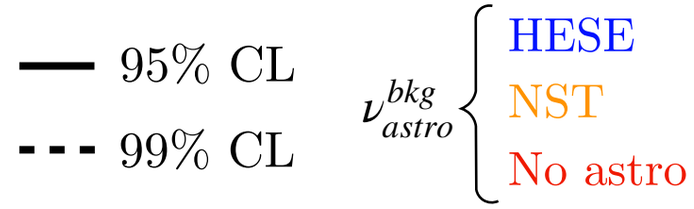
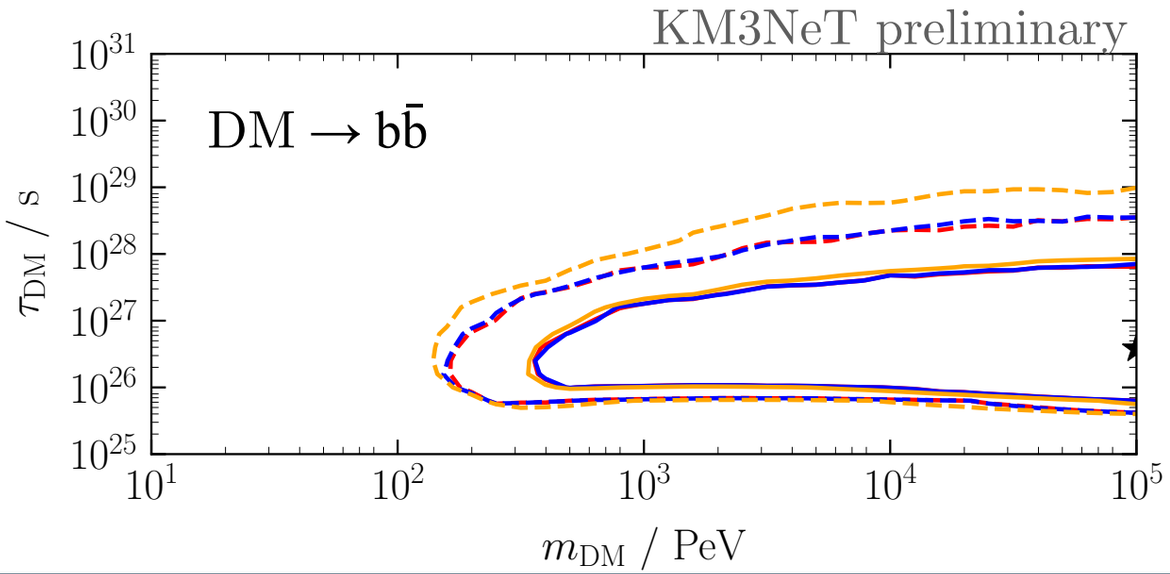
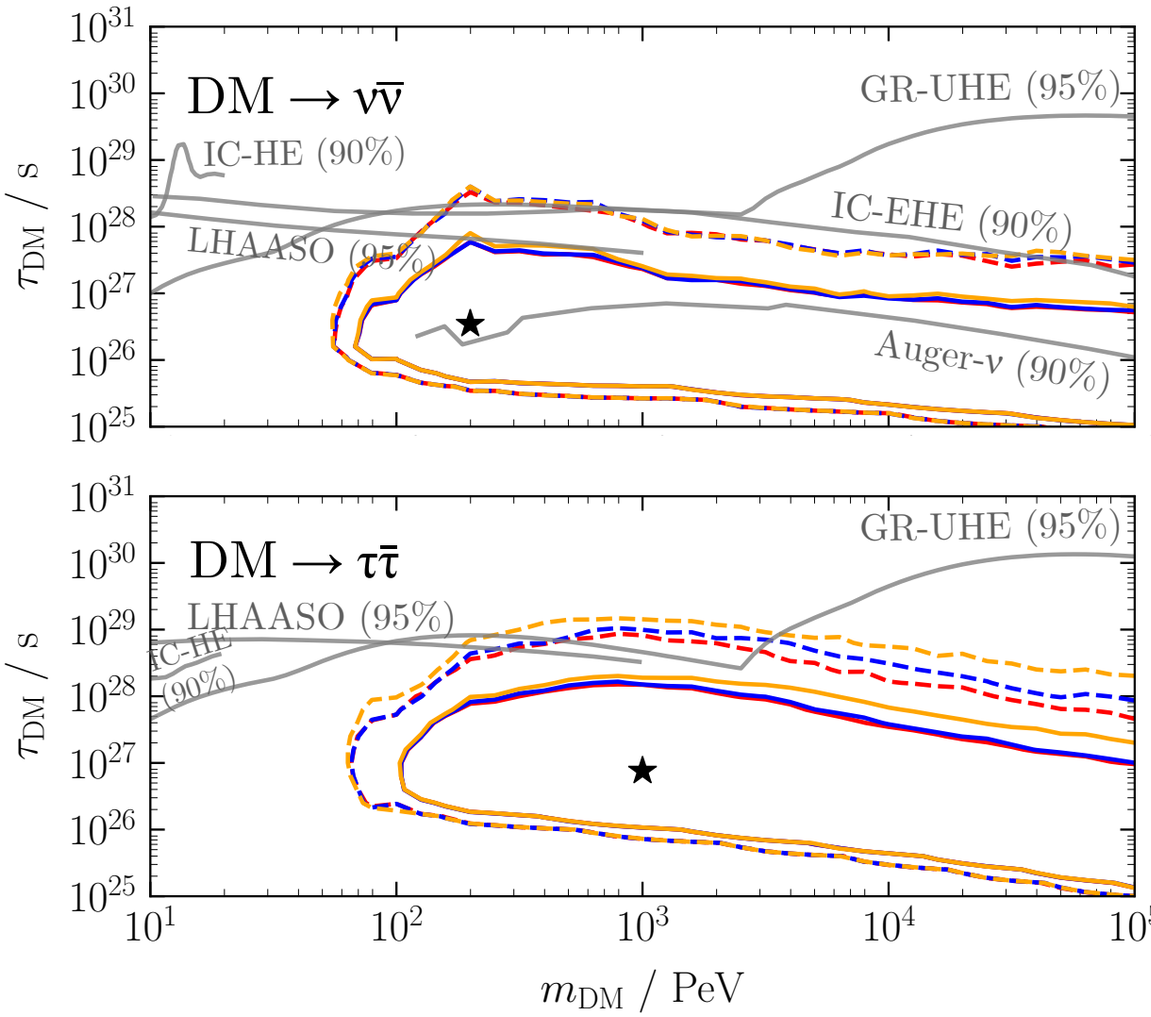


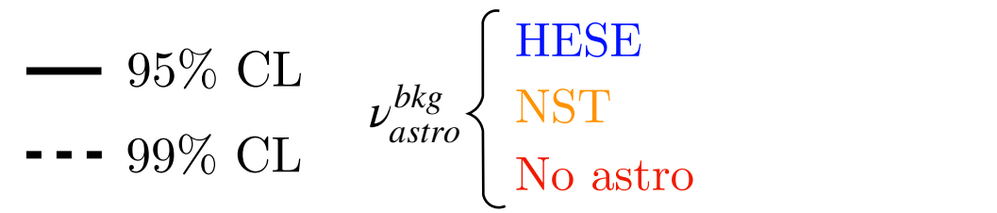


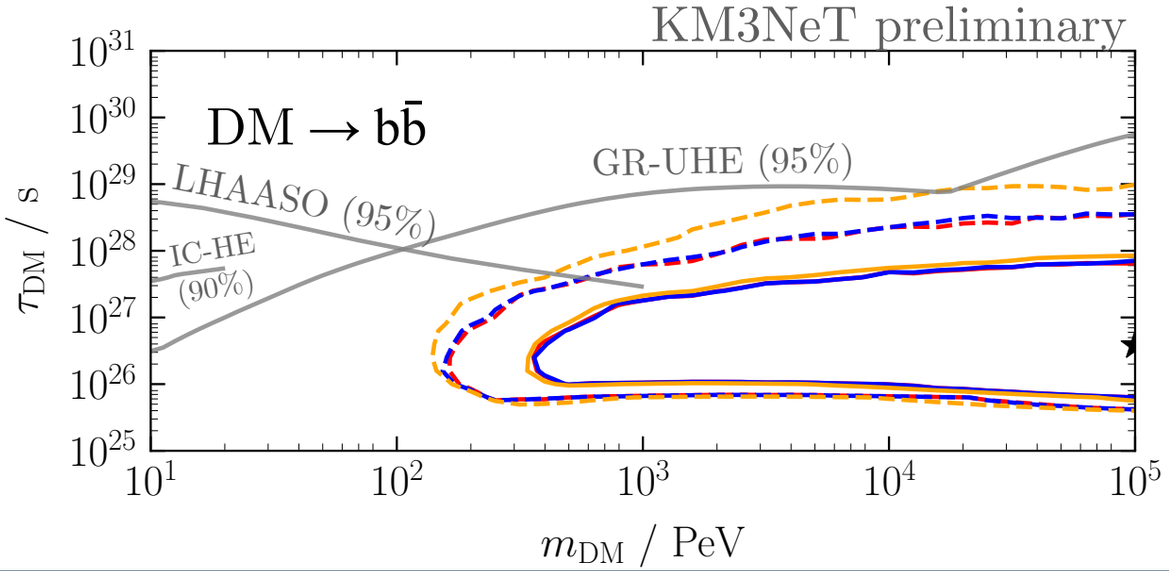


Global landscape

- Preferred regions can be compared with limits from other experiments and messengers
  - Most of the preferred regions in tension with bounds from ultra high energy gamma ray (dominated by Auger and KASKADE-Grande)
  - Bounds from neutrinos also exclude some areas of the preferred region







Conclusions

- Studied the possibility that KM3-20230213A would be the product of a heavy dark matter decay
- First analysis properly accounting for the peculiar energy spectrum of neutrino flux in DM decay
- Several insights:
  - Assuming DM hypothesis, no conclusion can be drawn regarding a galactic vs extragalactic origin
  - DM mass must by above the ~100PeV to explain the energy of the event
  - Only limited portions of the preferred regions remain compatible with bounds from other experiments
- Prospects -> more data from ARCA and a joint analysis with other neutrino experiments will be useful to improve current result

Acknowledgments

Proyecto realizado con la Beca Leonardo de Investigación Científica y Creación Cultural 2024 de la Fundación BBVA. La Fundación BBVA no se responsabiliza de las opiniones, comentarios y contenidos incluidos en el proyecto y/o los resultados derivados del mismo, los cuales son total y absoluta responsabilidad de sus autores.