Dark matter searches with the KM3NeT telescope

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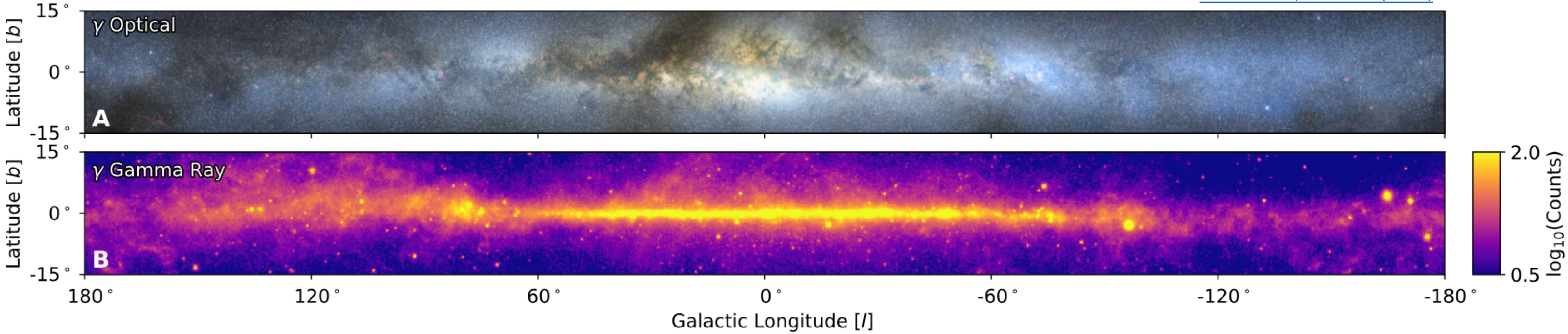
CAN symposium - June 2024

Neutrinos as cosmic messengers

Science 380, no. 6652 (2023)



$$p + p \rightarrow p + n + \pi^{+}$$ → Neutrinos

$$\rightarrow p + p + \pi^{0}$$ → Gamma rays

Neutrinos as cosmic messengers

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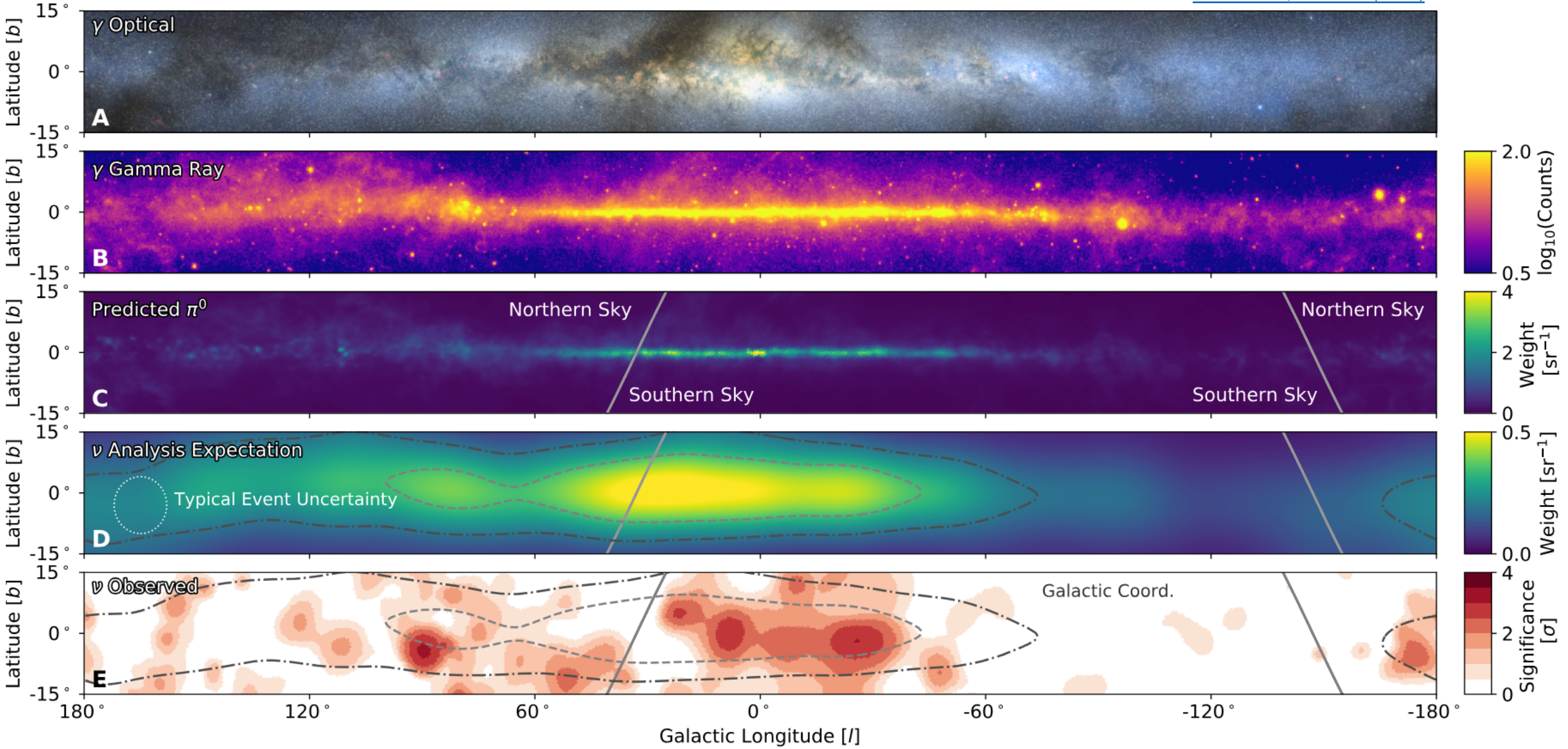
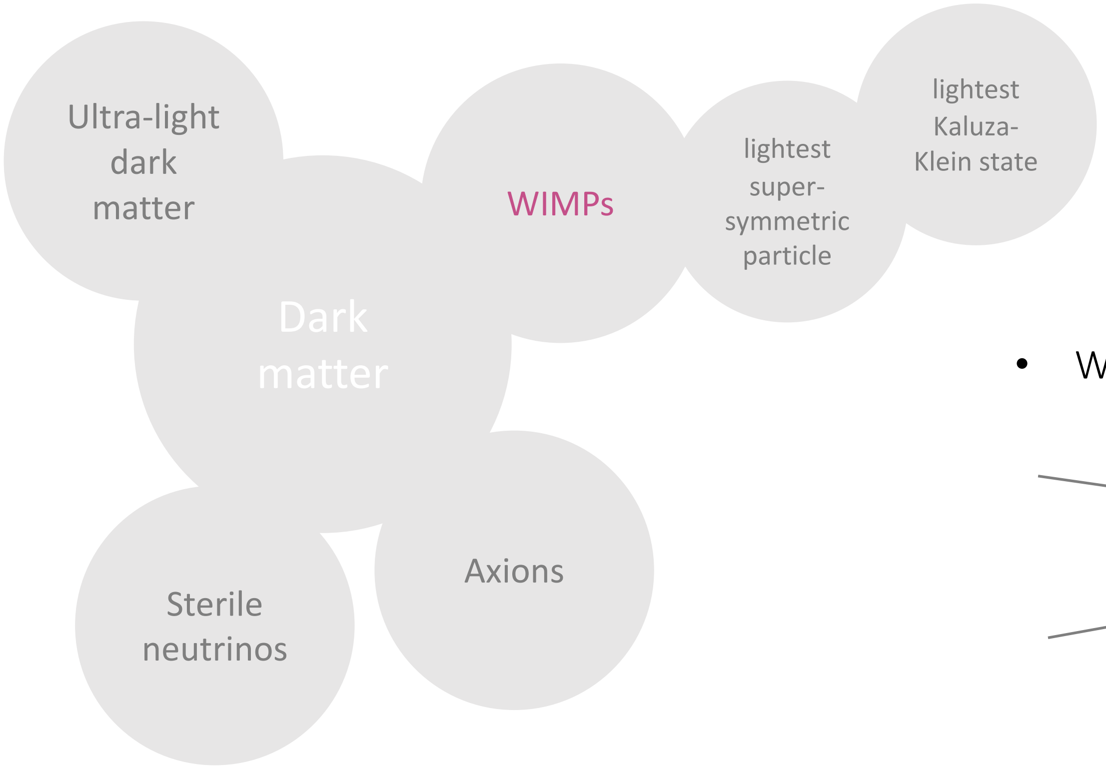
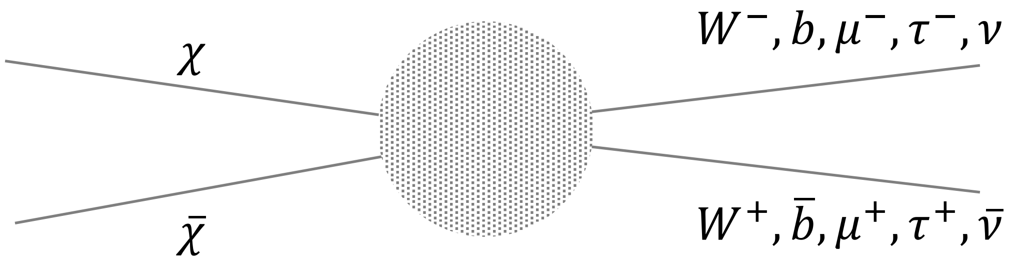


What else can neutrinos teach us?

- Cosmological observations set little constraints on the nature of dark matter



- WIMP annihilations

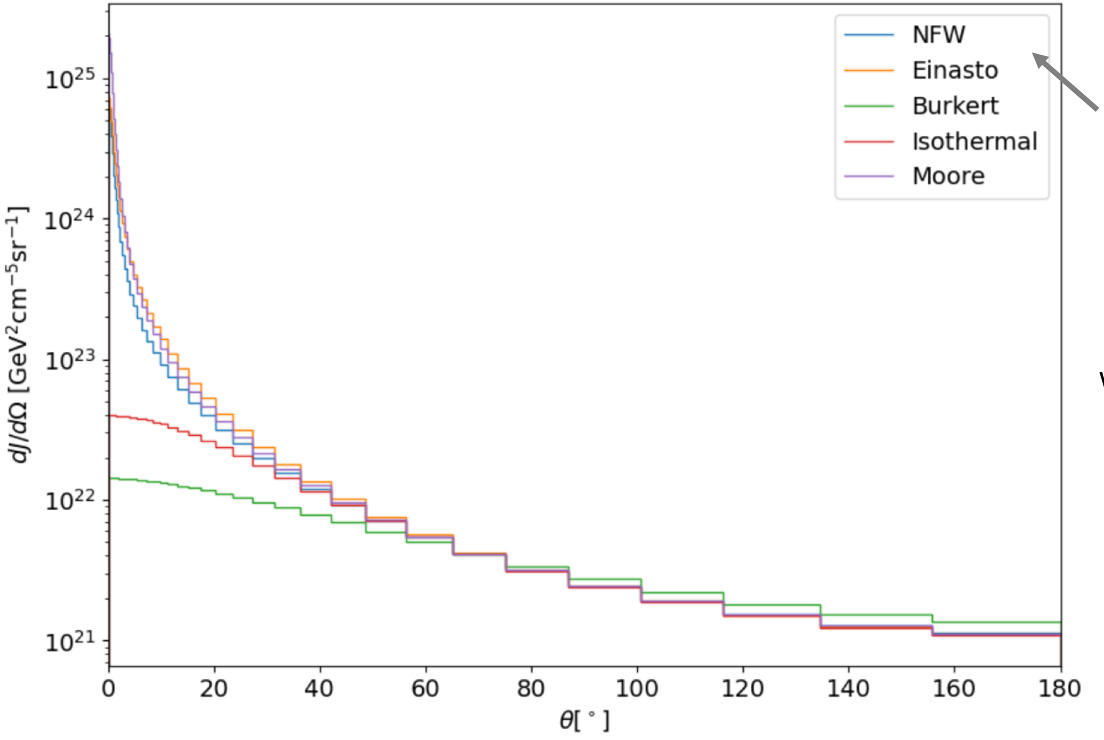


- Anomalous neutrino flux from regions with high dark matter density, as the Galactic centre!?

Modelling the source: simulation of a dark matter neutrino signal

Creation of neutrinos by WIMP dark matter annihilation in the galactic centre

Spatial distribution around galactic centre:



Different profiles allowed by observations

Within 40 deg around the Galactic centre:

NFW: 80% signal

Burkert: 55% signal

$$\frac{d\Phi_\alpha^c}{dE\,dt} = \frac{1}{4\pi}\frac{<\sigma v>}{2m_\chi^2}\frac{dN_\alpha^c}{dE}\int_{\Delta\Omega}\int_{l.o.s.}\rho^2(\theta,l)dl\,d\Omega$$

Spectra

Dark matter distribution around Galactic Centre

Neutrino flux proportional to dark matter density

Modelling the source: simulation of a dark matter neutrino signal

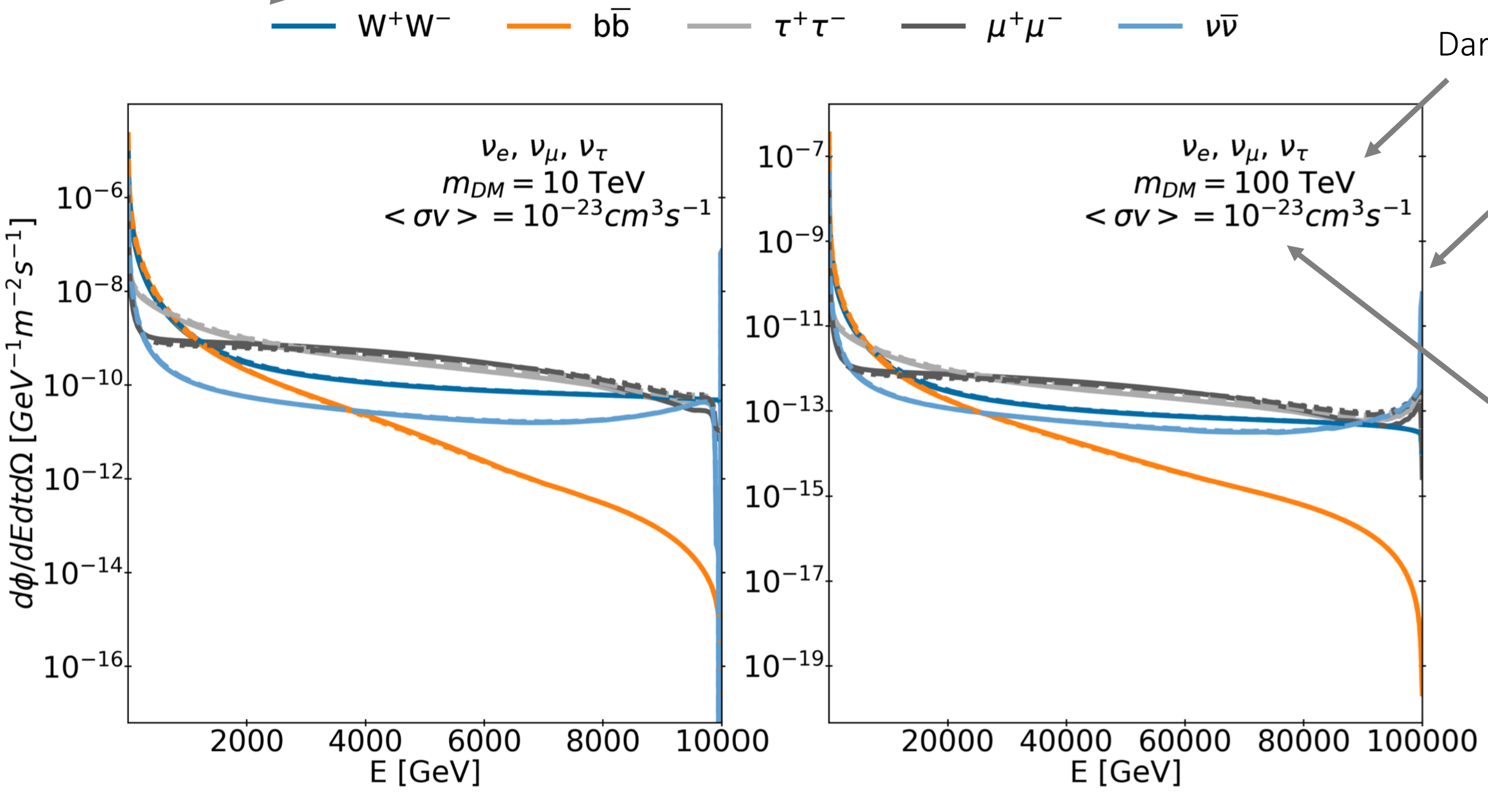
Creation of neutrinos by WIMP dark matter annihilation in the galactic centre

Annihilation channel

Dark matter mass

most interesting signature: the peak

Flux:



Annihilation cross-section

Cut-off at dark matter mass

$$\frac{d\Phi_\alpha^c}{dE\,dt} = \frac{1}{4\pi}\frac{<\sigma v>}{2m_\chi^2}\frac{dN_\alpha^c}{dE}\int_{\Delta\Omega}\int_{l.o.s.}\rho^2(\theta,l)dl\,d\Omega$$

Spectra

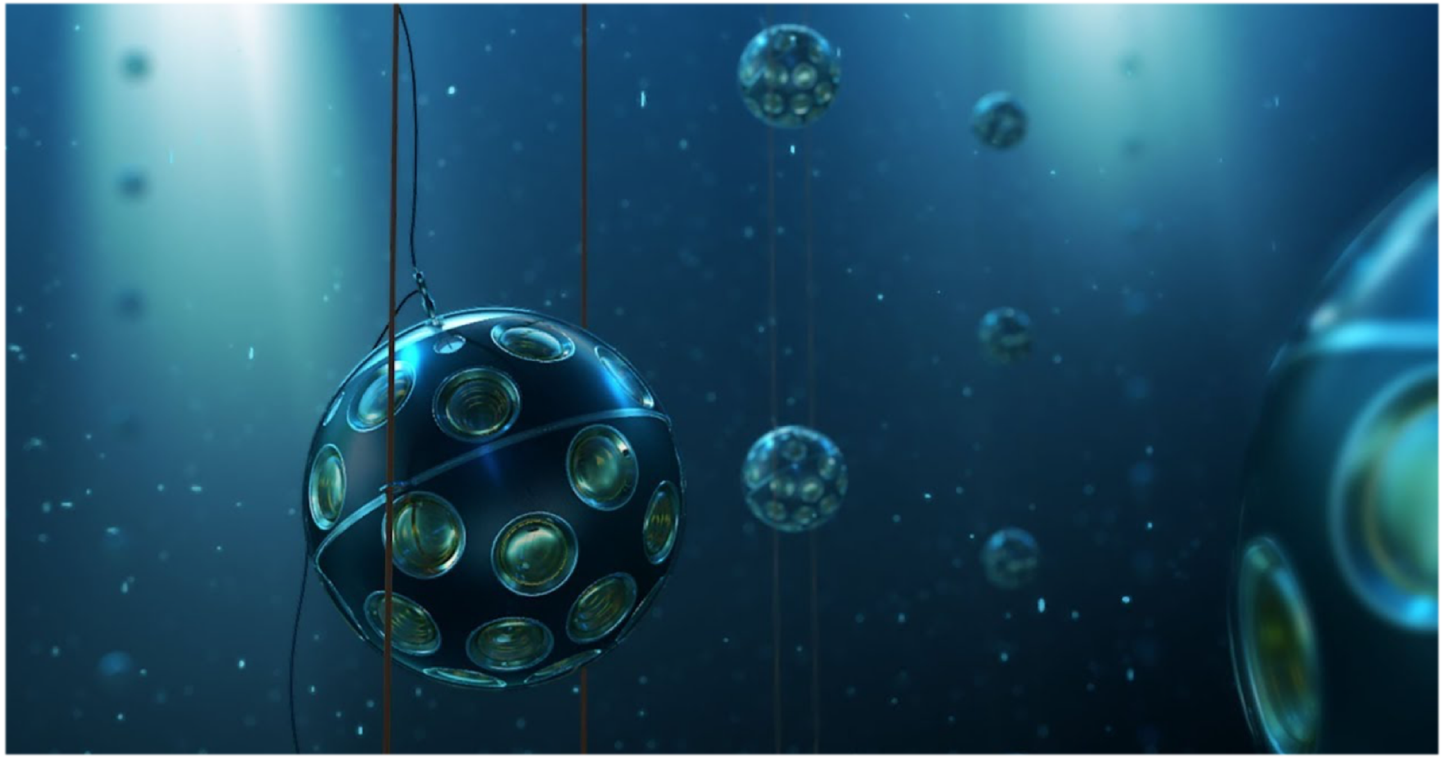
Dark matter distribution around Galactic Centre

Neutrino flux proportional to annihilation cross-section

The KM3NeT telescope

Detectable neutrino energies GeV - PeV

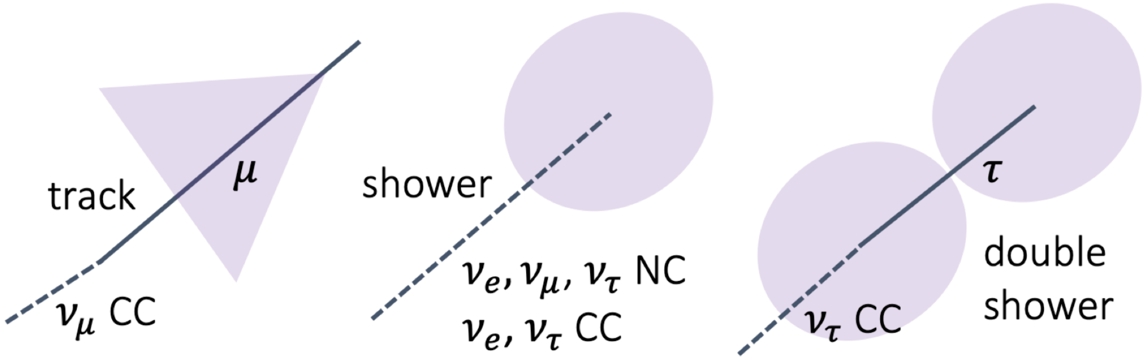
Water Cerenkov detector in the Mediterranean sea



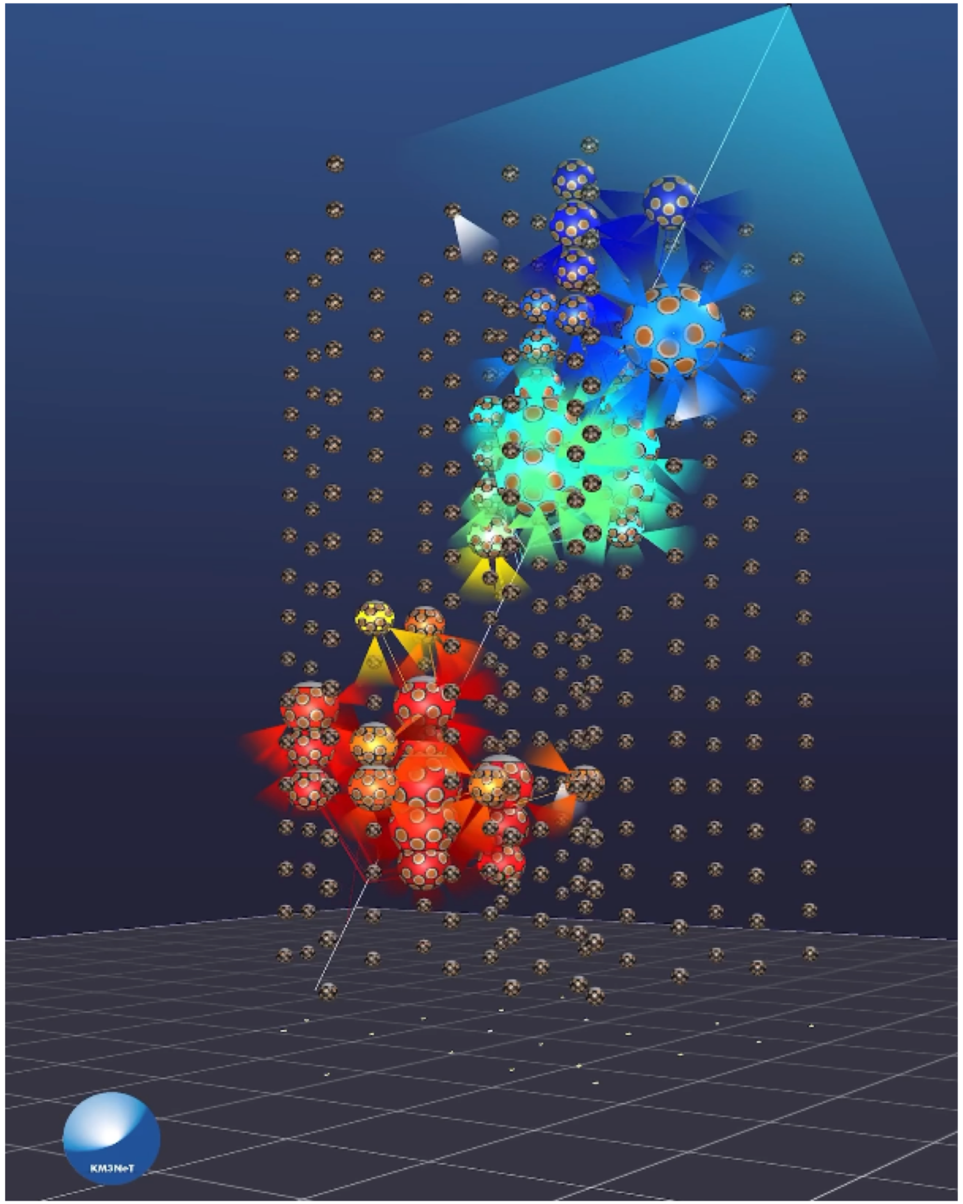
Two sites:

ARCA (neutrino astronomy)
ORCA (neutrino oscillations)

different type of neutrino interactions
↓
different type of events



How does the KM3NeT/ARCA data look like?



Total event rate of ARCA with 21 detection strings (ARCA21):

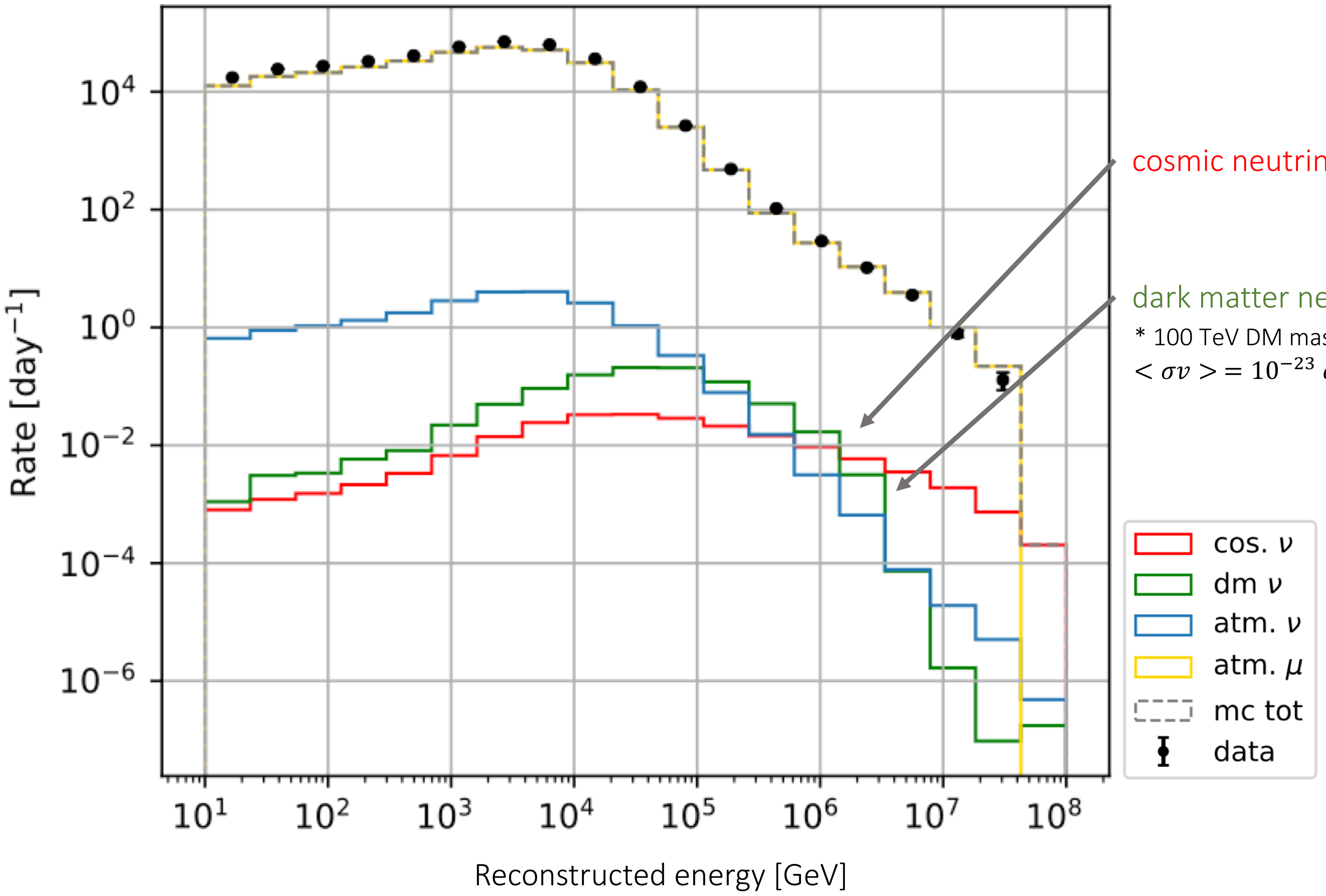
$\sim 10^6$ events per day

($\sim$ 40 neutrinos per day)

Data selection

How can we differentiate neutrinos created by dark matter from other type of events?

Detector: ARCA21 (~70 days)



cosmic neutrinos

dark matter neutrinos

* 100 TeV DM mass, annihilating into $\nu\bar{\nu}$, $<\sigma v> = 10^{-23}\ cm^3 s^{-1}$

DATA-MC agreement thanks to:

- Improvements in calibration, reconstruction and simulations

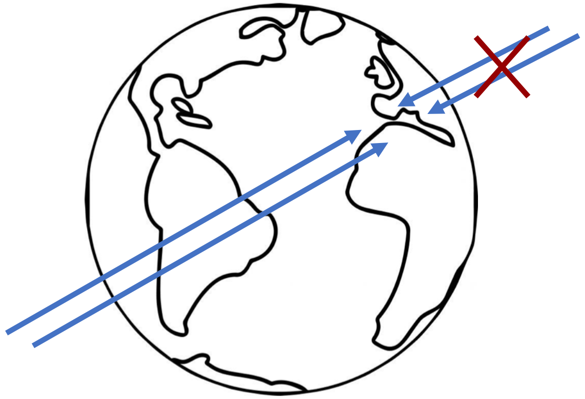
(all with strong Nikhef contributions)

Data selection

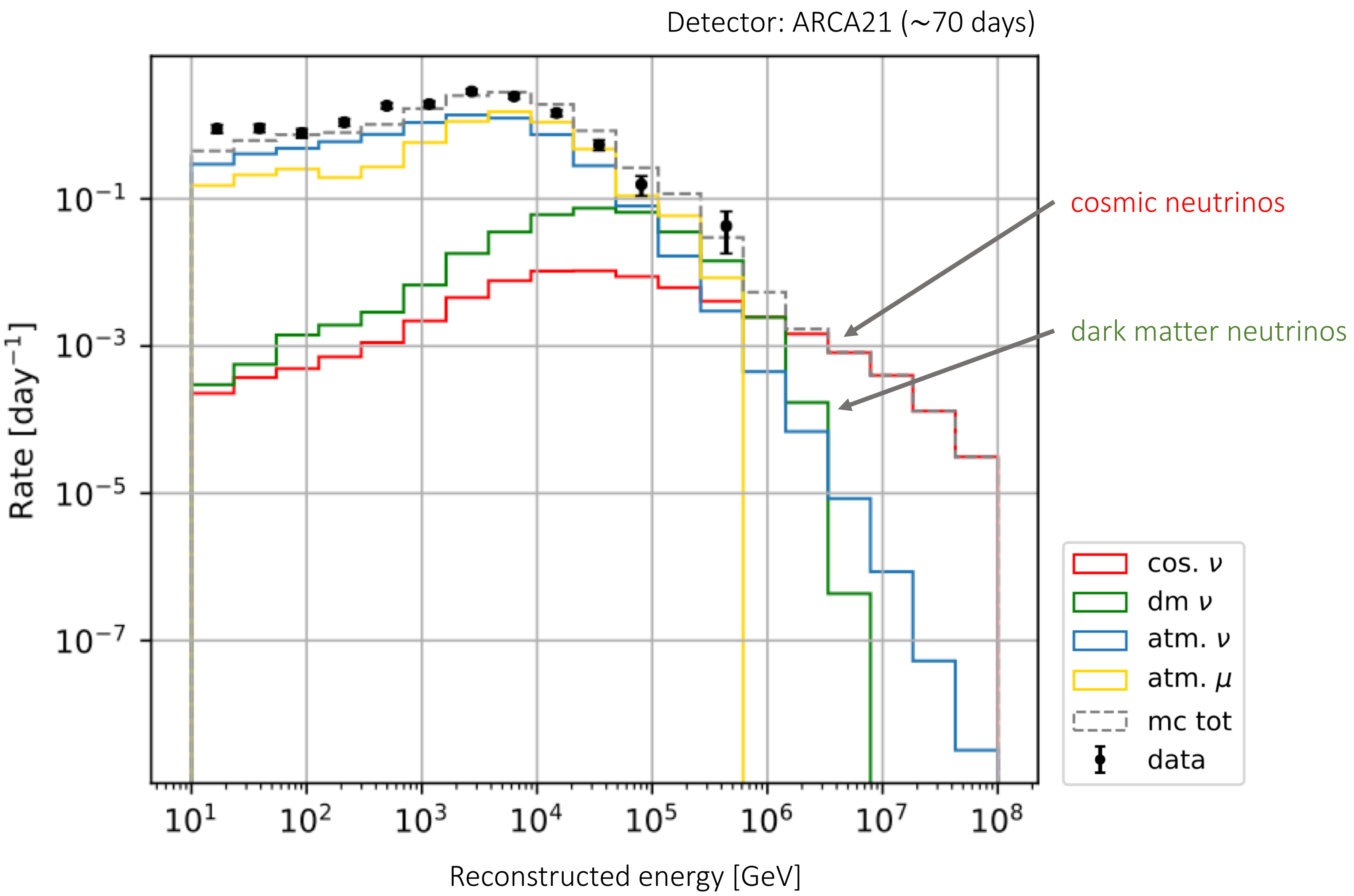
How can we differentiate neutrinos created by dark matter from other type of events?

Selection:

- We cut all events coming from above the horizon



- We apply quality cuts + Boosted Decision Tree



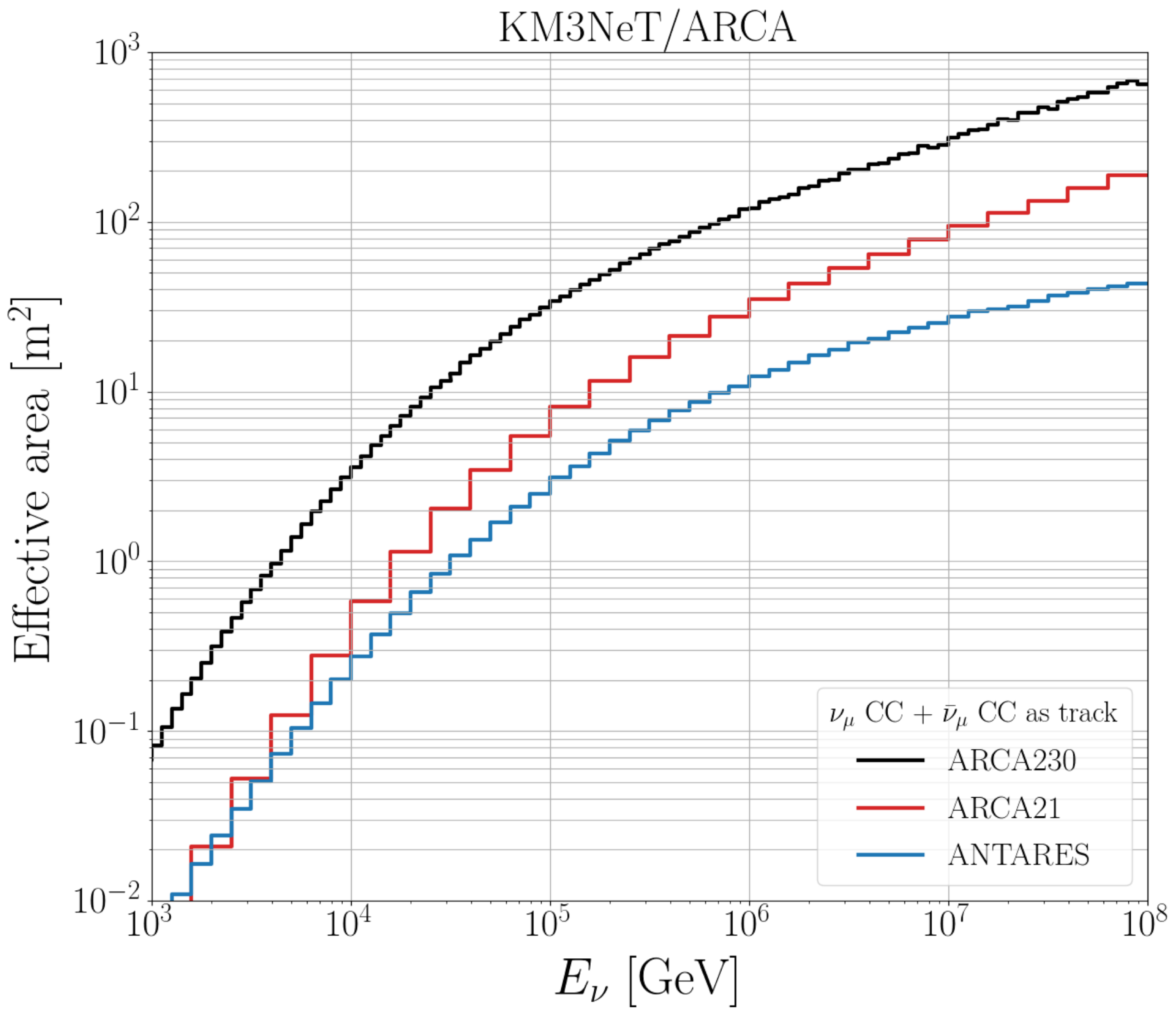
Detector response

KM3NeT/ARCA: a growing detector

Growing detector leads to:

- Higher effective area
  → More neutrinos / day

$$N_{events} = \phi \cdot A \cdot t$$

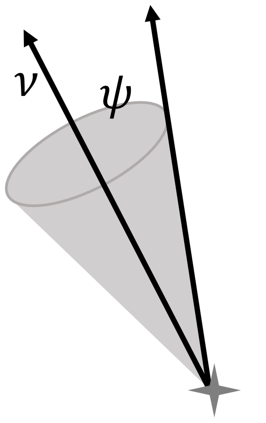


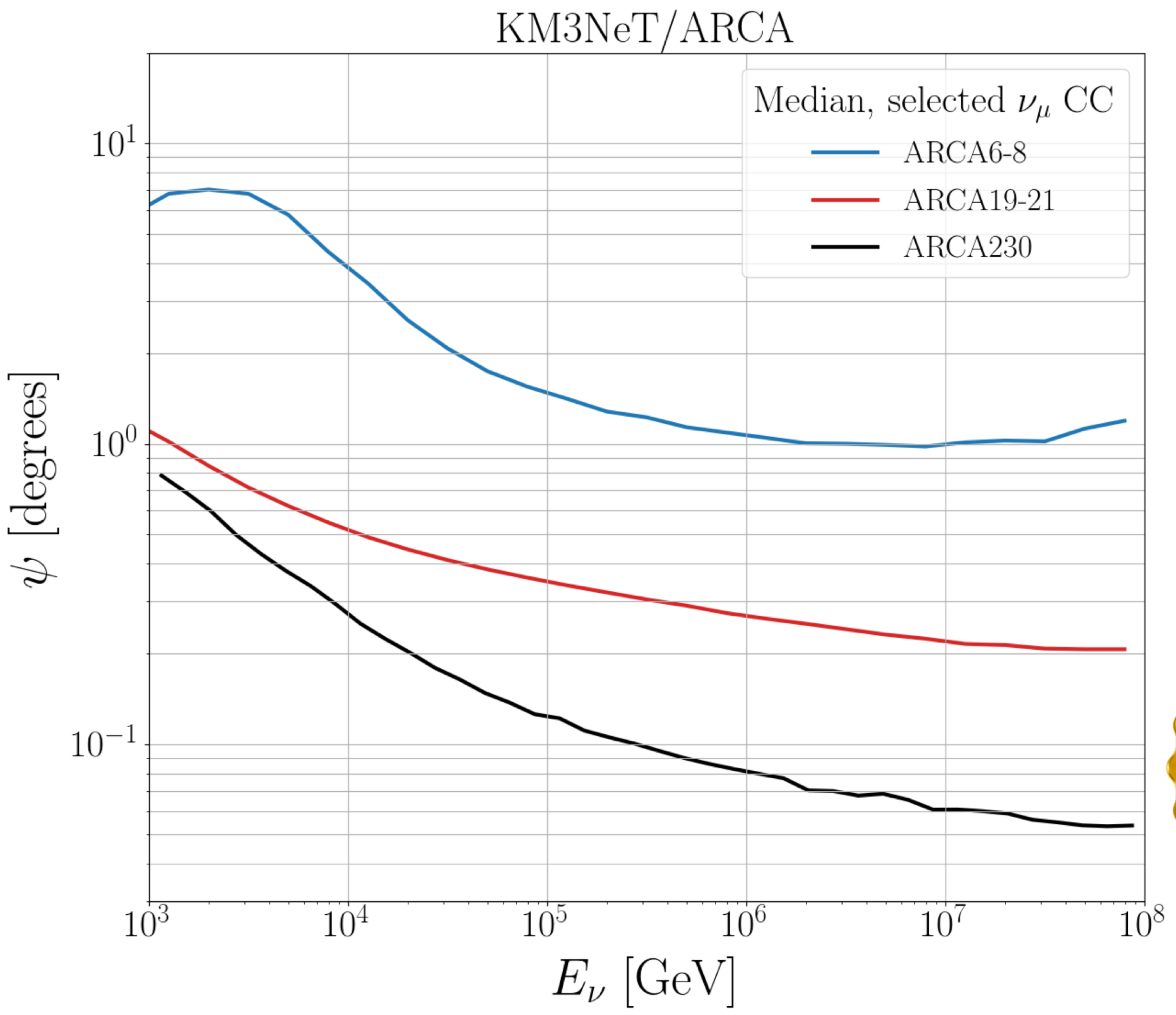
Detector response

KM3NeT/ARCA: a growing detector

Growing detector leads to:

- Higher effective area
- Better angular resolution



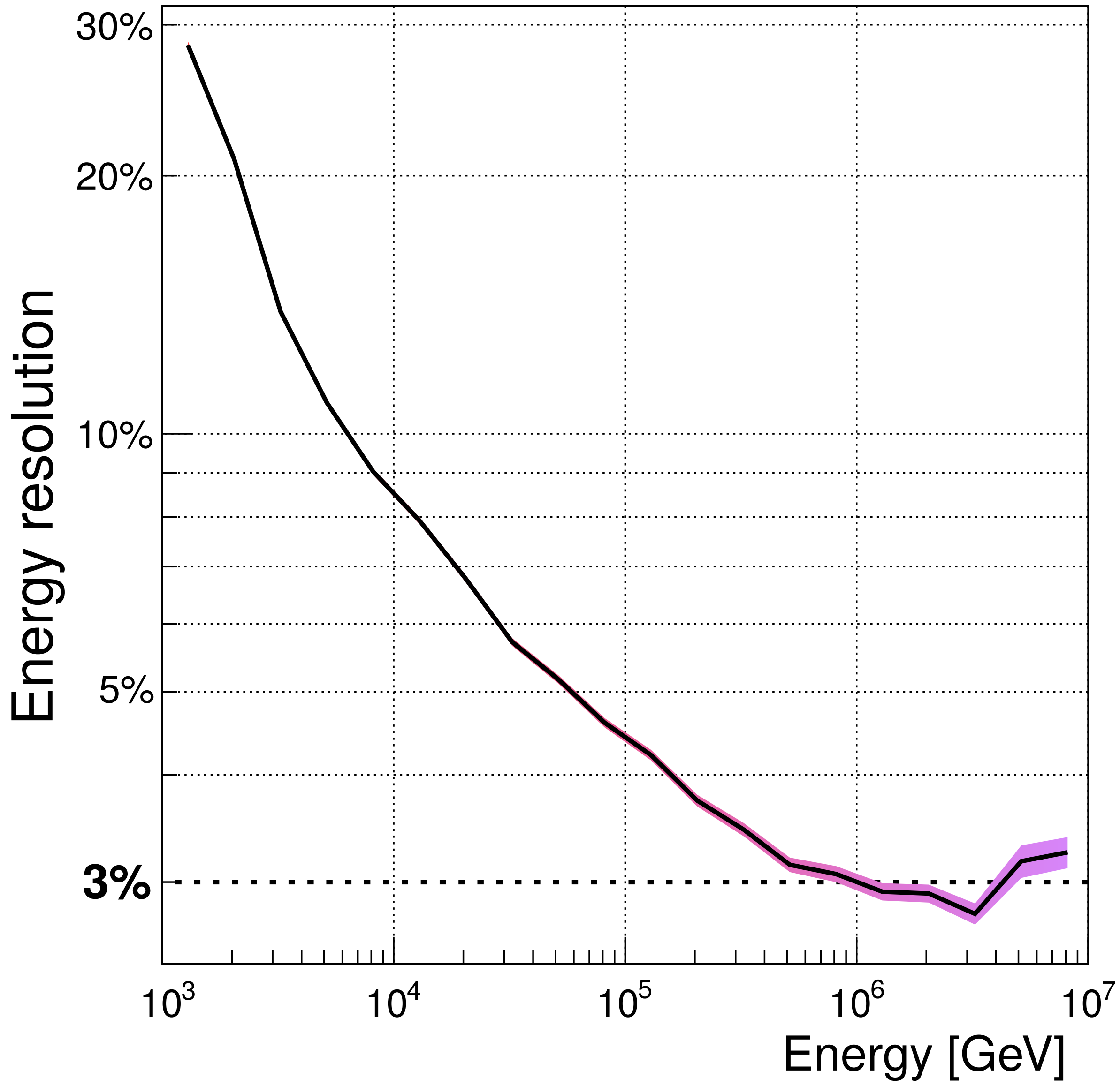


Detector response

KM3NeT/ARCA: a growing detector

Growing detector leads to:

- Higher effective area
- Better angular resolution
- Including showers
  → Better energy resolution

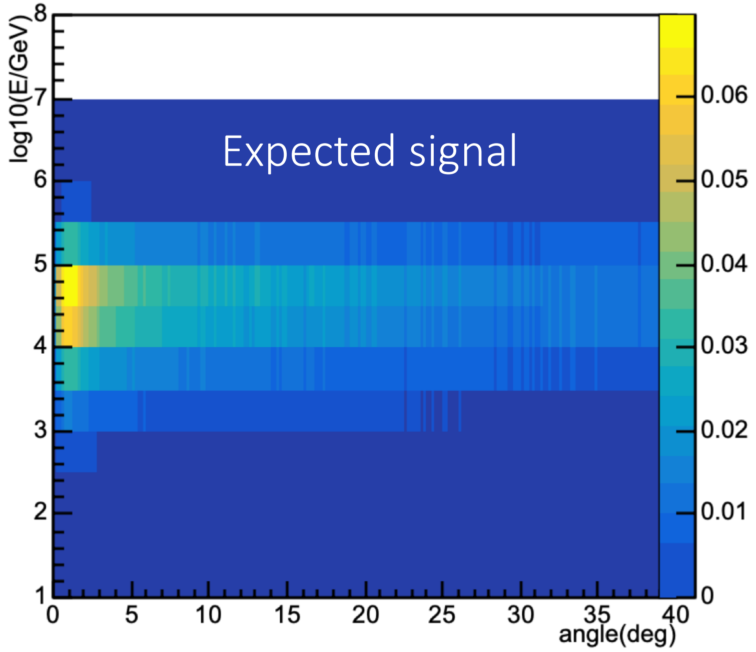


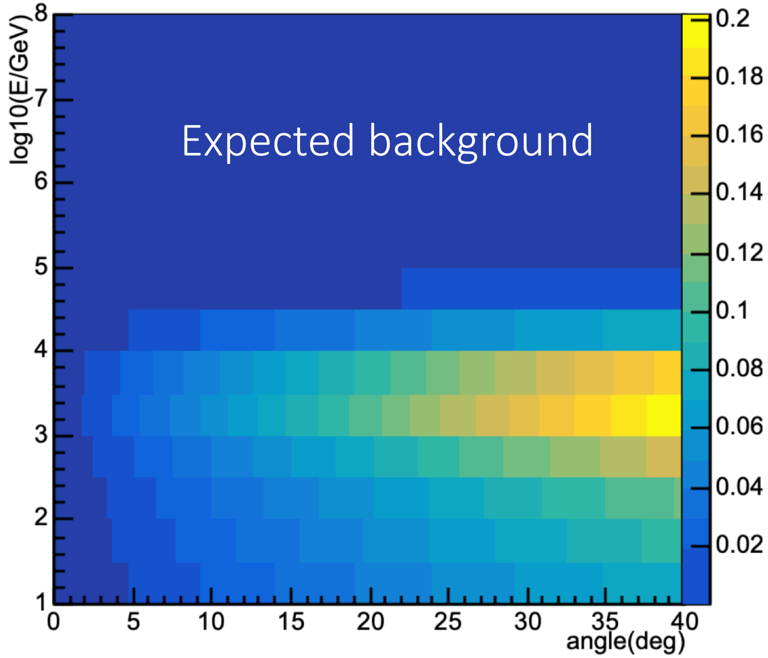
Method

How do we find the dark matter neutrinos?

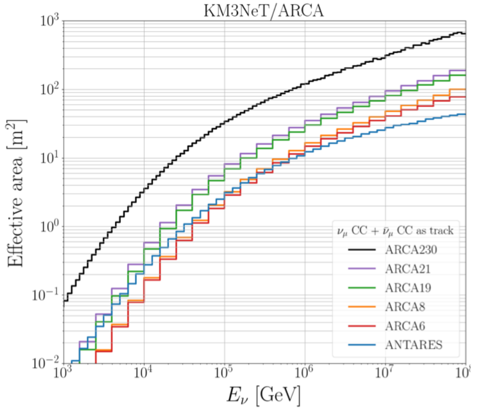
100 TeV DM mass,
$\nu\bar{\nu}$ annihilation channel,
$<\sigma v> = 10^{-23}\ cm^3 s^{-1}$

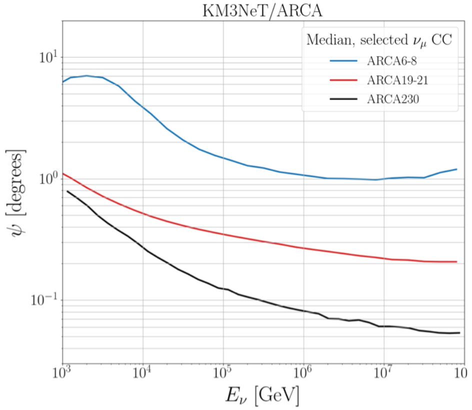
Source model

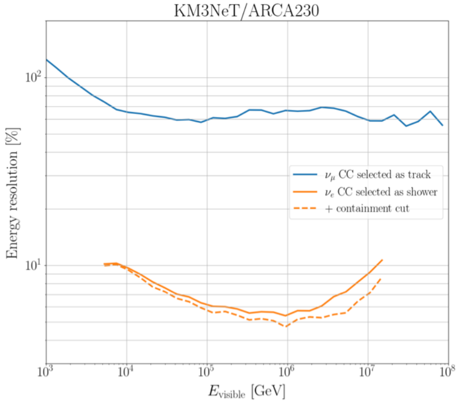




Detector response







Method

Binned likelihood analysis

$$L(\mu) = \prod_i \frac{\exp\left(-(B_i + \mu S_i)\right)(B_i + \mu S_i)^{N_i}}{N_i!}$$

Likelihood
(product of Poisson probability of each bin)

Backgroung
(in bin i)

Signal
(in bin i)

Signal strength
(scaling factor)

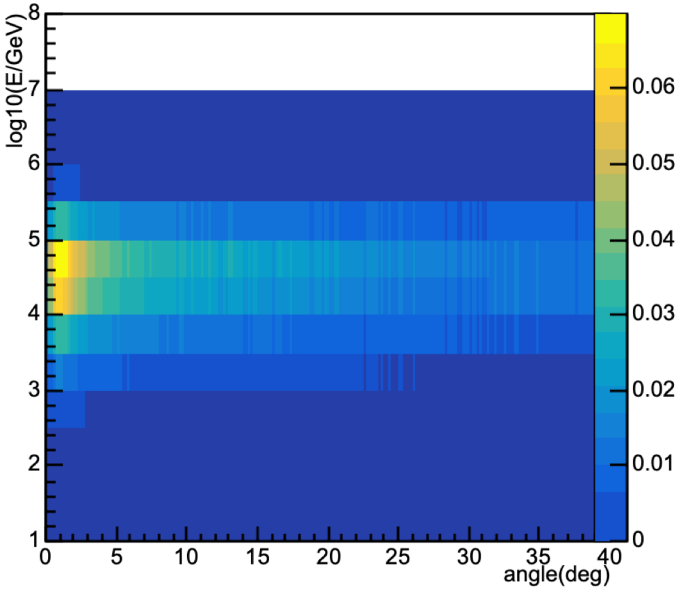
Data events
(or pseudo-experiment)

Test-statistic

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

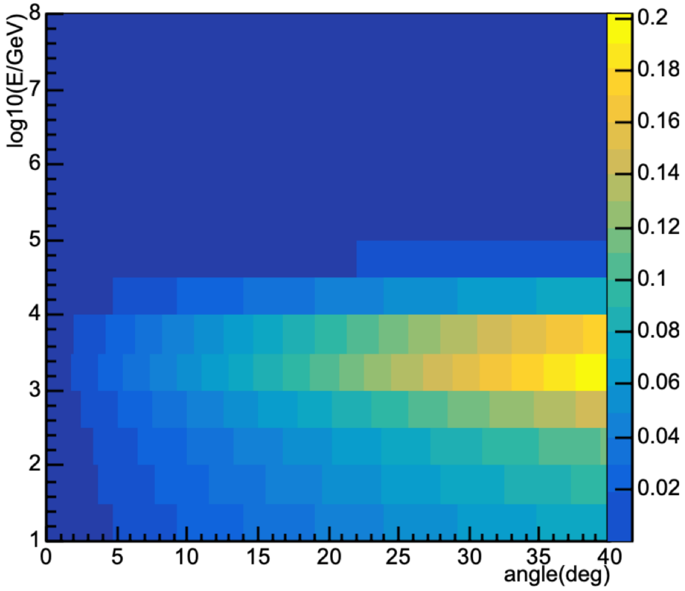
Signal strength maximising the likelihood of the data

Expected signal rate



100 TeV DM mass, $\nu\bar{\nu}$, $<\sigma v> = 10^{-23}\ cm^3 s^{-1}$

Expected background rate



We compute the required signal strength to reject with a 90% confidence level the signal hypothesis with respect the only background one

$$\frac{d\Phi}{dE\,dt} = \frac{1}{4\pi}\frac{\hat{\mu}\langle\sigma v\rangle}{2m_\chi^2}\frac{dN_\nu}{dE}\int\int \rho^2 dl\, d\Omega$$

We reject annihilation cross-sections larger than $\hat{\mu}\langle\sigma v\rangle$

Results

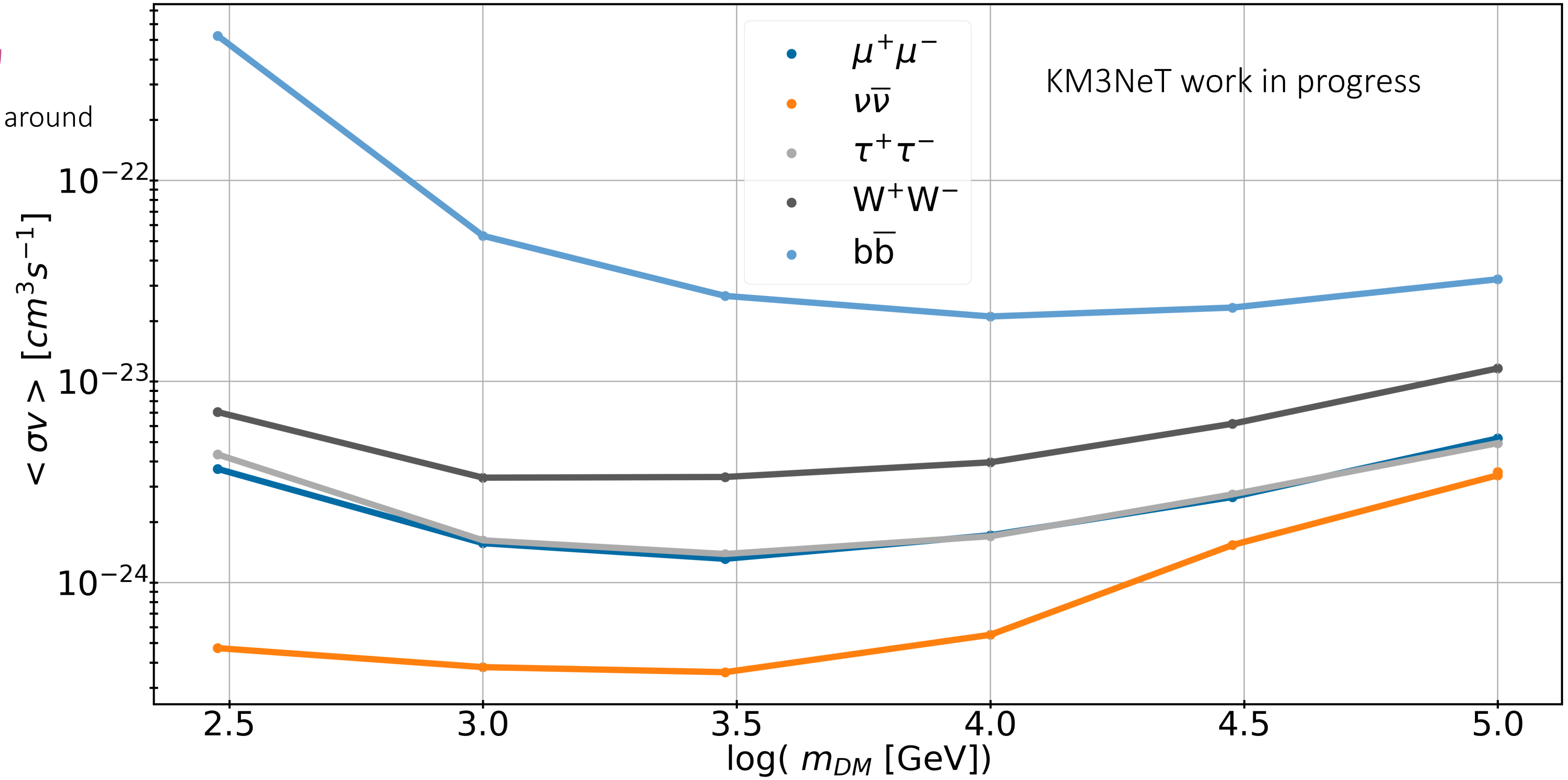
For dark matter searches from our galaxy

- Test different M_{DM} and annihilation channels
- Limit or sensitivity on the dark matter annihilation cross-section

$$\frac{d\Phi_\alpha^c}{dE\,dt} = \frac{1}{4\pi}\frac{<\sigma v>}{2m_\chi^2}\frac{dN_\alpha^c}{dE}\int_{\Delta\Omega}\int_{l.o.s.}\rho^2(\theta,l)dl\,d\Omega$$

Annihilation cross-section and dark matter mass — Spectra — Dark matter distribution around Galactic Centre

Sensitivities full ARCA detector 1yr (MC data)



Results

For dark matter searches from our galaxy

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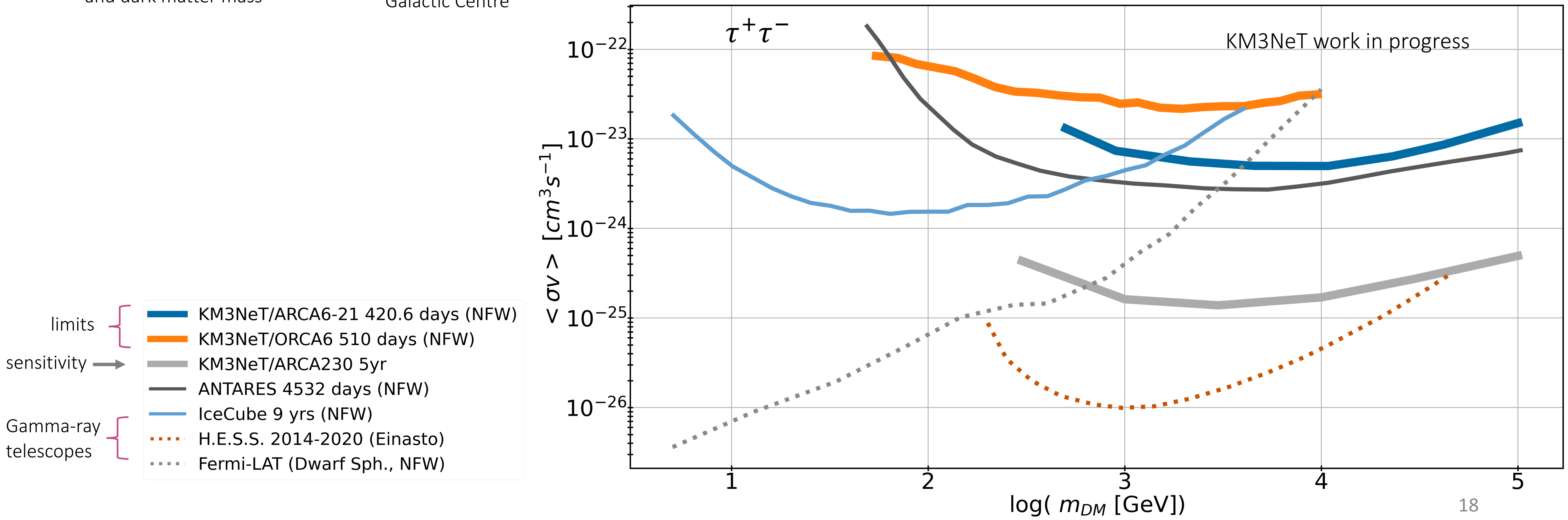
$$\frac{d\Phi_\alpha^c}{dE\,dt} = \frac{1}{4\pi}\frac{<\sigma v>}{2m_\chi^2}\frac{dN_\alpha^c}{dE}\int_{\Delta\Omega}\int_{l.o.s.}\rho^2(\theta,l)dl\,d\Omega$$

Annihilation cross-section and dark matter mass

Spectra

Dark matter distribution around Galactic Centre

Limits and sensitivities in context

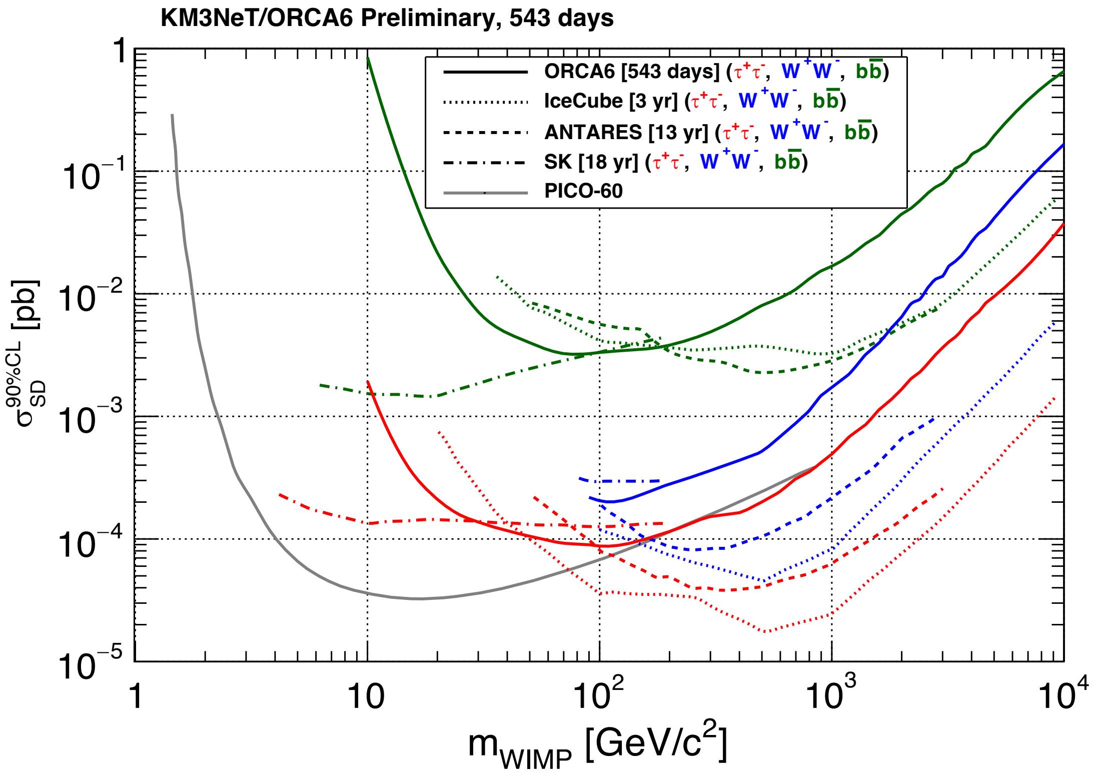


Results

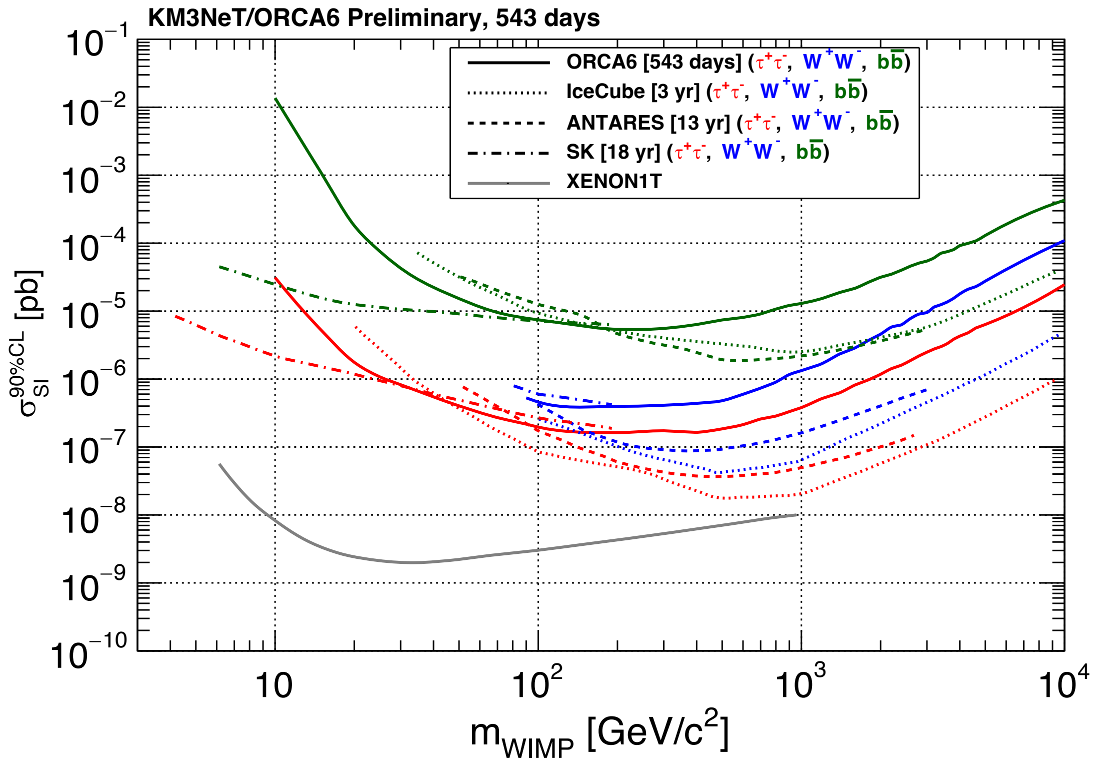
For dark matter searches from the Sun

- Limit on the dark matter spin dependent and spin independent cross-section

spin dependent

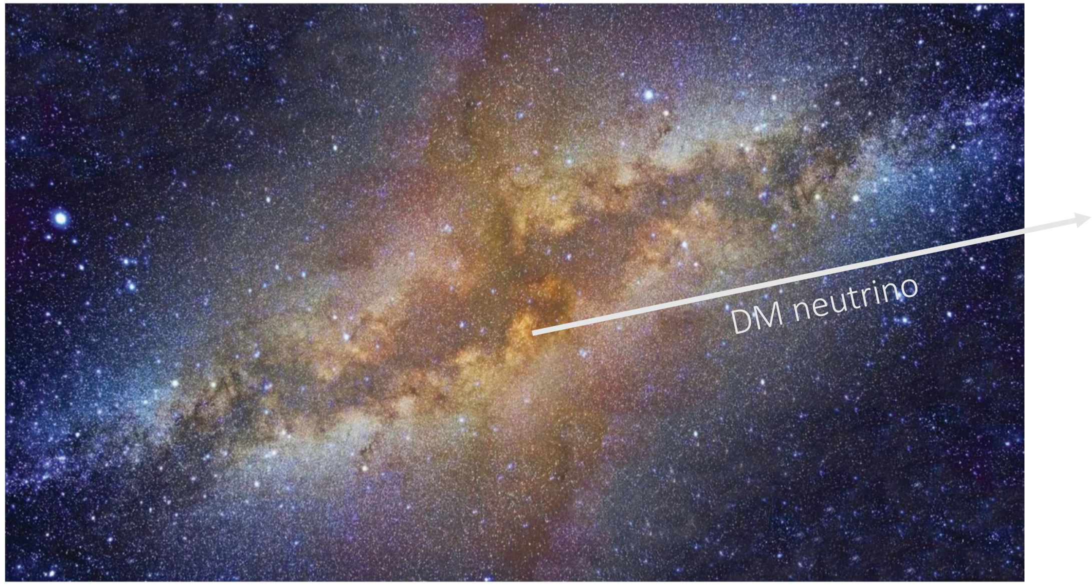


spin independent



Conclusions

Looking at the neutrino sky with KM3NeT



- Good data-MC agreement

- Improving limits with growing detector to WIMP dark matter properties

- Monochromatic lines can be a smoking gun signature of dark matter

- More can be done…!

What are your favourite dark matter models that we can test with KM3NeT data?