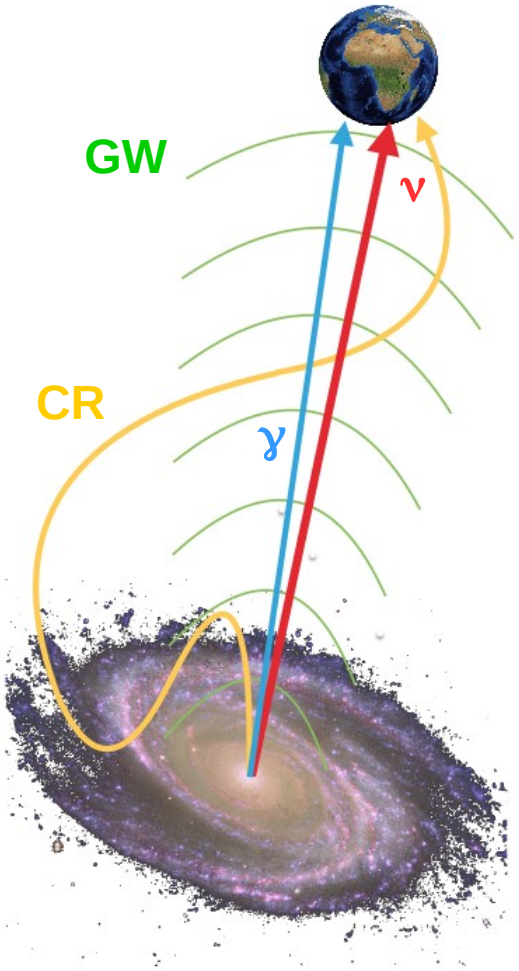
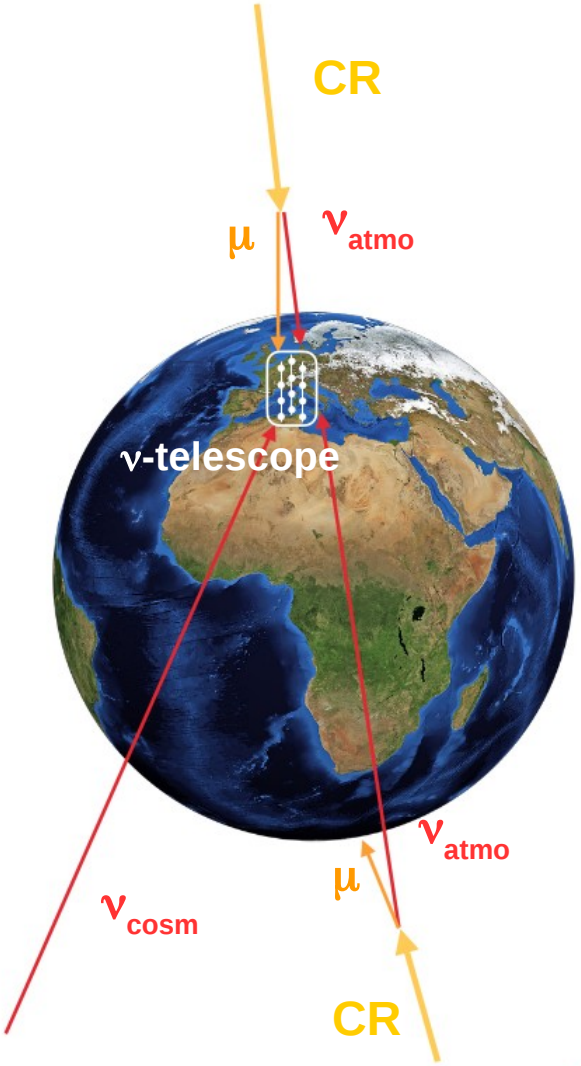
Study of the high-energy neutrino flux with the ANTARES and KM3NeT telescopes

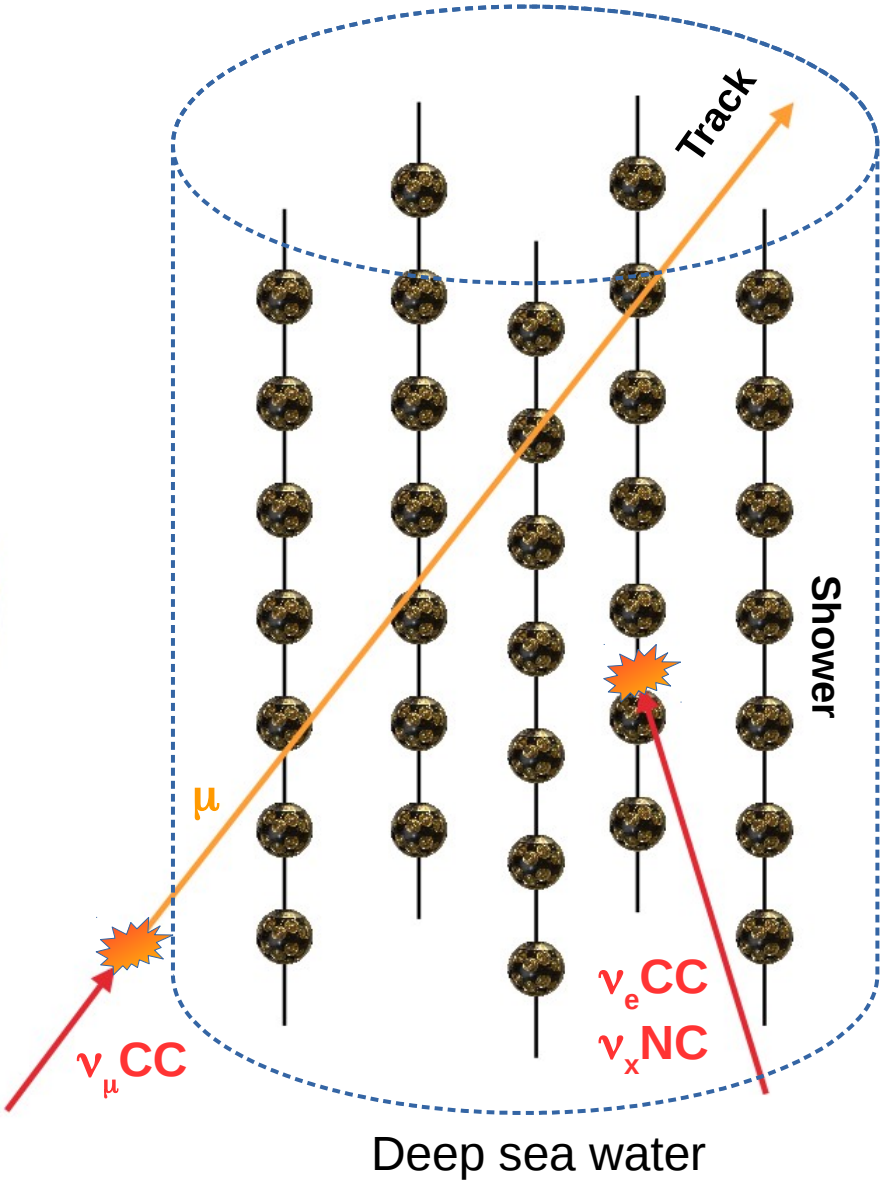
Luigi Antonio Fusco
Laboratoire APC, Paris

Heavy-Quark Hadro Production from Collider to Astroparticle Physics
Mainz, Germany. Sep 30th – Oct 11th 2019

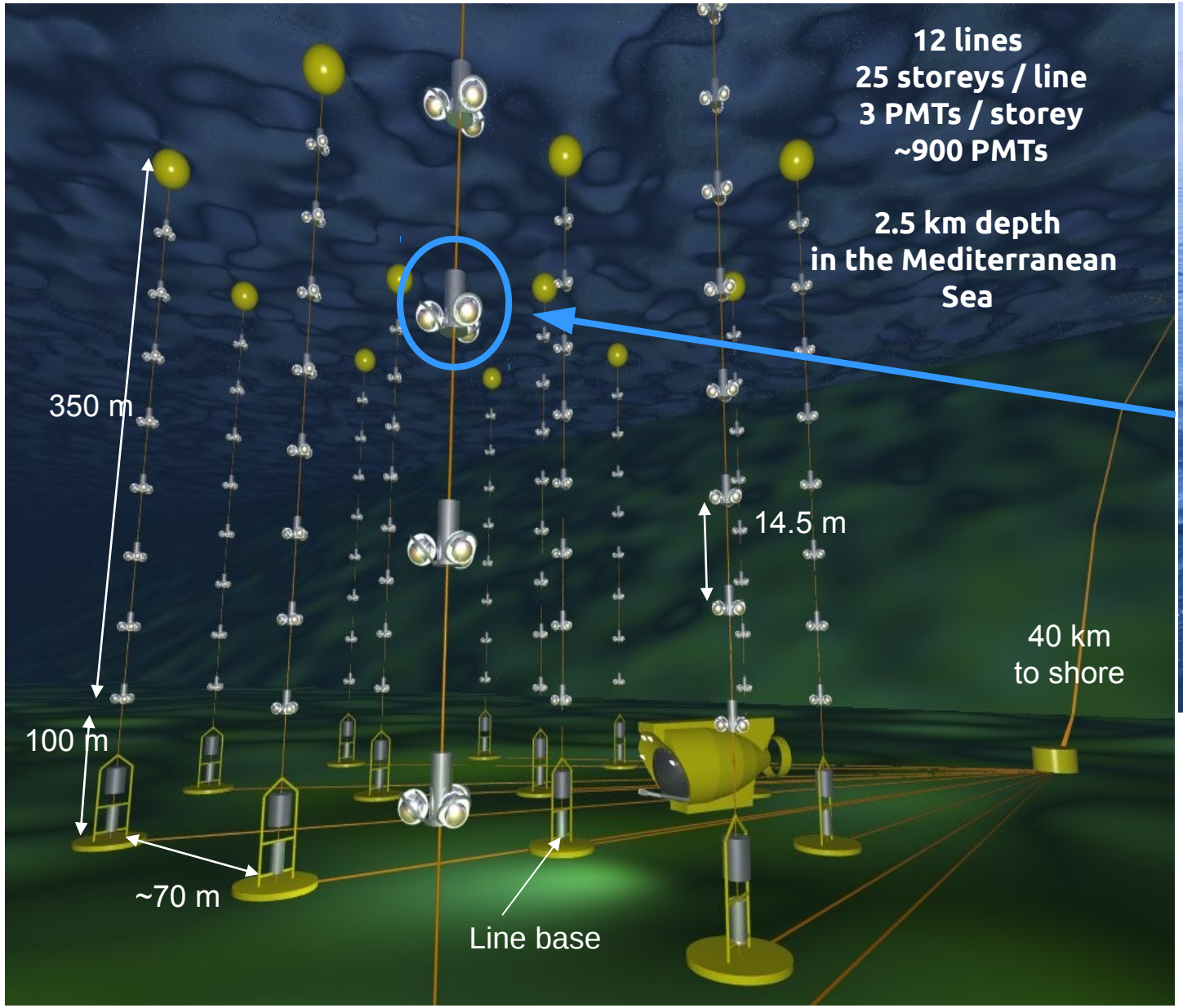
Neutrino astronomy in a nutshell







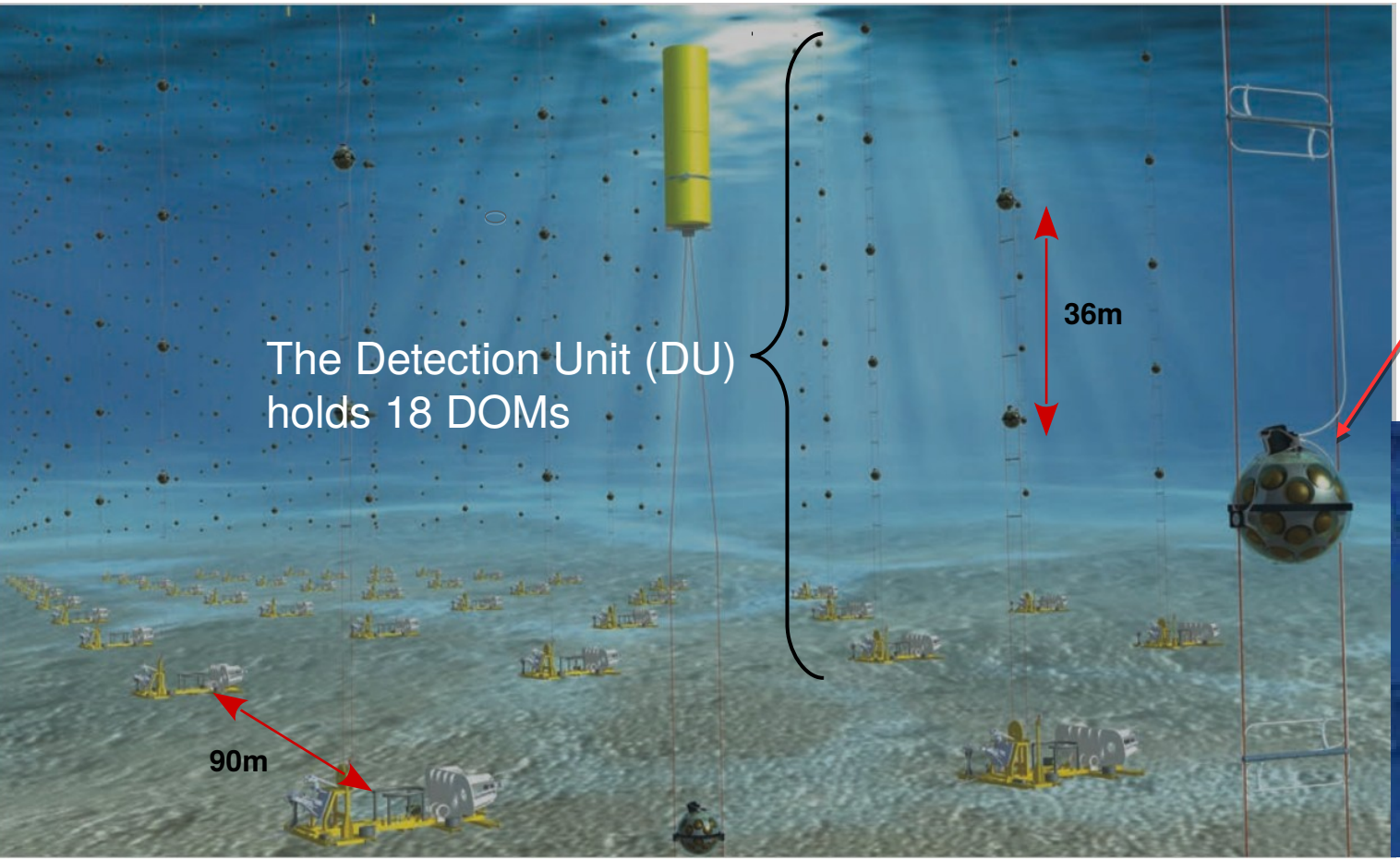
The ANTARES neutrino telescope



~0.01 km³

Taking data since 2007

The KM3NeT/ARCA neutrino telescope

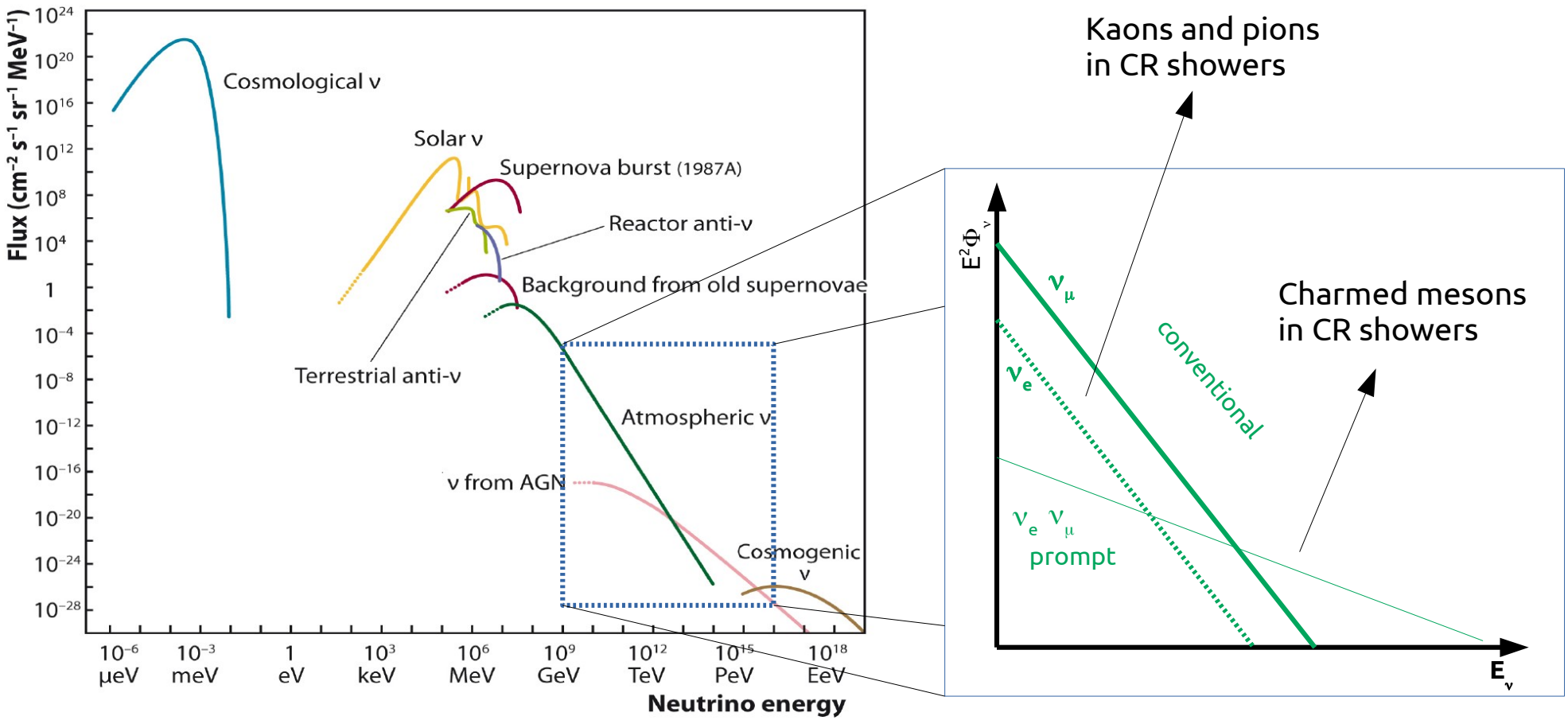


The optical sensor:
Digital Optical Module (DOM). Each DOM comprises 31 3'' PMTs

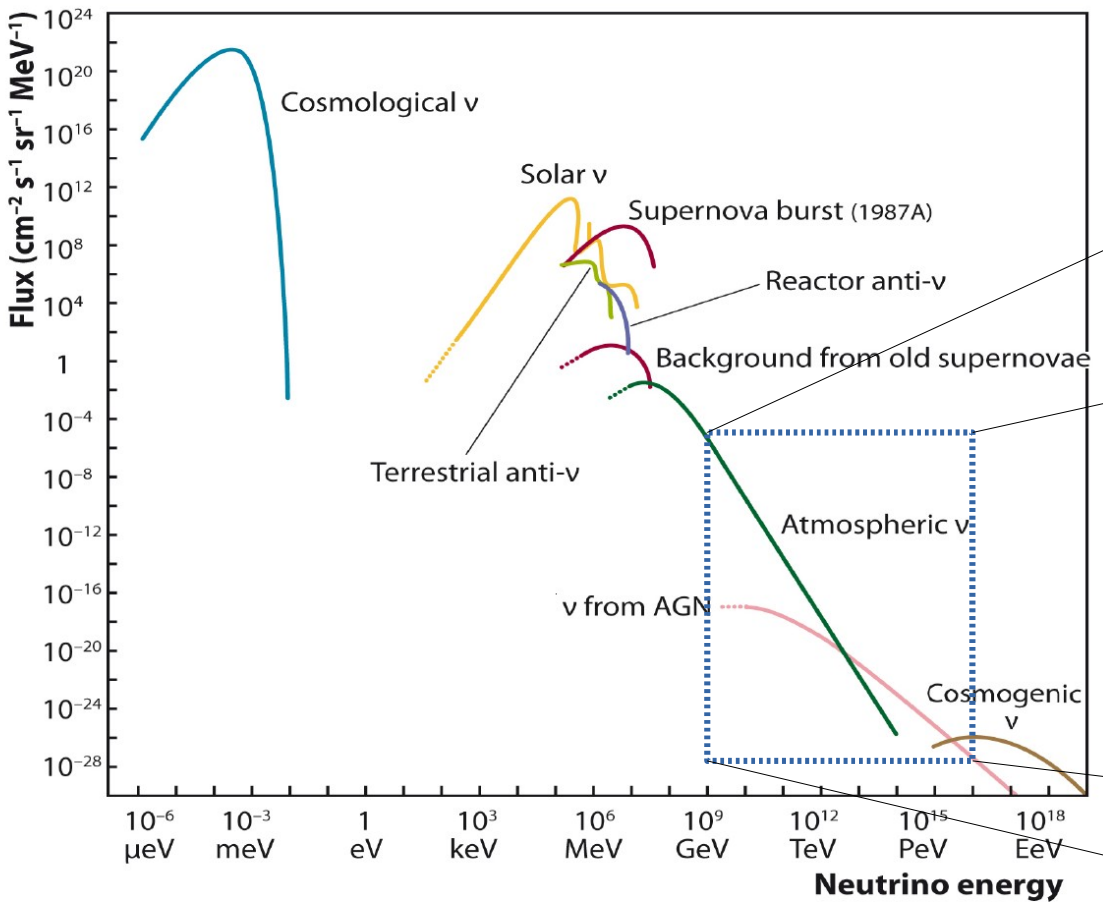
2 Building blocks, 115 DU each, will constitute ARCA
→ ~km³ instrumented volume

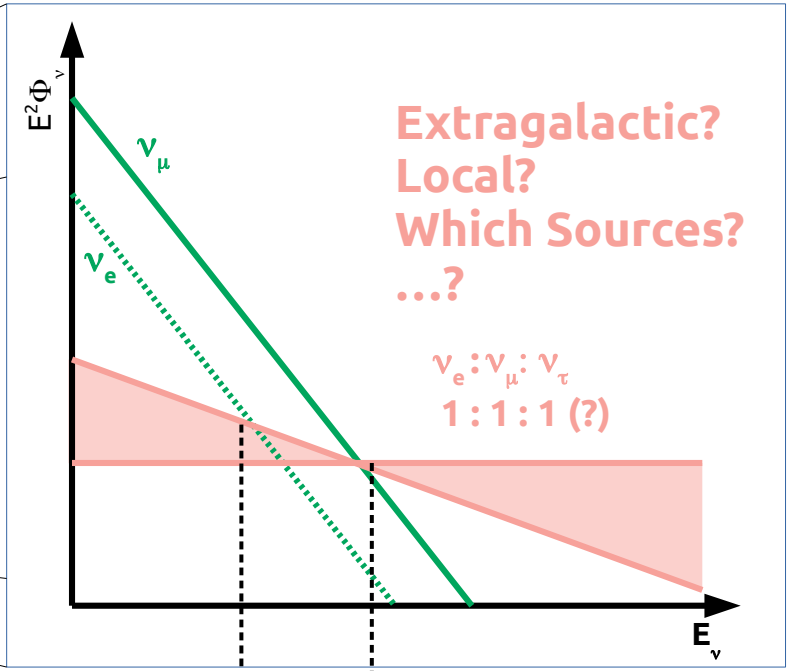
Unprecedented reconstruction performances
~0.1° for tracks, ~2° for showers

Diffuse neutrino fluxes



Diffuse neutrino fluxes

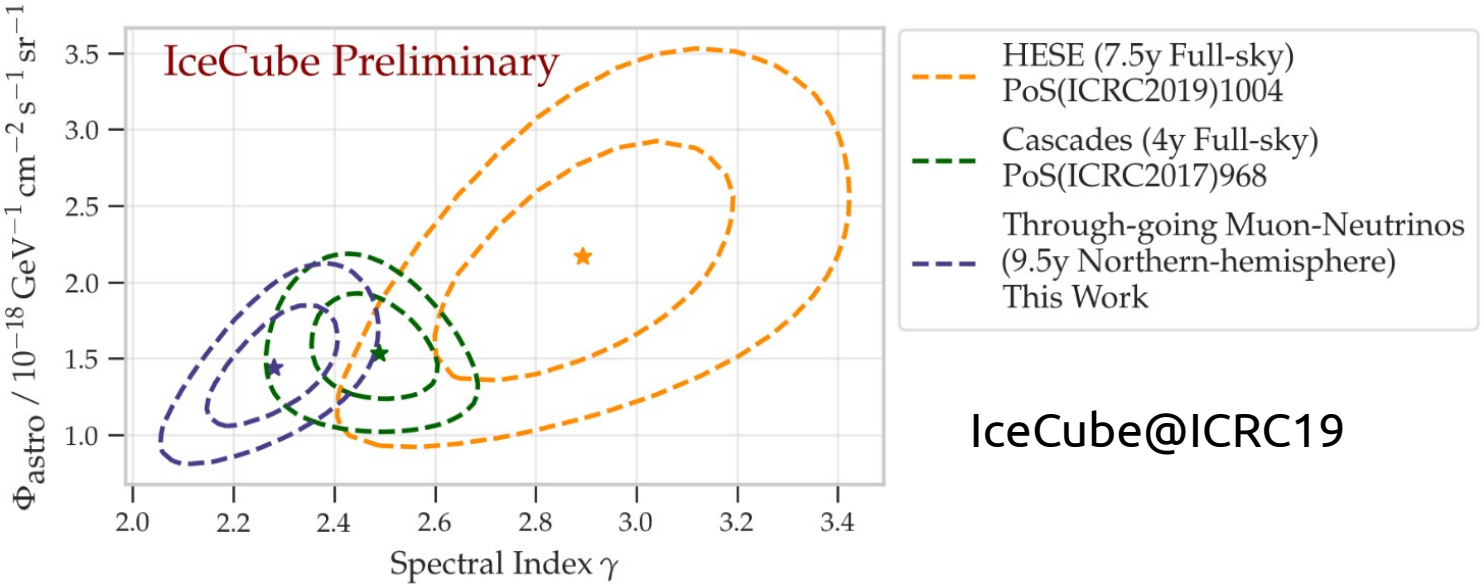




Atmos-to-Cosmic transition 30-200 TeV

High-energy diffuse neutrino fluxes

- IceCube detection → highly significant, isotropic, in flavour equipartition
- Power-law spectral behaviour
  - Too soft?
  - hard in the track channel/Northern Sky
  - soft in the shower channel/all-sky



IceCube@ICRC19

ANTARES all-flavour searches for a diffuse flux of cosmic neutrinos

Track-like events (ν_μCC + taus-to-tracks)

→ large volume + good background rejection
→ limited energy resolution + high threshold (>100 TeV)
→ pure neutrino sample (99.7%)

Shower-like events (ν_xNC + ν_eCC + taus-to-showers)

→ good energy reconstruction and lower background (>10 TeV)
→ only in a limited fiducial volume (~1/20 km^3)
→ large CR muon contamination at the highest energies (20-40%)

ANTARES can be complementary to IceCube – even if less sensitive

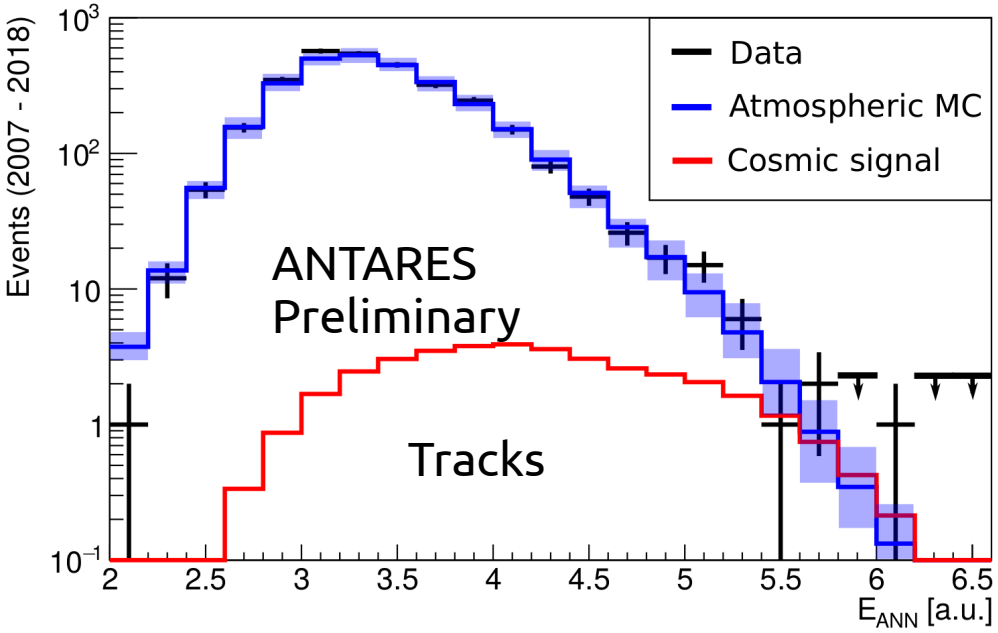
New results (2007-2018, 3380d livetime)

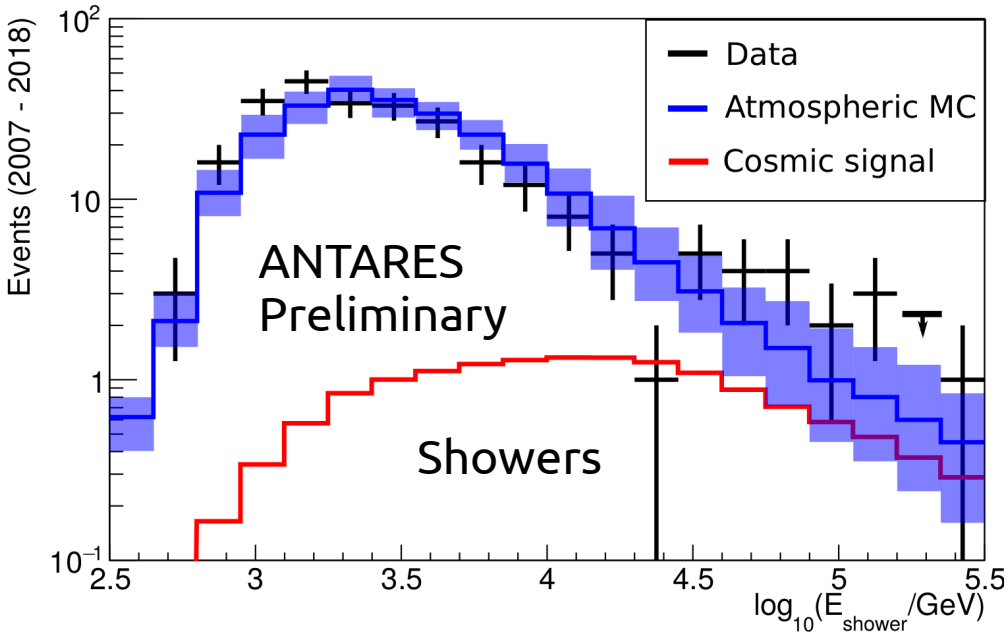
Preliminary

*Jan 2016 – Jun 2018 added to the previous sample from ApJ Lett **853**, L7 (2018)*

Overall → data: 50 events (**27** tracks + **23** showers)
Overall → bkg MC: 36.1 ± 8.7 (stat.+syst.) of which **19.9** tracks and **16.2** showers

Null-cosmic rejected at 90% c.l. using counting statistics (*Conrad et al.* method, with syst.)
Atmospheric background scaled up by ~25%





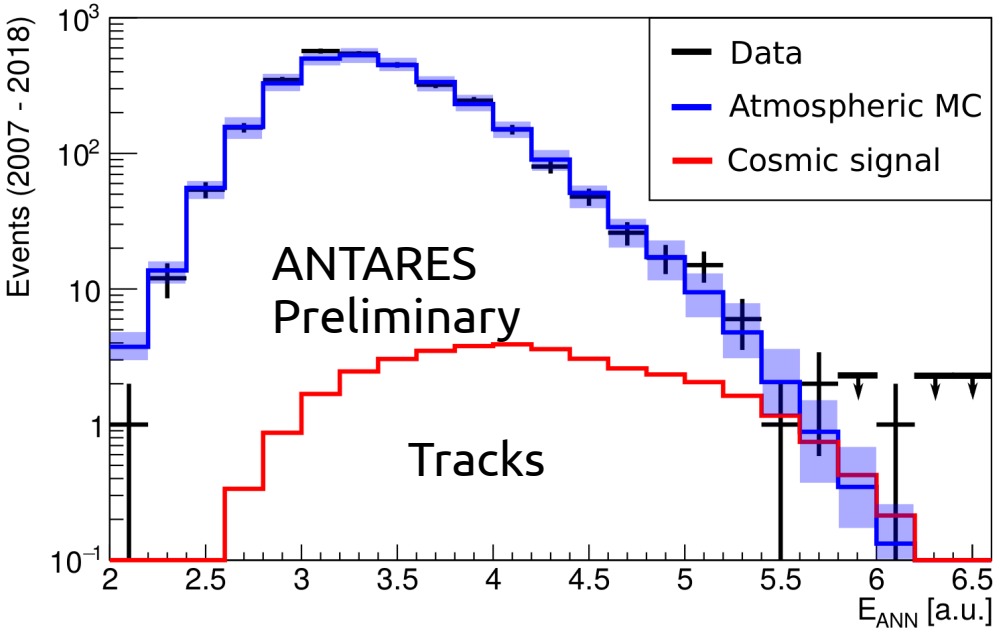
New results (2007-2018, 3380d livetime)

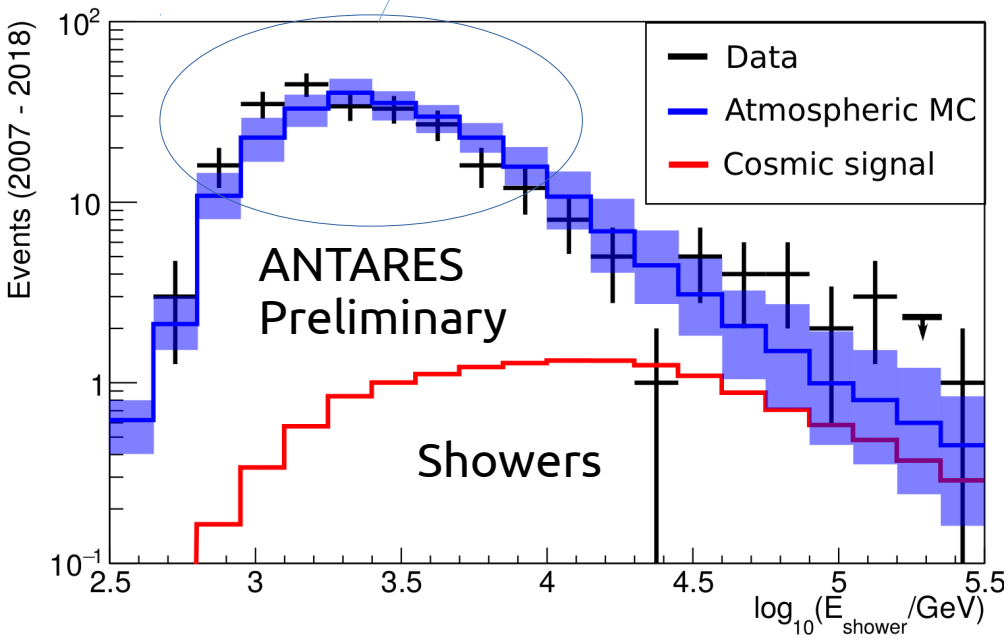
Preliminary

MC Error bands include

– conventional atmospheric uncertainties
– prompt uncertainties (Enberg)
– CR modeling uncertainties (H3a)
– (showers only) CR muons uncertainties

Energy scale systematic biases the results





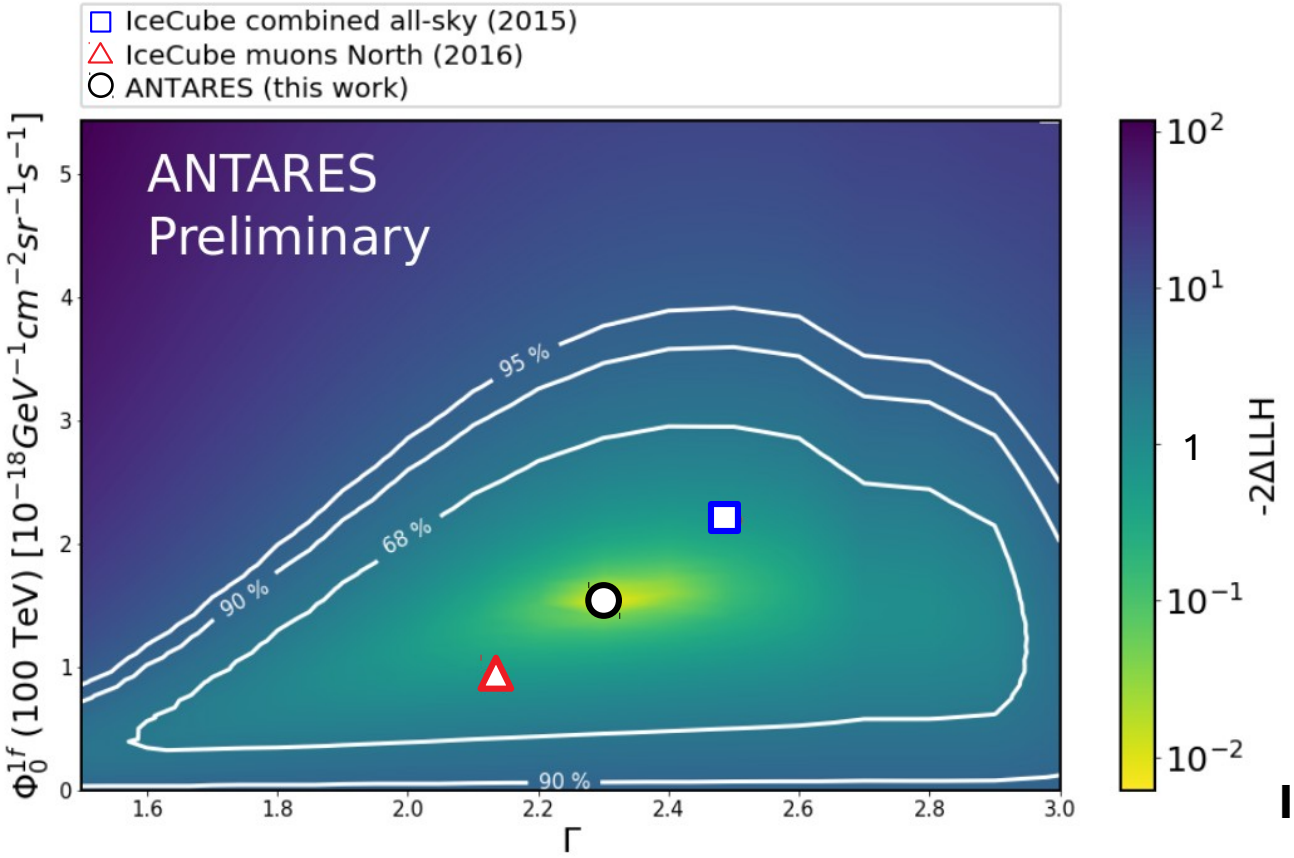
ICRC19 results

New results (2007-2018)

Preliminary

***Likelihood fitting* of the high-energy sample**

Atmospheric (Honda + Enberg together) fitted simultaneously with the cosmic flux normalisation and spectral index of the ***track and shower samples together***



$\Phi^{1f}(100\ \text{TeV}) = (1.5 \pm 1.0)$
$10^{-18}\ (\text{GeV cm}^2\ \text{s sr})^{-1}$
$\Gamma = 2.3 \pm 0.4$

Atmospheric flux
1.25 x (Honda + Enberg)

From the fit
1.8σ excess
0-cosmic excluded c.l. >90%

ICRC19 results

New results (2007-2018)

Preliminary

Individual fitting of the separate samples

Tracks $\Phi^{1f}(100\ \text{TeV}) = (0.8^{+0.5}_{-0.4})\ 10^{-18}\ (\text{GeV cm}^2\ \text{s sr})^{-1}$
$\Gamma = 2.0^{+0.8}_{-0.4}$
Atmospheric flux: **1.3 x (Honda+Enberg)**

Showers $\Phi^{1f}(100\ \text{TeV}) = (2.1 \pm 0.8)\ 10^{-18}\ (\text{GeV cm}^2\ \text{s sr})^{-1}$
$\Gamma = 2.4 \pm 0.4$
Atmospheric flux: **1 x (Honda+Enberg)**

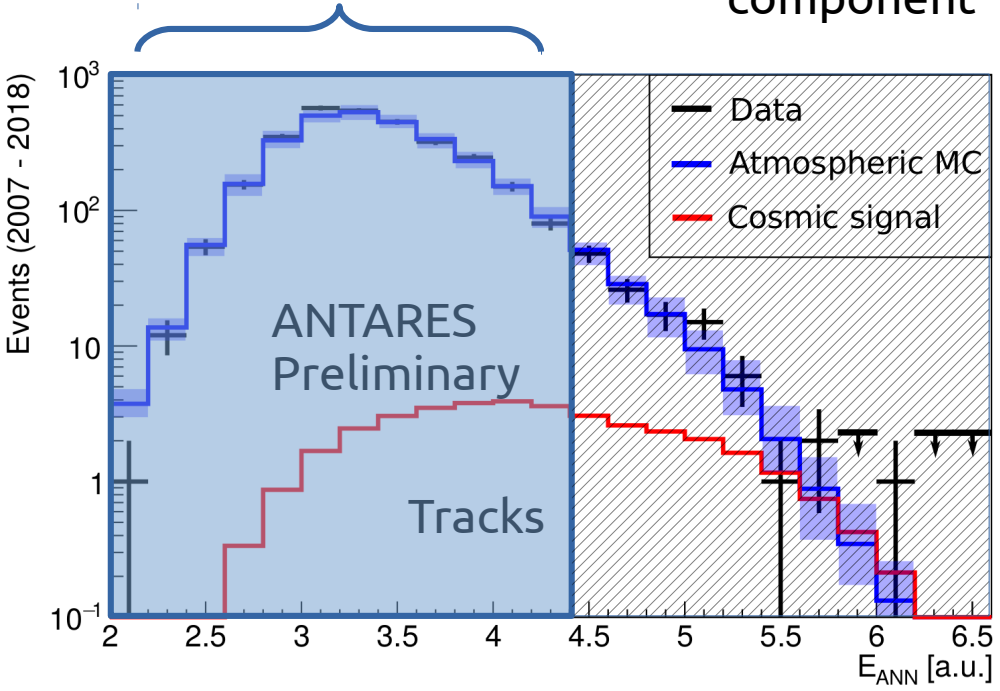
Not really significant but still interesting

New results (2007-2018)

Preliminary

Atmospheric neutrinos

Low-energy sample → Dominated by the conventional component → Constrain its contribution by fitting the distribution



$\Phi_{conv} = 1.3 \pm 0.1 \times \Phi_{Honda}$

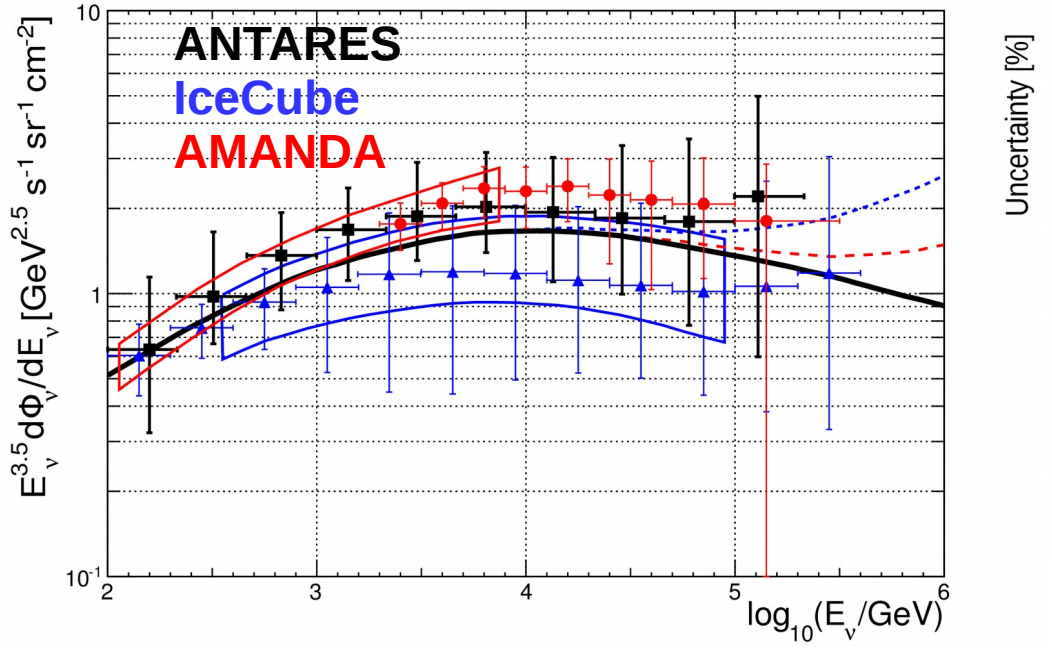
$\Delta\Gamma = -0.1 \pm 0.1$

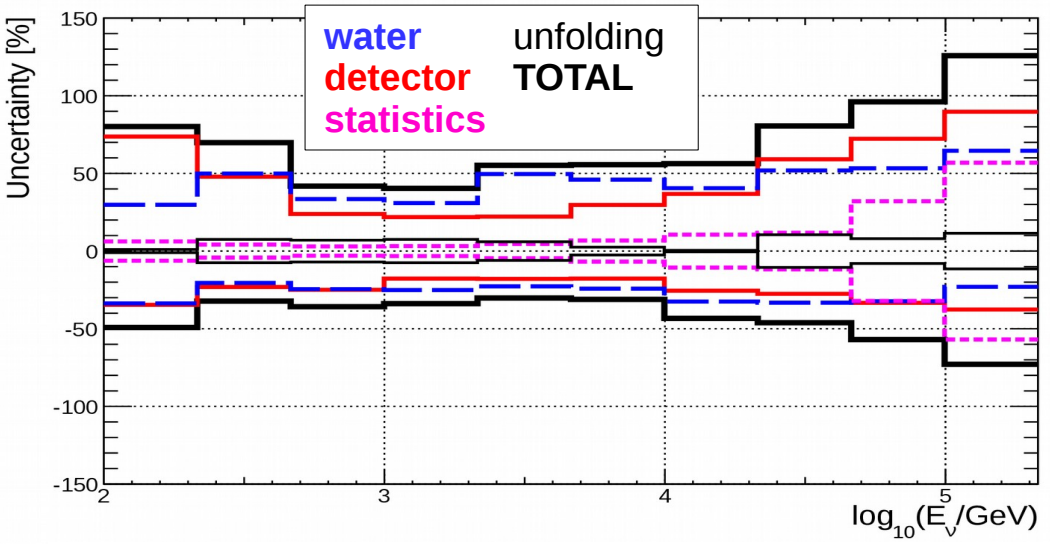
Reminder, the old unfolding result

EPJC 73:2606 (2013)

2008-2011 data
<% CR muon contamination
SVD and Bayesian unfolding

(to be updated with full ANTARES dataset)





New results (2007-2018)

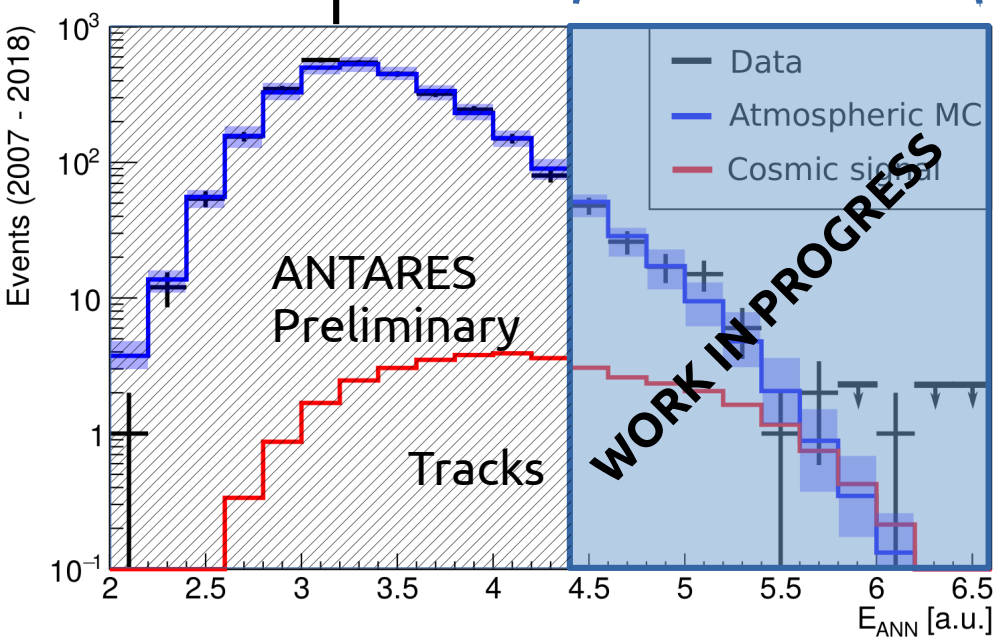
Preliminary

Atmospheric & cosmic neutrinos

$\Phi_{conv} = 1.3 \times \Phi_{Honda}$

$\Delta\Gamma = -0.1$

High-energy sample: cosmic + prompt



Fix conventional to the low-energy fit

Assess the prompt/cosmic contribution in the results

+ more on atmospherics from a new shower sample selection in development

Current work in ANTARES

- New MC with full-optimisation (expect better energy estimations, at least)
  - Reduce systematics on OM and Water properties
- Implement an updated shower selection
  - boost the statistics (x2?) + purer sample (~few% CR muon contamination)
  - Showers outperform tracks in energy resolution (~10% in ANTARES for semi-contained events) → boost sensitivity in energy-dependent analyses
- Better modelisation of atmospheric fluxes
  - MCEq fluxes now implemented in our MC chain

Current work in ANTARES

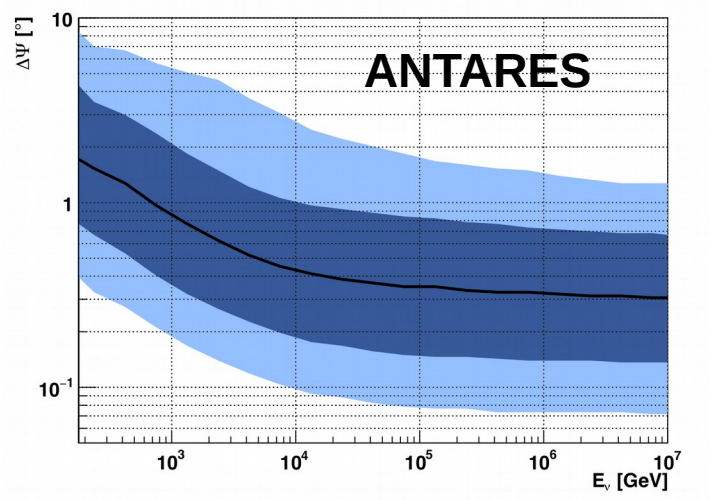
- Implement an updated shower selection
  - boost the statistics + purer sample
  - Showers outperform tracks in energy resolution (~10% in ANTARES for semi-contained events) → boost sensitivity in energy-dependent analyses

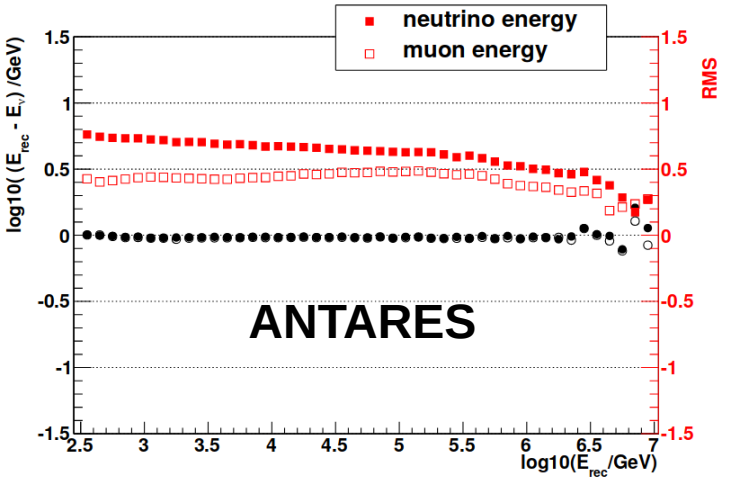
- Electron neutrino unfolding expected by early next year
  - Work on energy systematics and in general on the comparison between numu and nue results

Perspectives for KM3NeT/ARCA

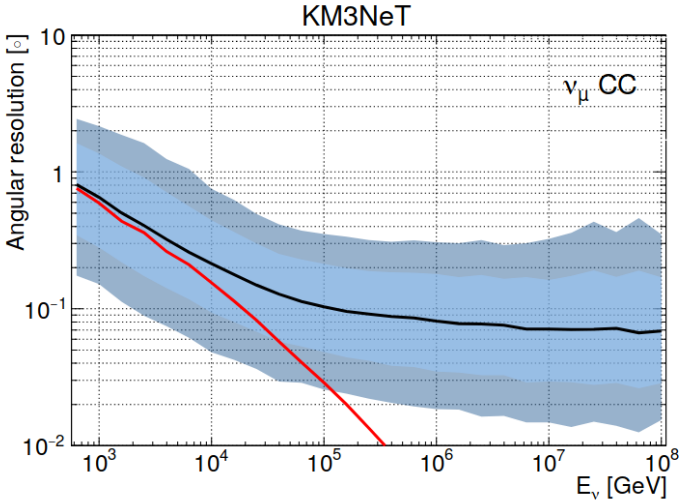
- Under construction, expected completion (when funding granted): ~mid 20s
- Will outperform ANTARES in statistics (exp. 100k ev/yr) and reconstruction (energy resolution ~2 times better)
- High significance in both cascades and tracks for the observation of cosmic neutrino fluxes

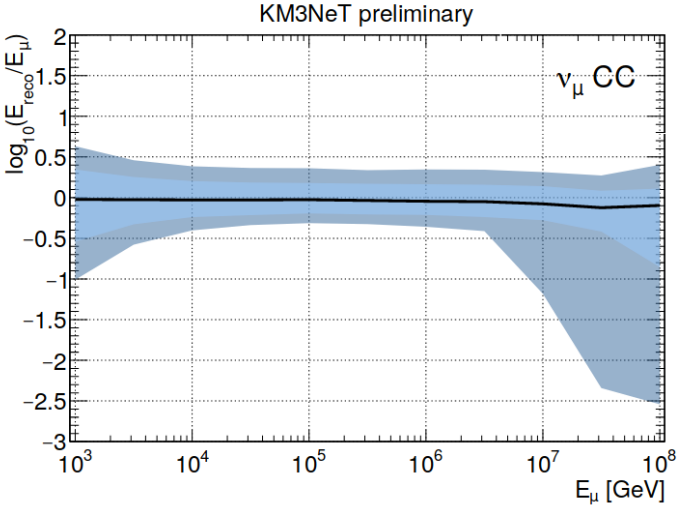
Perspectives for KM3NeT/ARCA



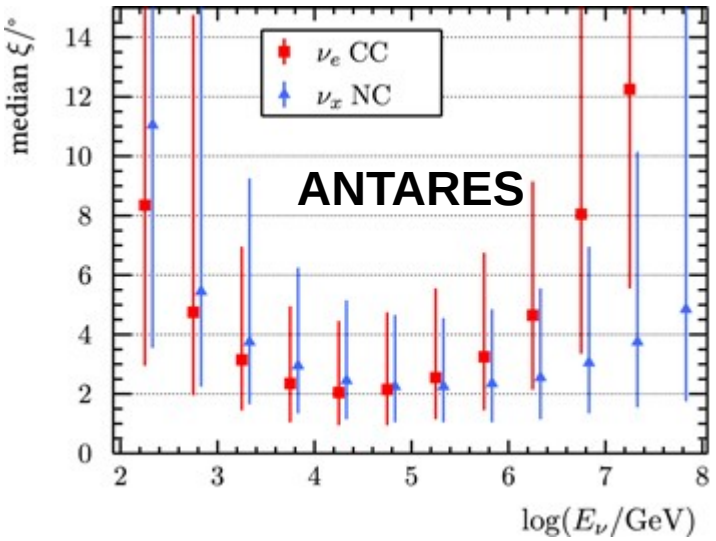


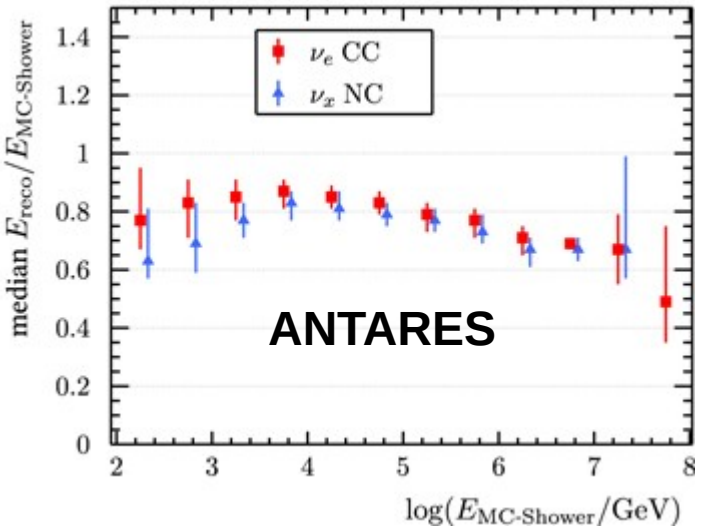
Track Reconstruction



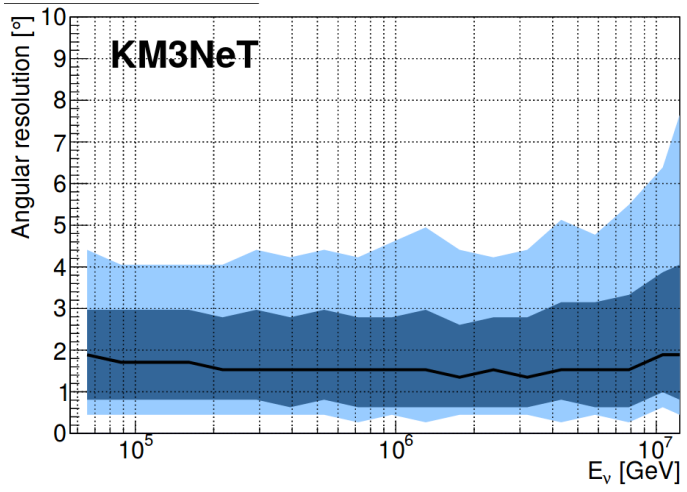


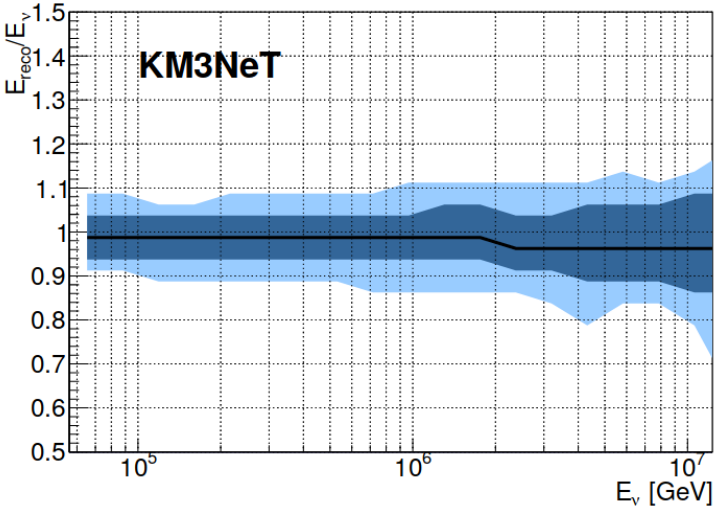
Perspectives for KM3NeT/ARCA



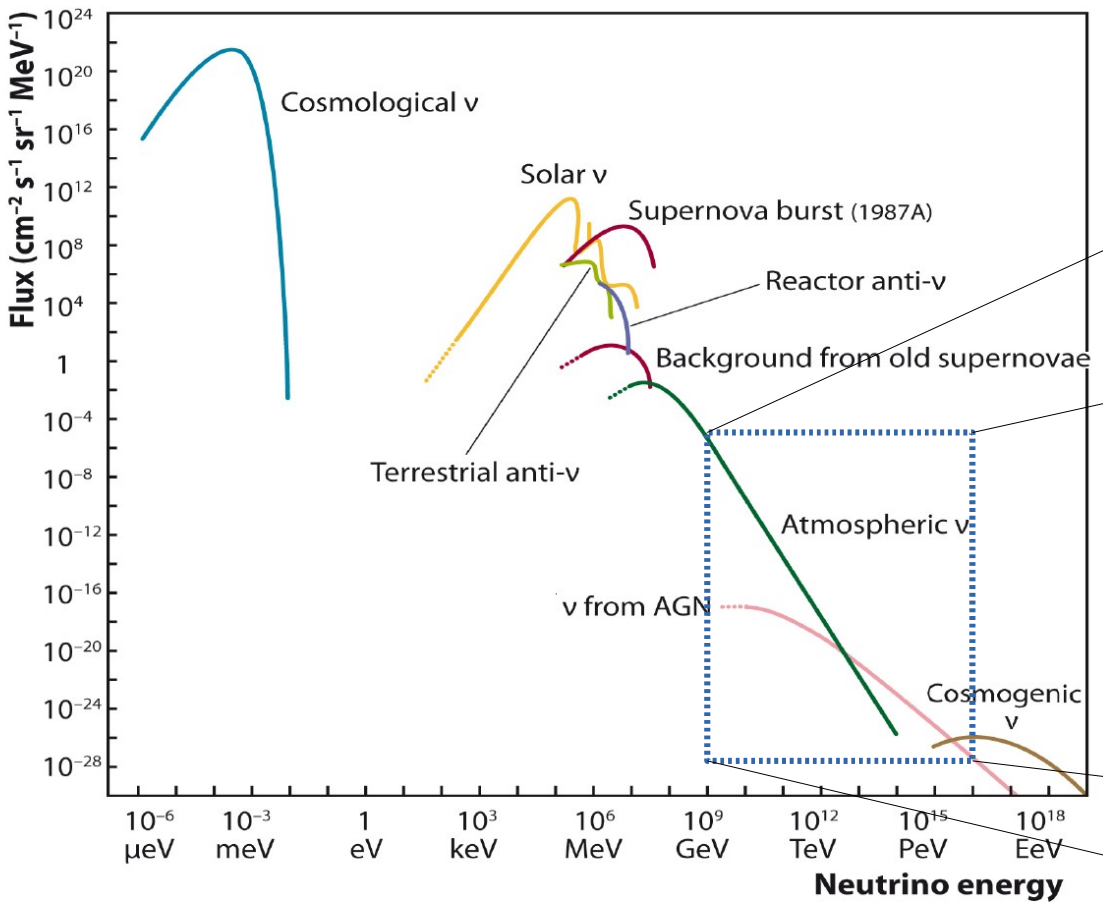


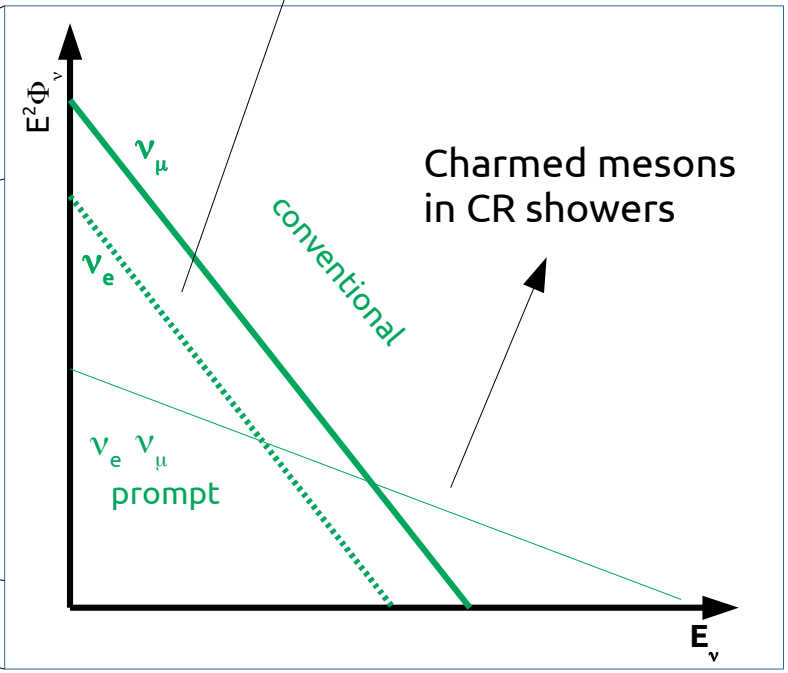
Cascade Reconstruction





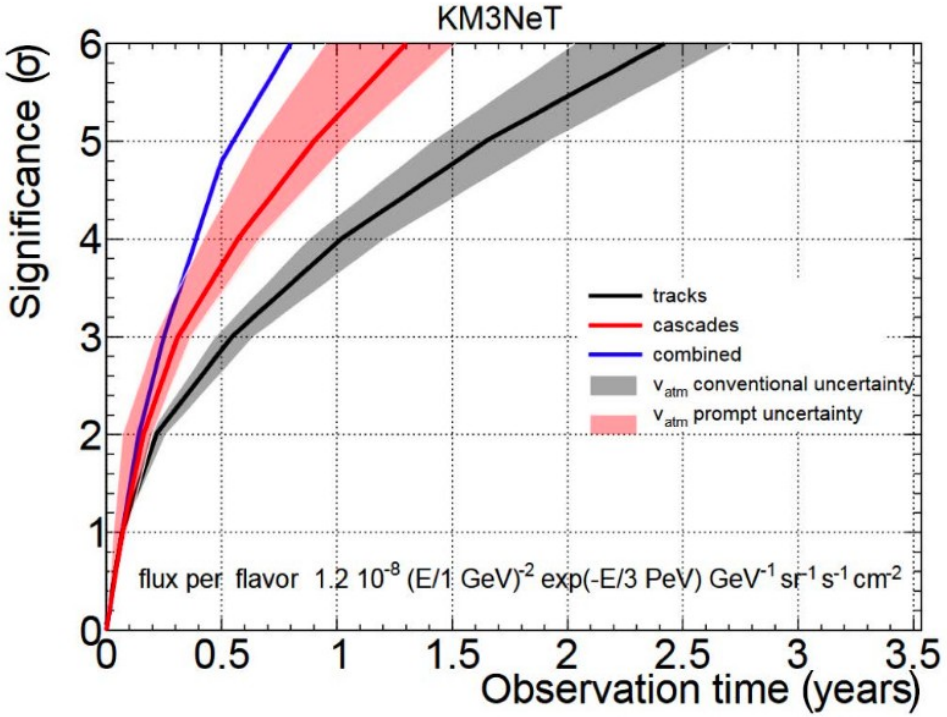
Perspectives for KM3NeT/ARCA





Perspectives for KM3NeT/ARCA

- Optimised for cosmic source in the 10-100 TeV range
  - At the transition between conv-prompt-cosmic fluxes
  - High significance in the cascade channel where prompt is predominant



Studied so far only in the context of the HE cosmic diffuse searches

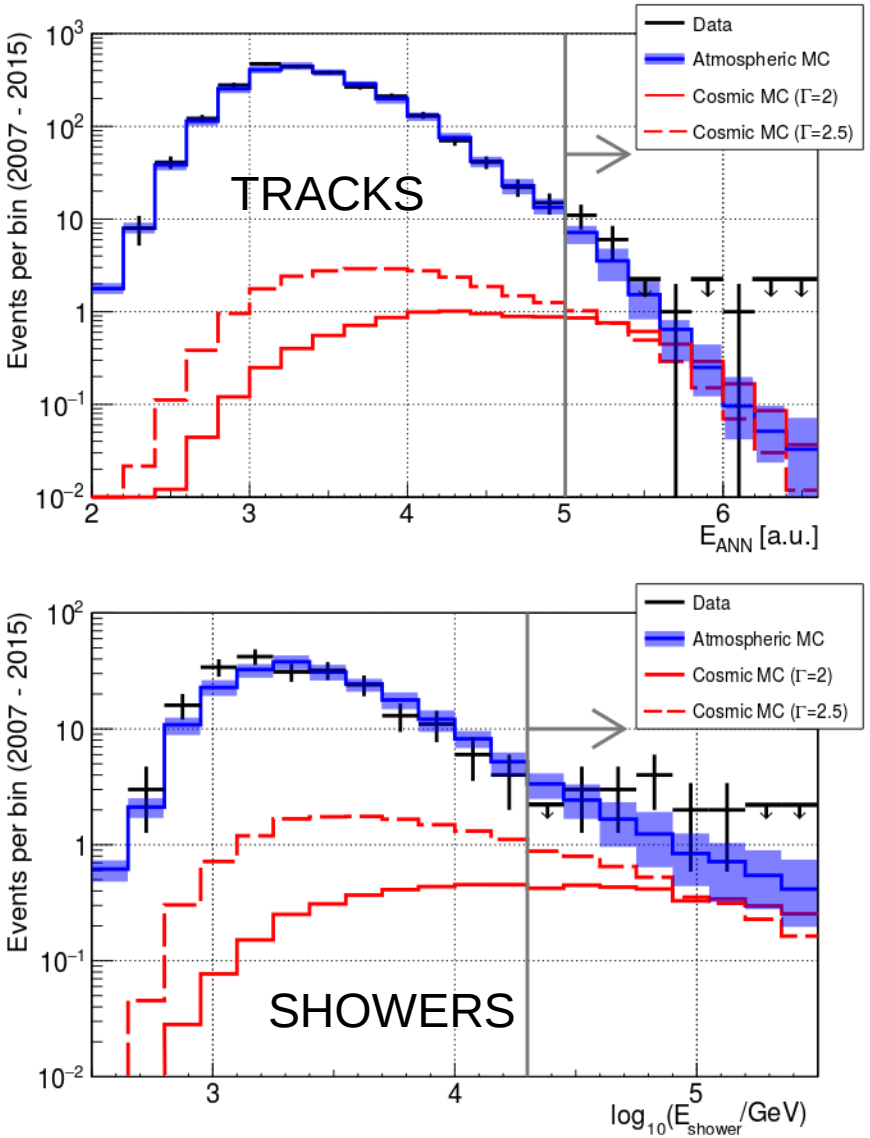
Analysis potential to be addressed
O(10) better than ANTARES at least within few years of observation

Conclusions and outlook

- Underwater/sea neutrino telescopes offer a complementary view with respect to IceCube
  - Different effects at play (atmosphere)
  - Different systematics
  - Cascade channel bears larger uncertainties
  - Event reconstruction in water performs greatly
- Larger overburden implies differences in the analysis strategy (no veto, still fewer atmospheric muons)
  - Some large statistics in atmospheric neutrino is expected for KM3NeT/ARCA

The ANTARES 2007 – 2015 results

ApJ Lett **853**, L7 (2018)



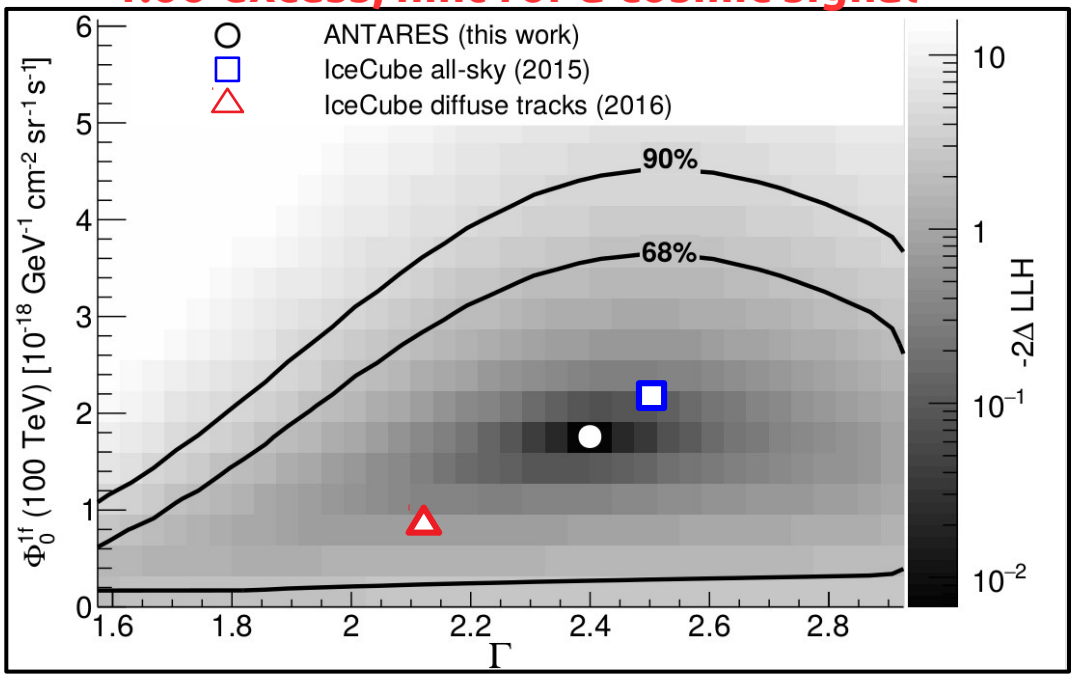
33 events (**19 tracks + 14 showers**) in **data**

24 ± 7 (stat.+syst.) events from **background MC**

Atmospheric flux 25% higher than models

Likelihood fitting of the excess

1.6σ excess, hint for a cosmic signal



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$\Gamma = 2.4^{+0.5}_{-0.4}$

New results (2016-2018, 880d livetime)

Preliminary

Jan 2016 – Jun 2018 to be *added to the previous sample*

Tracks, optmised selection

1.5 signal events are expected for an $E^{-2.5}$ signal spectrum with **6.4** background events

8 events in data

Showers, optimised selection

2.0 additional signal events with **5.7** expected in the background hypothesis

9 events in data

Presented at ICRC19