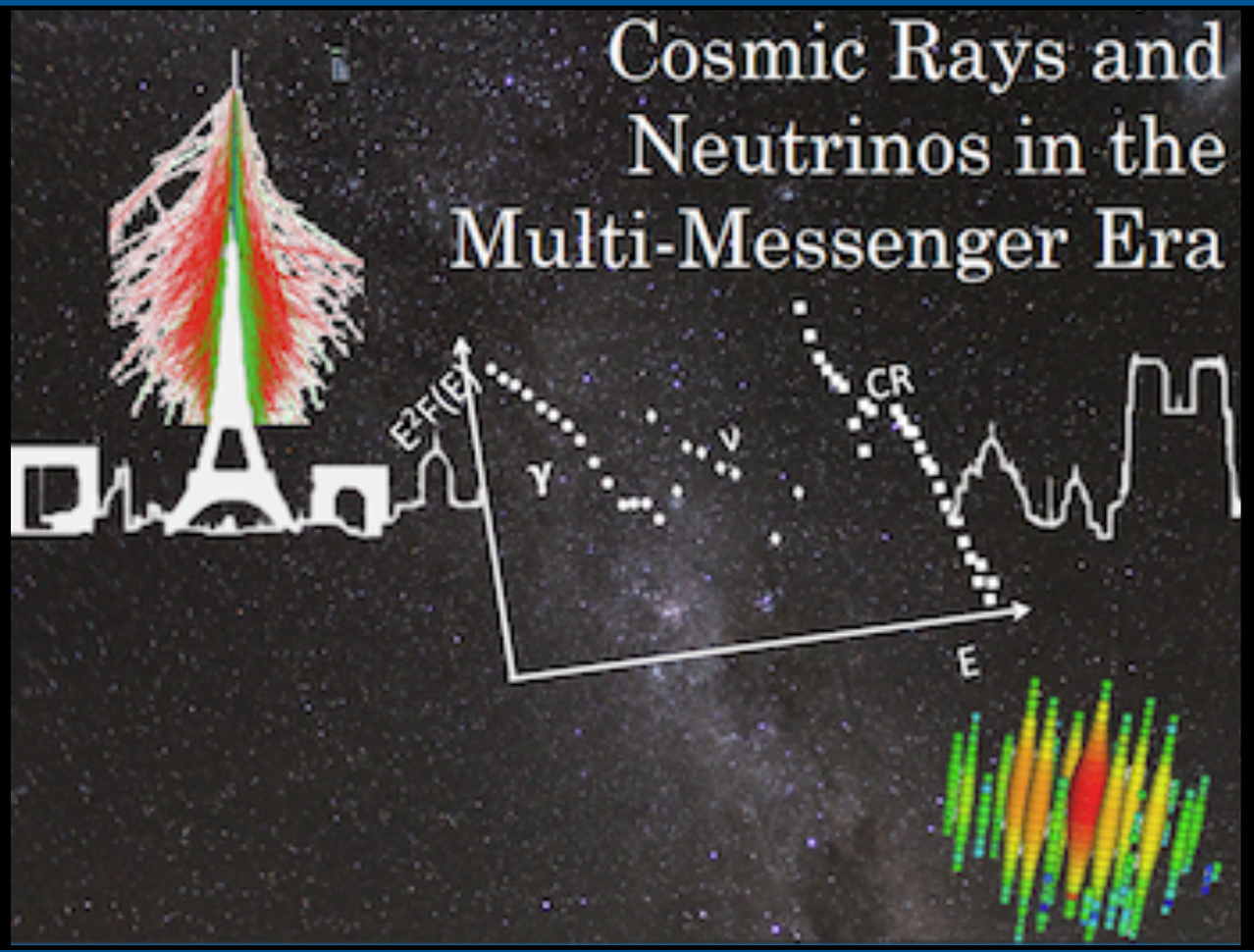


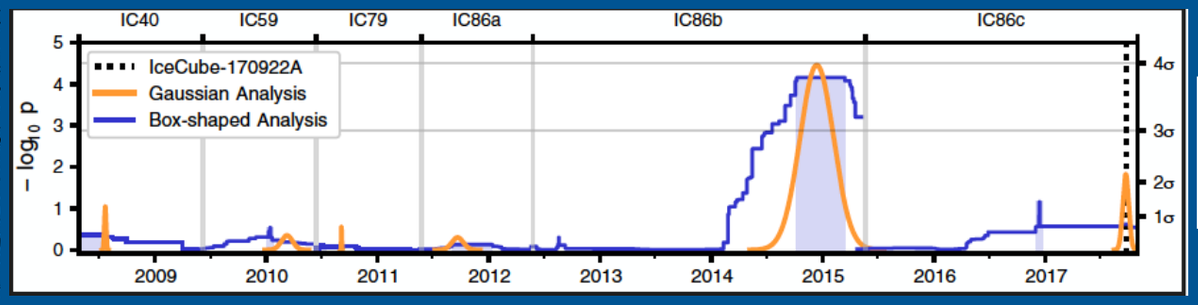
USING TRACKS FOR NEUTRINO ASTRONOMY

ROSA CONIGLIONE
INFN - LABORATORI NAZIONALI DEL SUD (ITALY)

THE BIRTH OF NEUTRINO AND MULTI MESSENGER ASTRONOMY

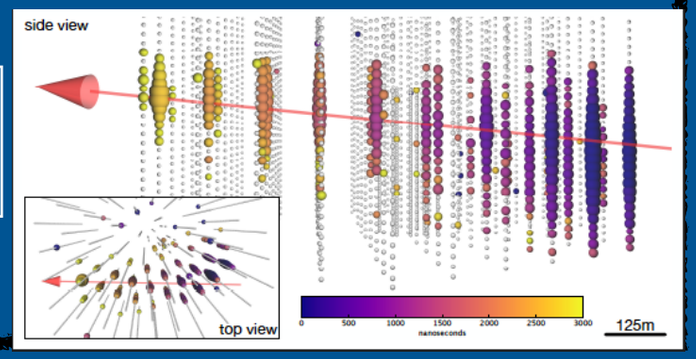
December 2013 - Observation of the first cosmic neutrinos at ~ 4 σ level

September 2017 - One high energy neutrino event (IC GW170817) detected by IceCube at +5.6° in declination. An increase of the activity in the same direction and time in high-energy gamma-rays, X-rays, Optical and radio observed



TXS 0506+056
Neutrino source identified

Track-like event of about 120 TeV traversing all the detector

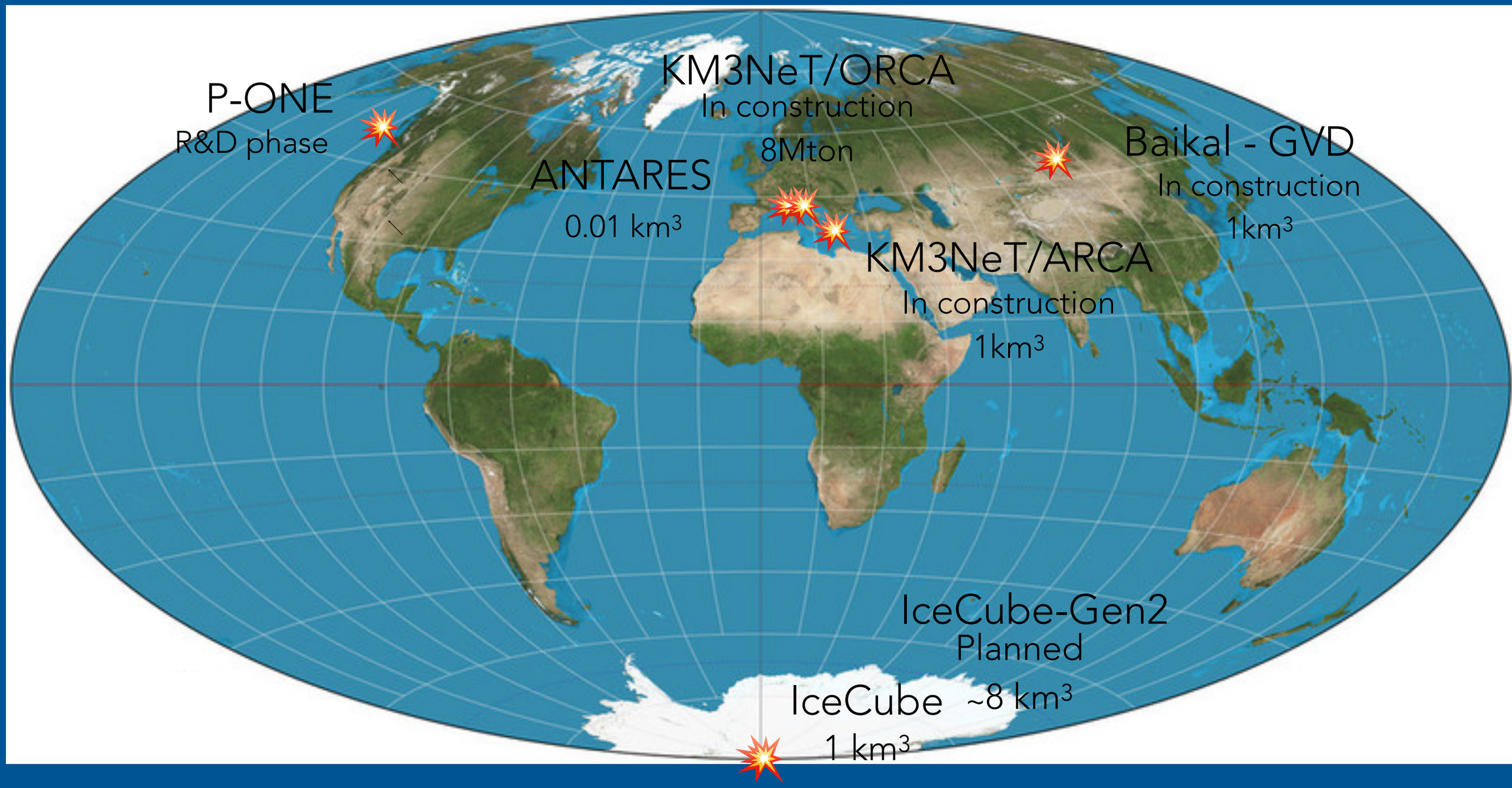


August 2017 - Event of Gravitational Waves (GW170817) from a neutron star merger well detected in VIRGO and LIGO - after 2 seconds gamma-rays in that direction from INTEGRAL e FERMI - after hours, days and week X-rays, radio and optical observations

NO neutrinos

Clear connection between different astrophysical messengers established

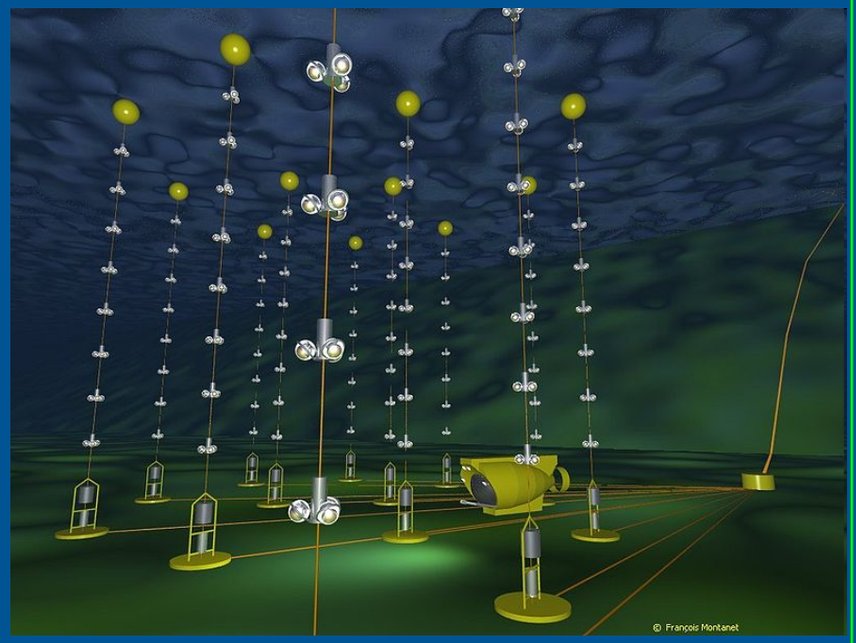
THE HIGH ENERGY NEUTRINO DETECTORS



THE HIGH ENERGY NEUTRINO DETECTORS

Arrays of optical sensors in the deep water/ice environment

ANTARES

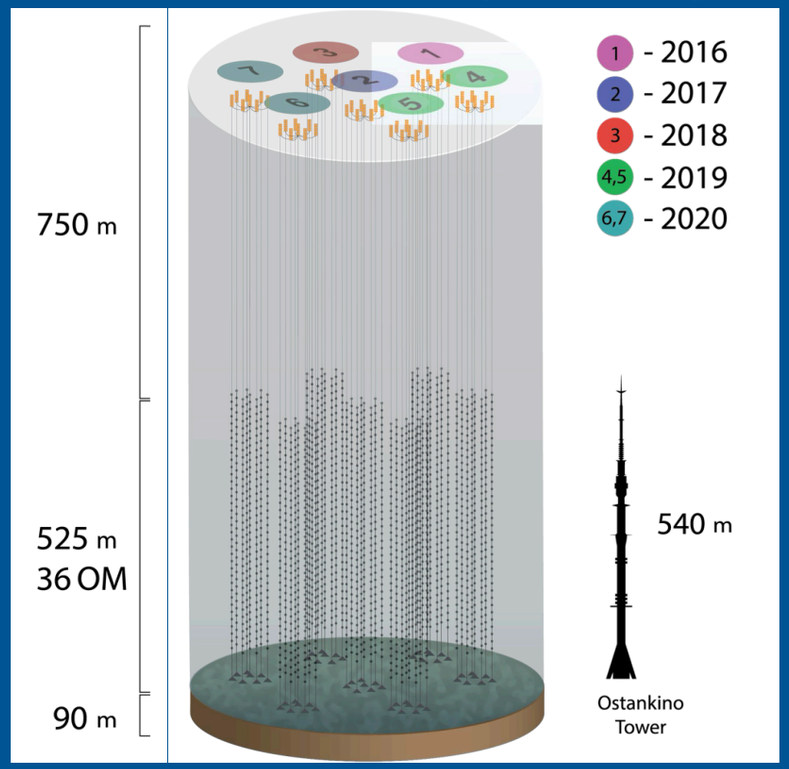


- Depth 2470m
- Volume 0.01 km^3
  - 12 lines of 75 10" PMTs (885 total)

Detector completed in 2008
Taking data since 12 years

Baikal GVD

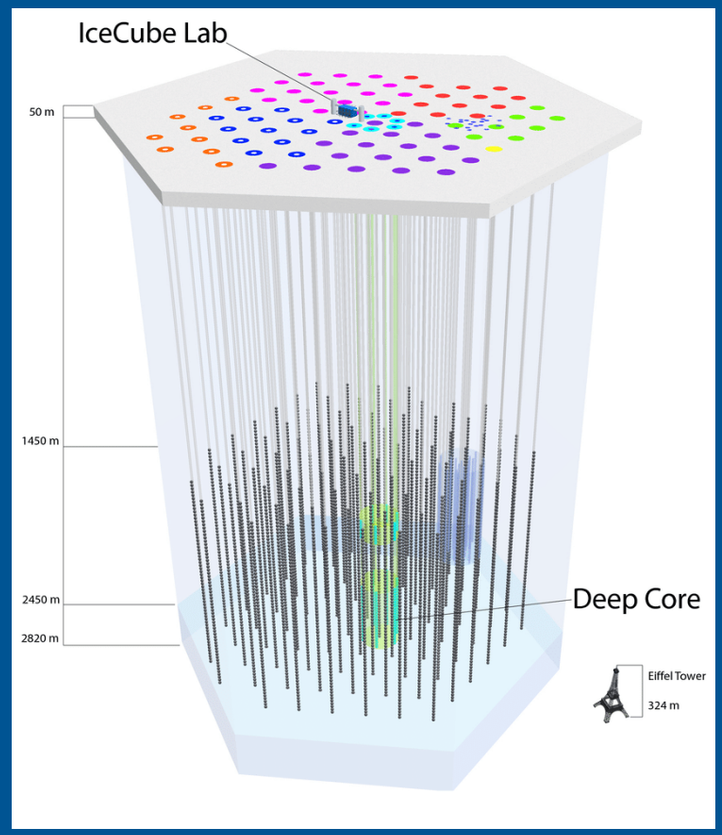
7 clusters already deployed



- Depth 1366 m
- Volume 0.35 km^3
  - 8 lines (2304 10" PMTs)

More clusters in the next years

IceCube



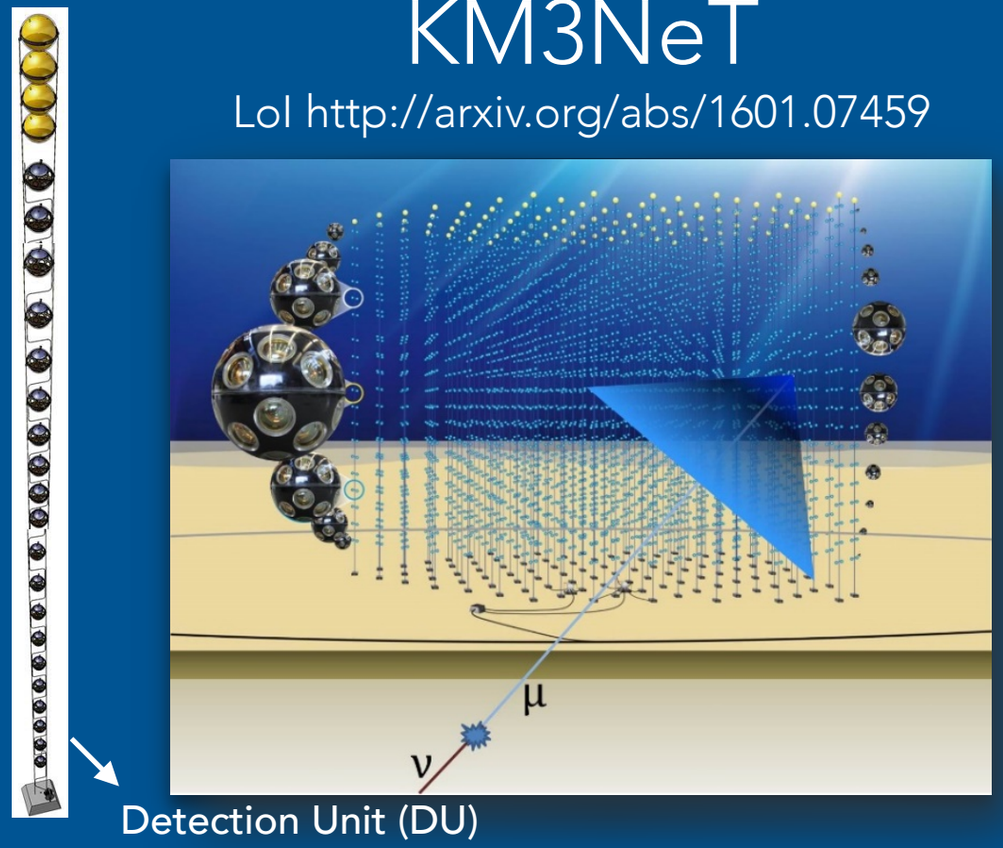
- Depth 2450m
- Volume ~1 km^3
  - 86 lines (2304 10" PMTs)

Detector completed in 2011
Taking data since ~ 10 years

Arrays of optical sensors in the deep water/ice environment

KM3NeT

LoI http://arxiv.org/abs/1601.07459



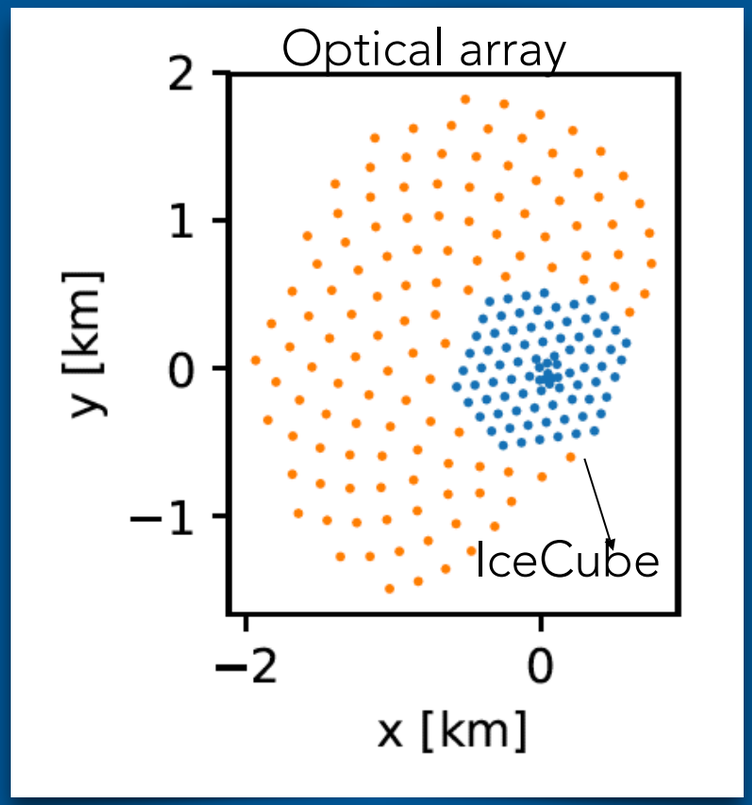
- ARCA
  - Volume 1 km^3 👉 neutrino astronomy
  - 230 Detection Units (4140 OM each one with 31 3″ PMTs)
- ORCA
  - Volume ~ 8 Mton 👉 neutrino properties
  - 115 Detection Units (2070 OM each one with 31 3″ PMTs)

Detector in construction

1 DU ARCA + 6 DUs ORCA in operation

IceCube-Gen2

arXiv:2008.04323v1 Aug. 2020

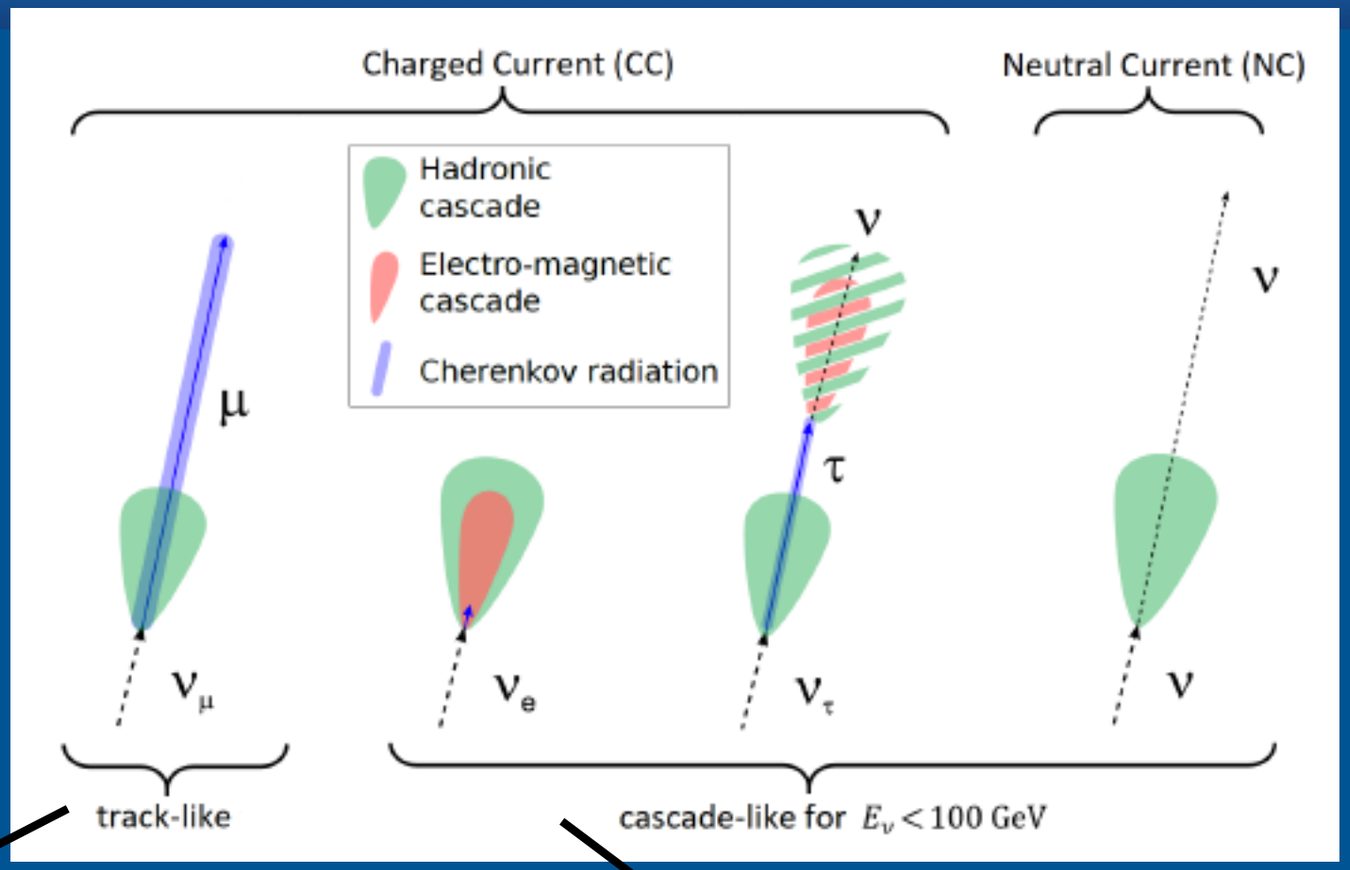


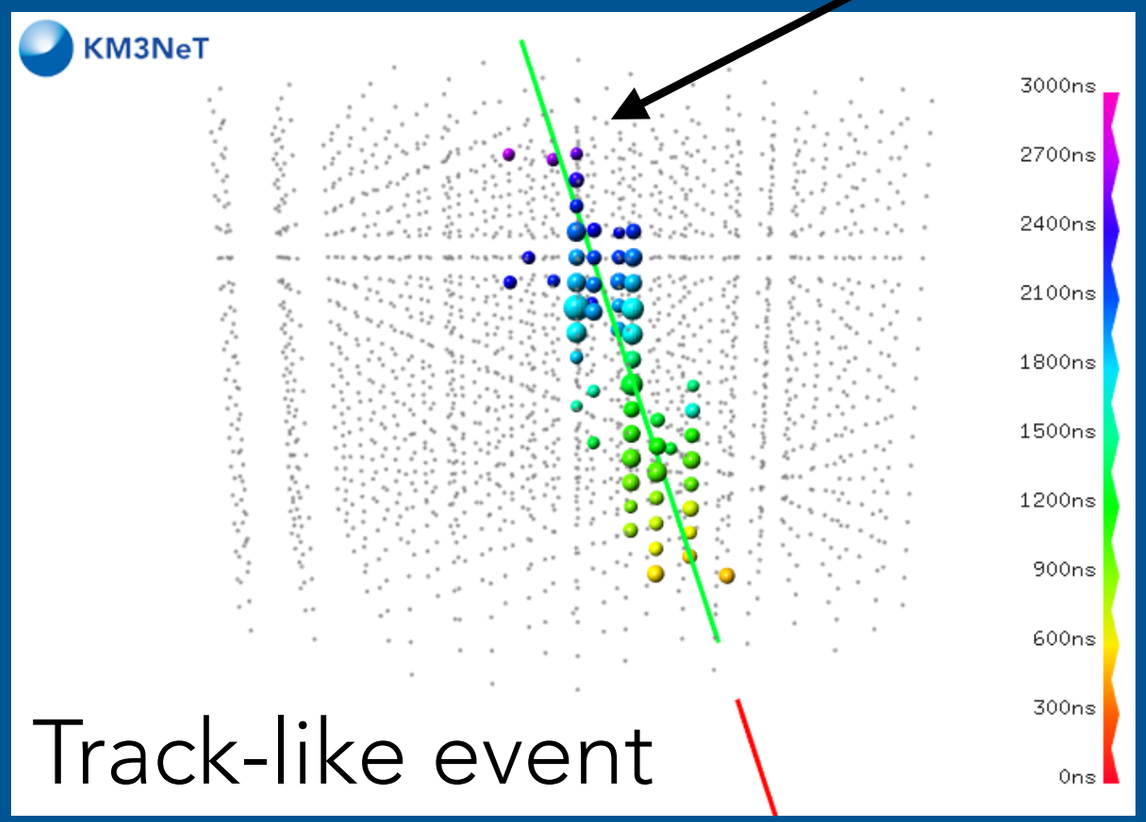
- Volume ~ 8 km3
  - 120 new strings at ~ 240m (9600 new modules)

Construction not yet started

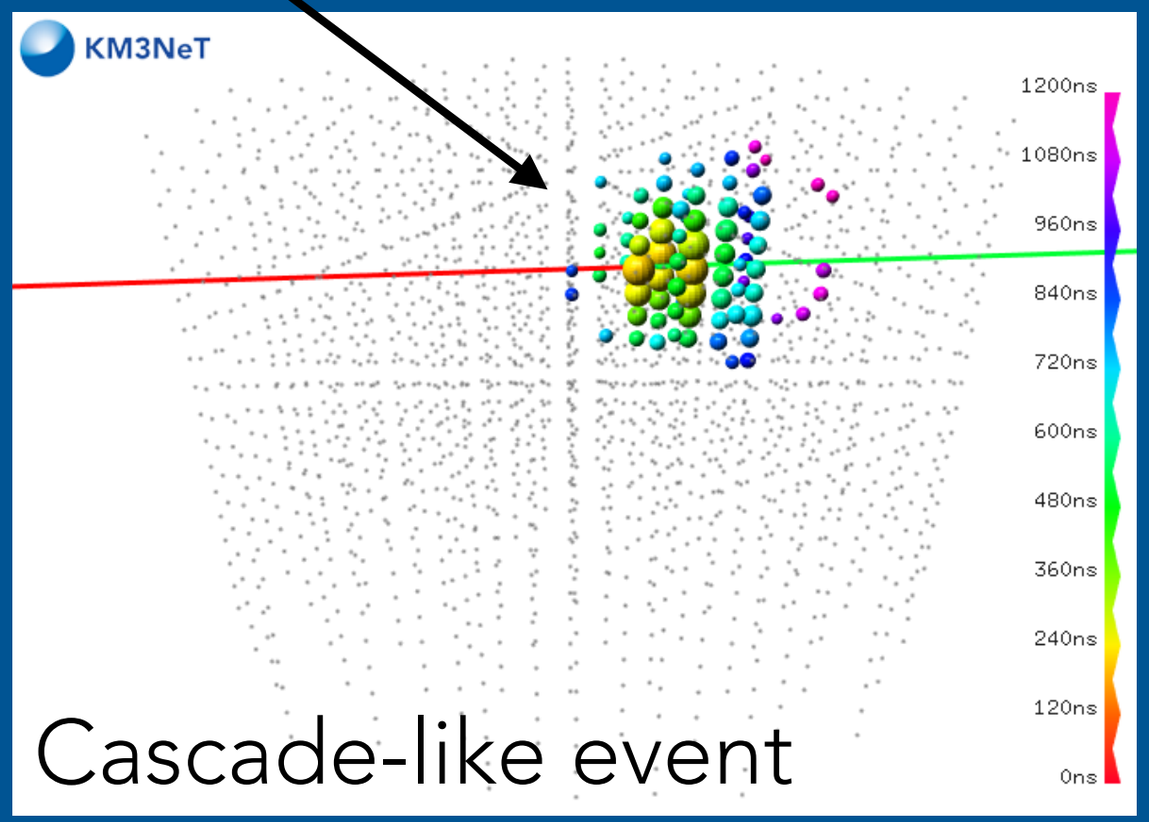
EVENT TYPES

How events look like in high energy neutrinos detectors





Track-like event



Cascade-like event

EVENT TYPE AND ANGULAR RESOLUTION

	TRACK*	CASCADE*
ANTARES	0.3°	3°
KM3NET	0.1°	1.5°
ICECUBE	0.3°	7°-8°
BAIKAL -GVD	0.25°	3° - 3.5°

*Resolution at 100 TeV

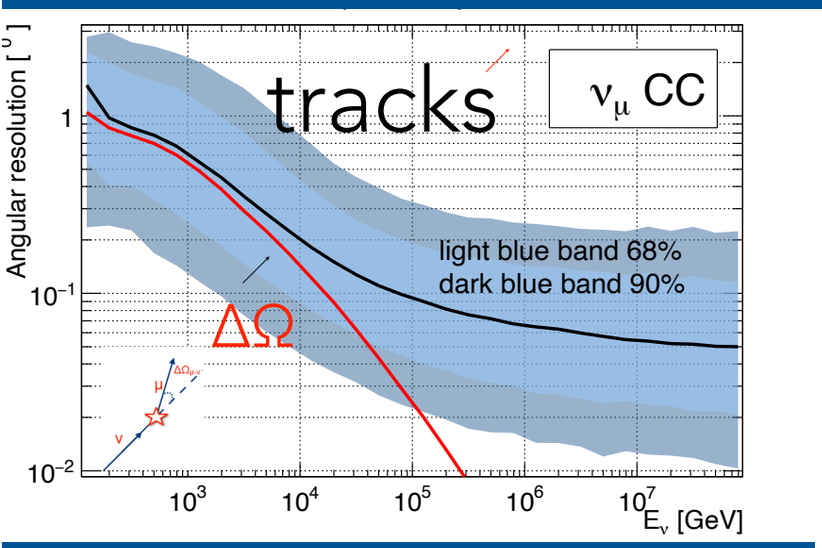
Tracks: very long path (Eμ>1TeV several km)
Big lever arm

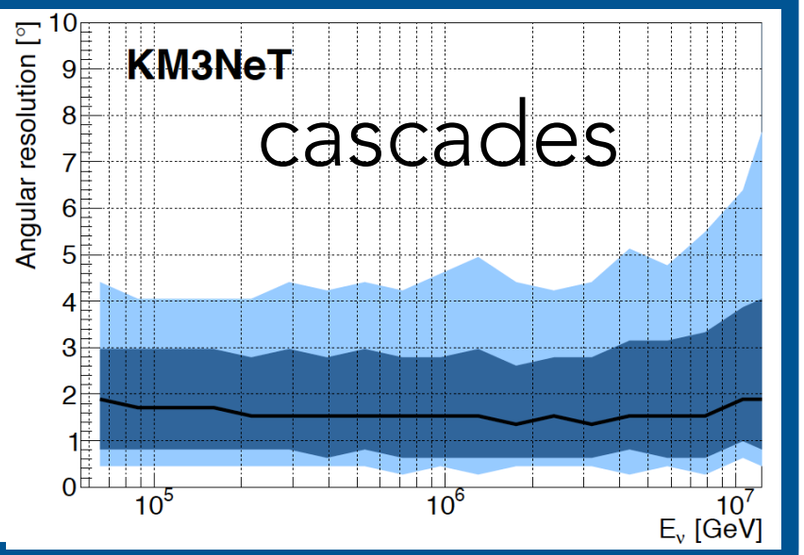
- Good angular resolution

Cascades: small path (Ecasc >1TeV some tens of meters)

- Modest angular resolution

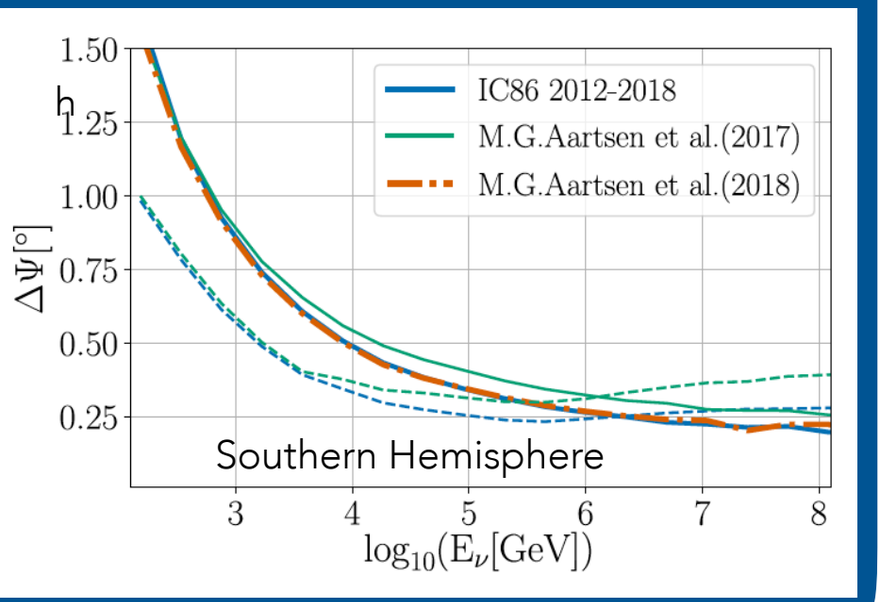
KM3NeT





IC resolution for tracks

from arXiv:1910.08488, 15 October 2019



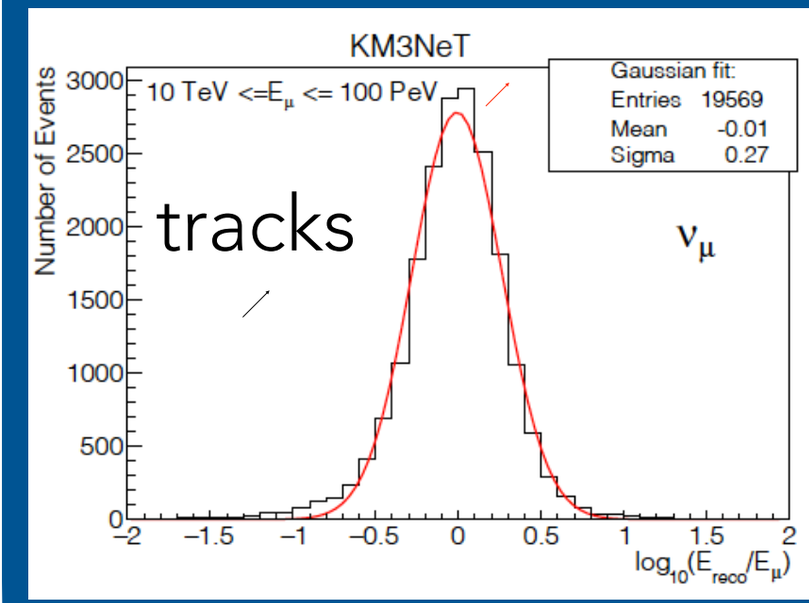
EVENT TYPE AND ENERGY RESOLUTION

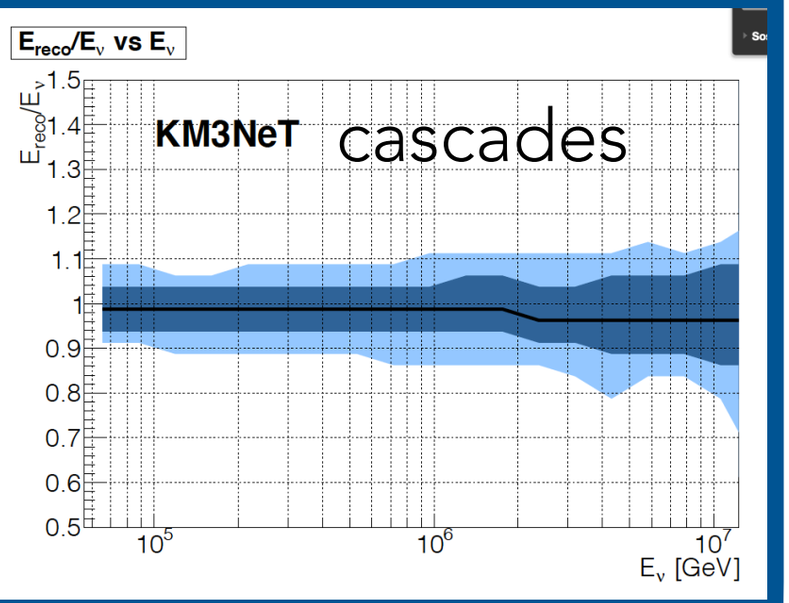
Tracks: very long path (Eμ>1TeV several km)
Neutrino interaction vertex far from the detector
- Modest energy resolution

Cascades: small path (E_{casc} >1TeV some tens of meters)
All the energy released inside the detector
- Good energy resolution

	TRACK IN LOG(E)	CASCADE
ANTARES	35%	5%
KM3NET	27%	5%
ICECUBE	~ 30%	10%
BAIKAL -GVD		

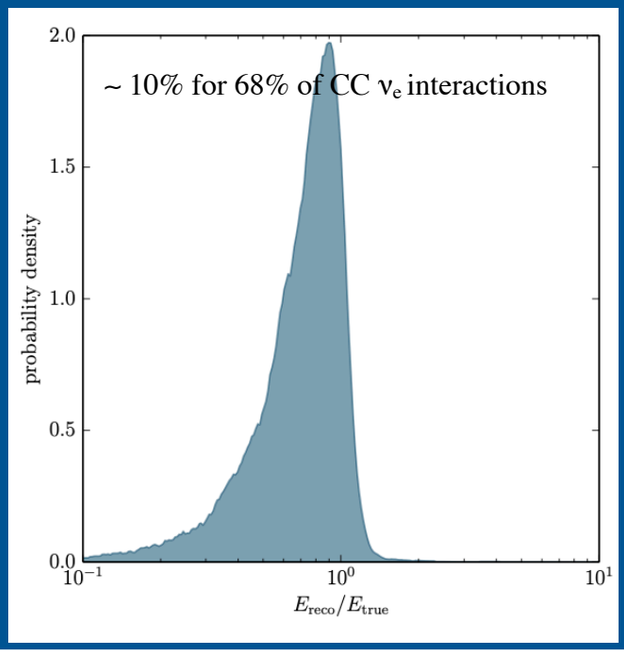
KM3NeT





IC energy resolution for cascades

ArXiv:1705.02383



EVENT TYPE AND NEUTRINO EFFECTIVE AREA

Tracks: very long path (Eμ>1TeV several km)
Neutrino interaction vertex far from detector

- Higher neutrino effective areas

Cascades: small path (Ecasc >1TeV some tens of meters)
Contained events

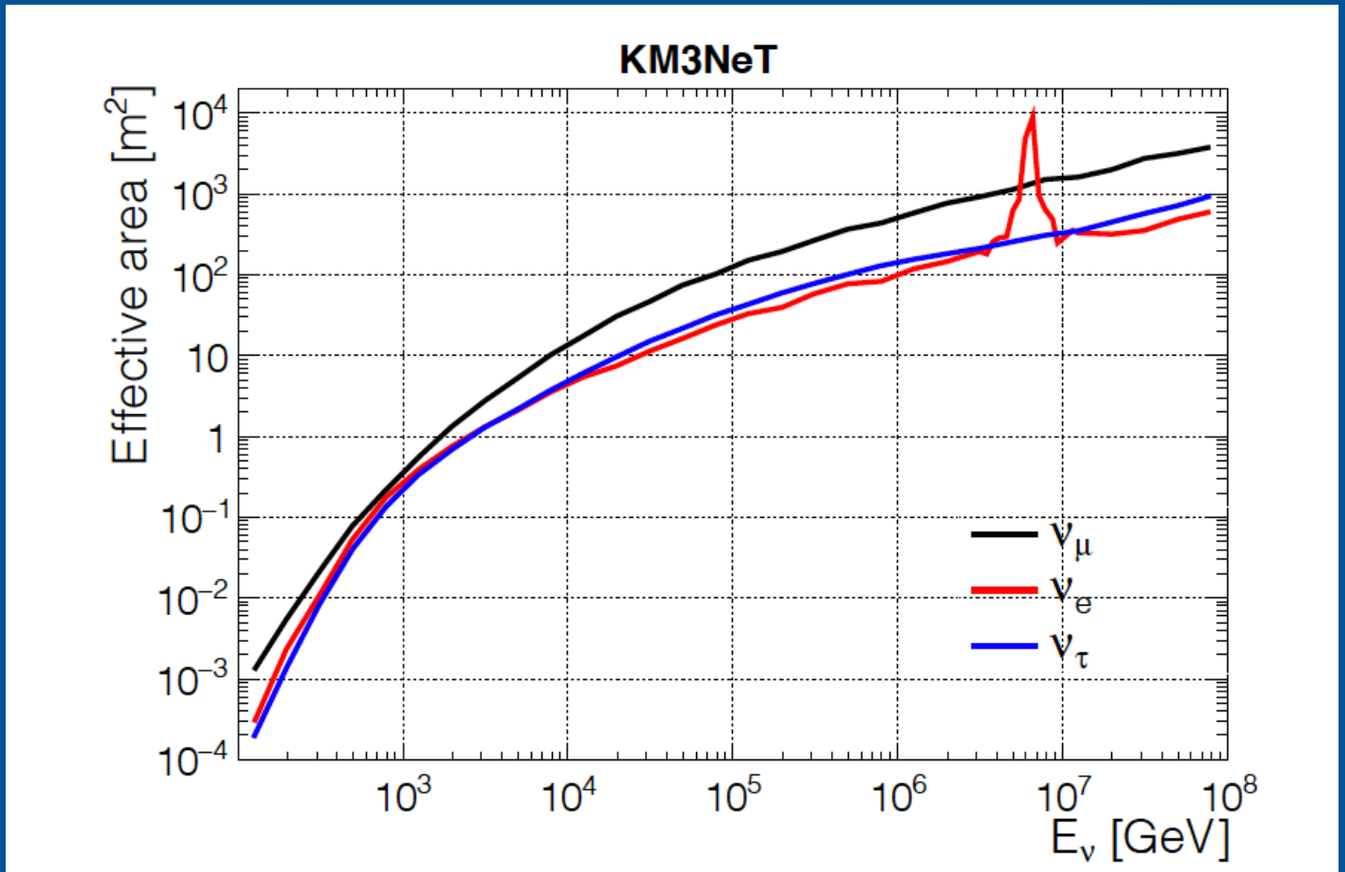
- Smaller effective areas

$$N(E) = A_{eff}(E) * \Phi_{source}(E)$$

$N(E)$ number of events detected

$A_{eff}(E)$ neutrino effettive areas

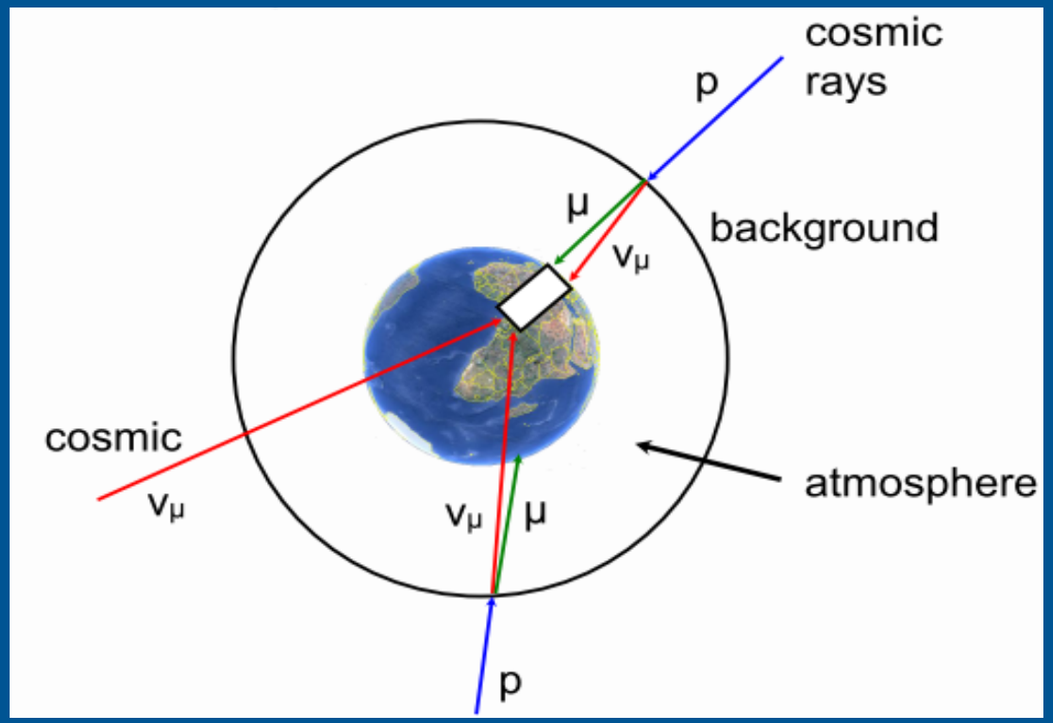
$\Phi_{source}(E)$ expected neutrino flux

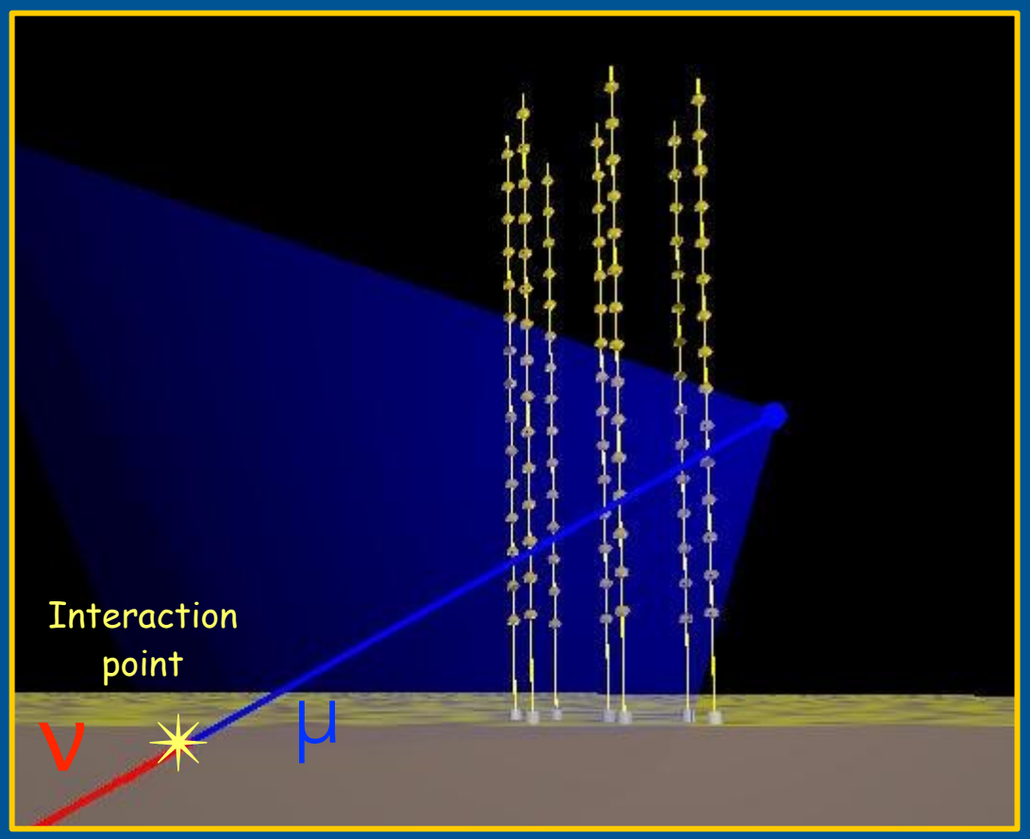


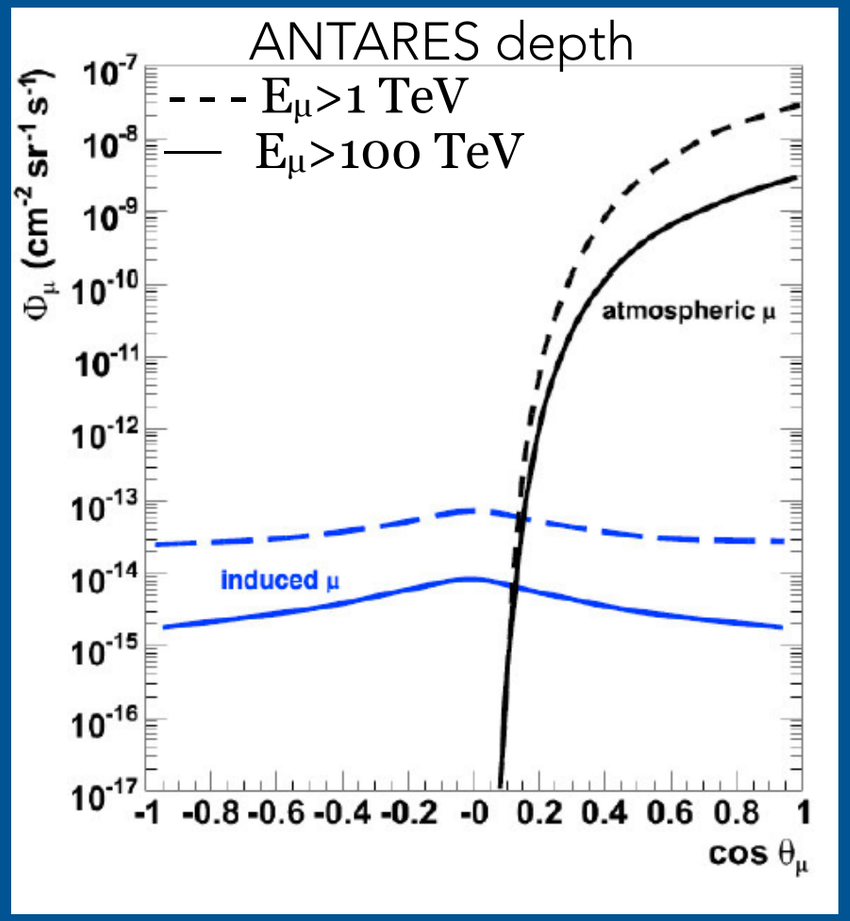
Higher effective areas for track events

DETECTION PRINCIPLE IN HIGH ENERGY NEUTRINO DETECTORS

Background from the interactions of Cosmic Ray with the atmosphere: muons and neutrinos produced







In KM3NeT/ARCA - 3500m depth: expected per year at reconstruction level

~ 50 million of μ_{atm} (E_μ>10TeV)

~ 0.3 million of ν_{atm} (E_ν>100GeV)

600 of cosmic ($\propto E^{-2}$) (E_ν>100GeV)

Looking for upgoing tracks 👉 easier rejection of atmospheric muons

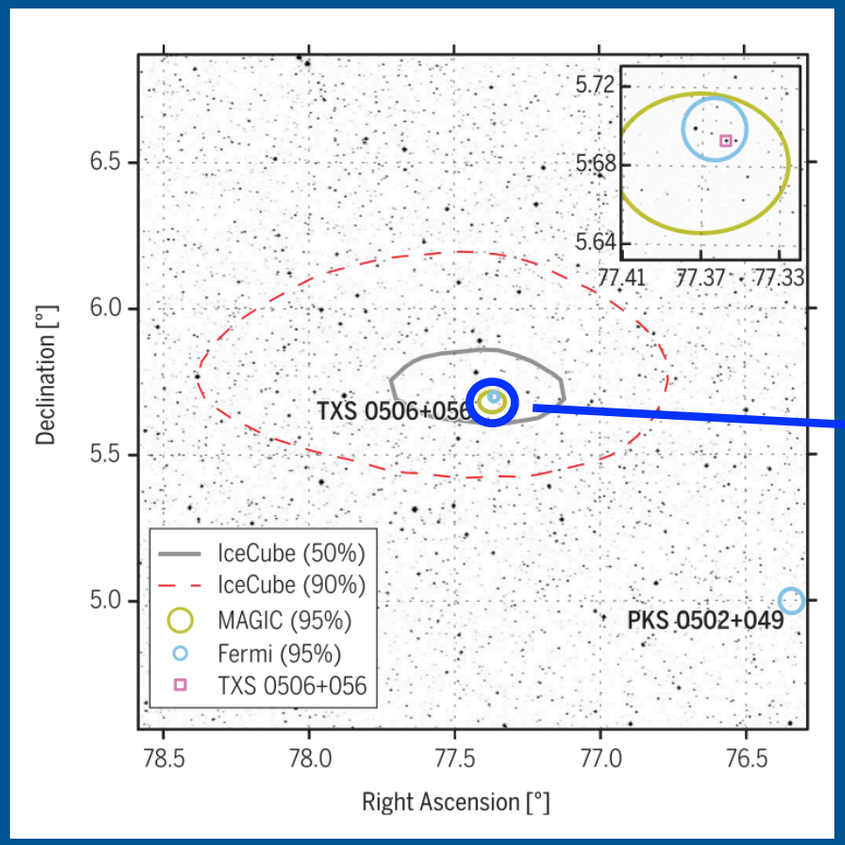
ANGULAR RESOLUTION A KEY POINT FOR NEUTRINO ASTRONOMY

👇

TRACK EVENTS THE GOLDEN CHANNEL FOR NEUTRINO ASTRONOMY

More precise sky maps

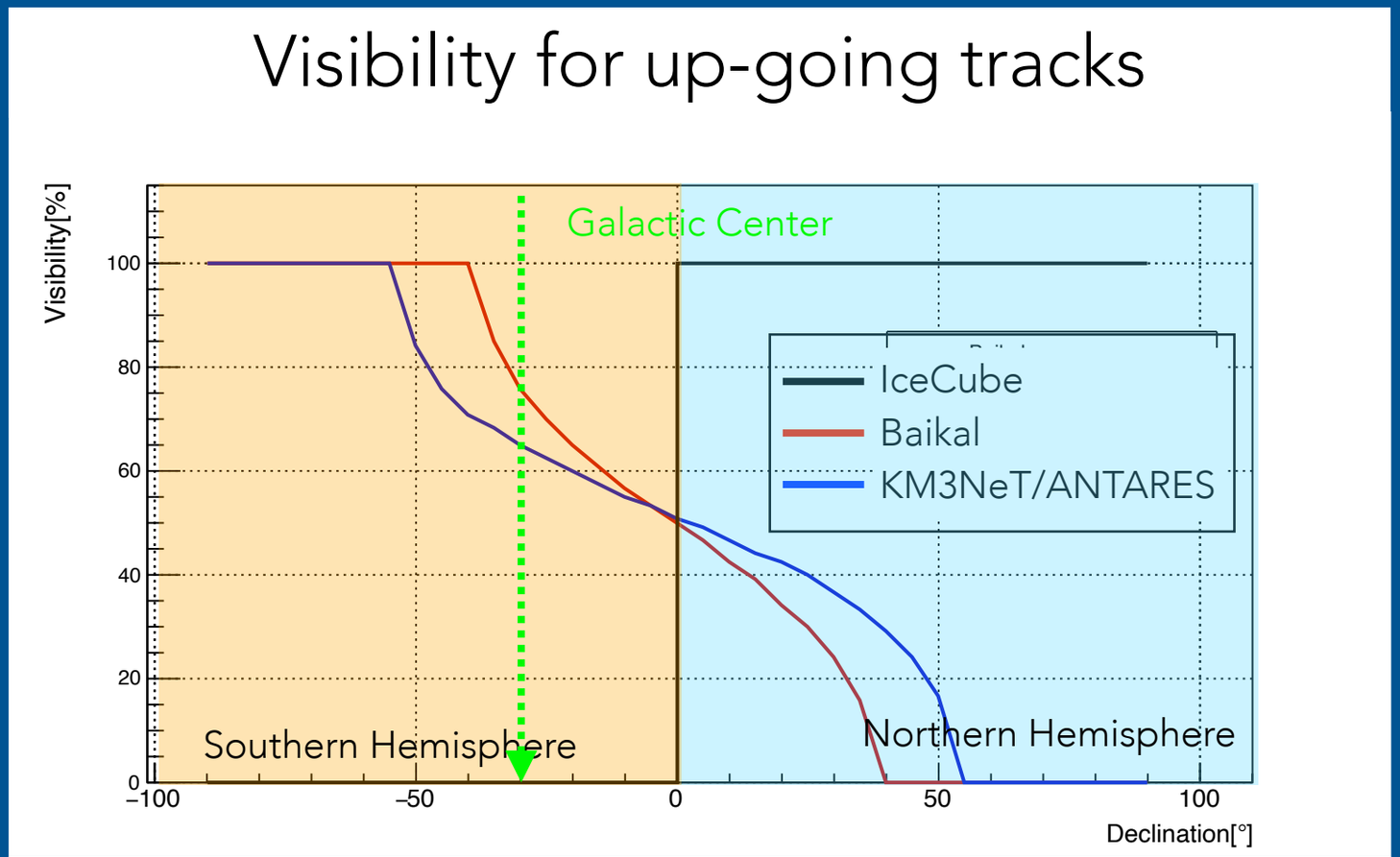
Better localization of sources for multimessenger astronomy



Expected KM3NeT/ARCA resolution at 50% for tracks for E_ν of about 200 TeV

UPGOING TRACKS FIELD OF VIEW

Through-going muon neutrino analyses will be sensitive mainly to the Southern Sky for detector located in the Northern Hemisphere and Northern Sky for IceCube



Northern and Southern located detectors complementary

Some recent results with track-like events

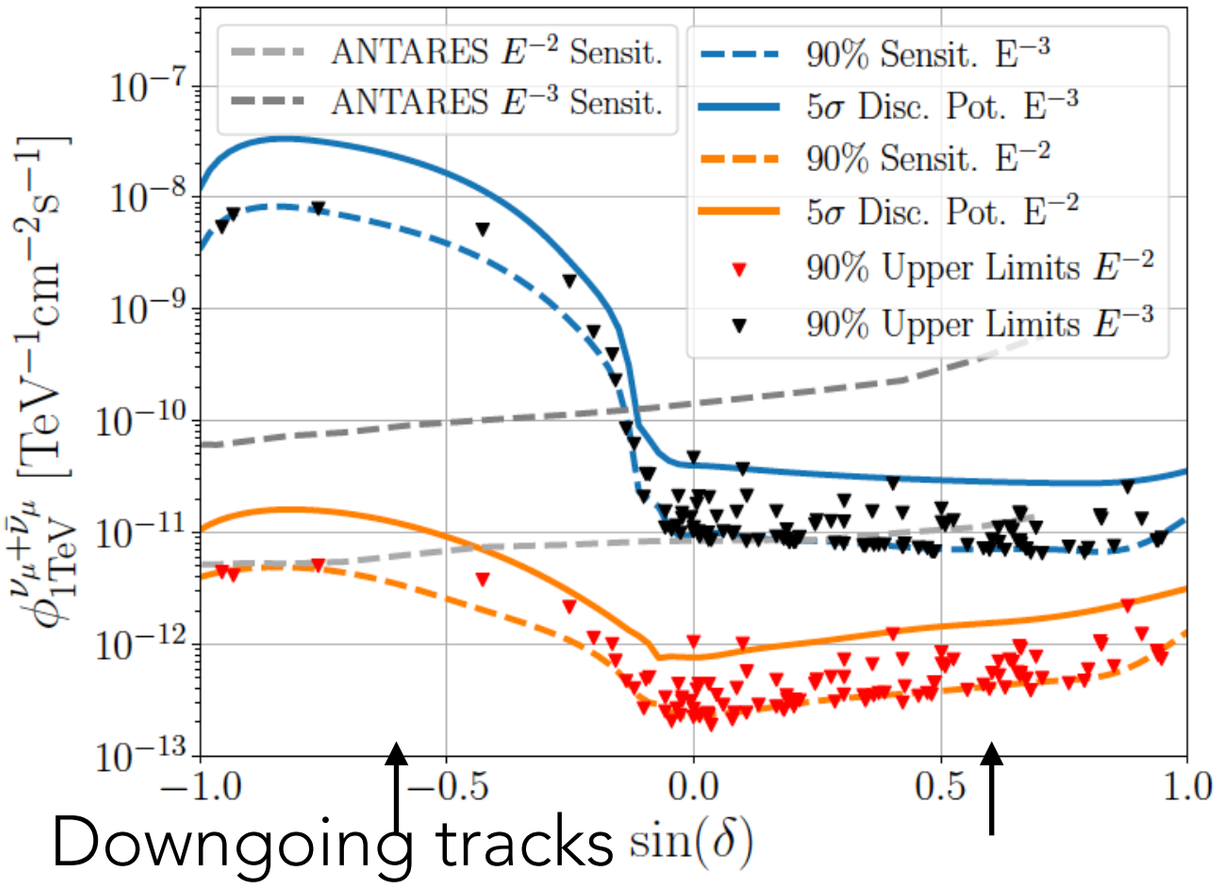
POINT-LIKE SEARCHES IN ICECUBE WITH TRACKS

arXiv:1910.08488 18 October 2019

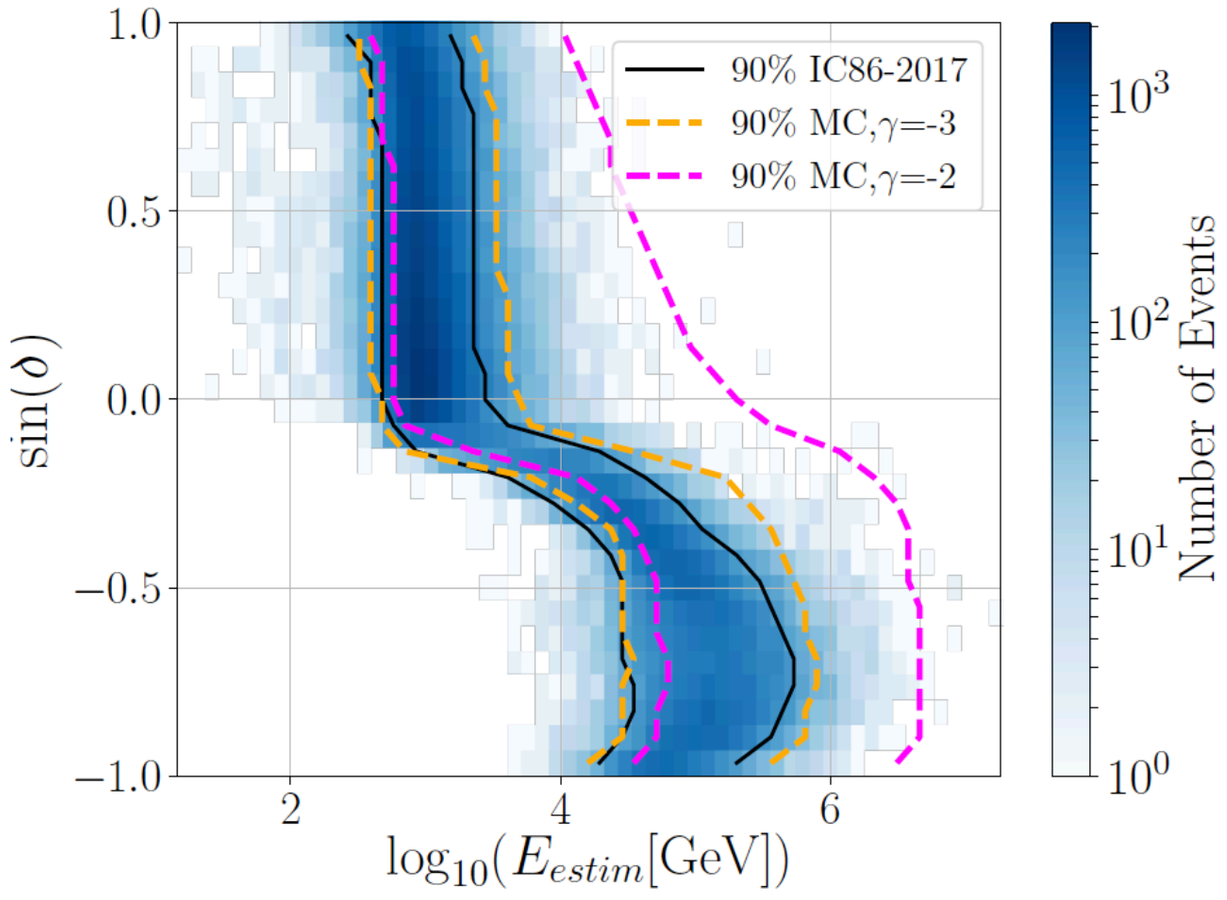
IC search for steady sources

Track like - events

10 years of IC data



Downgoing tracks



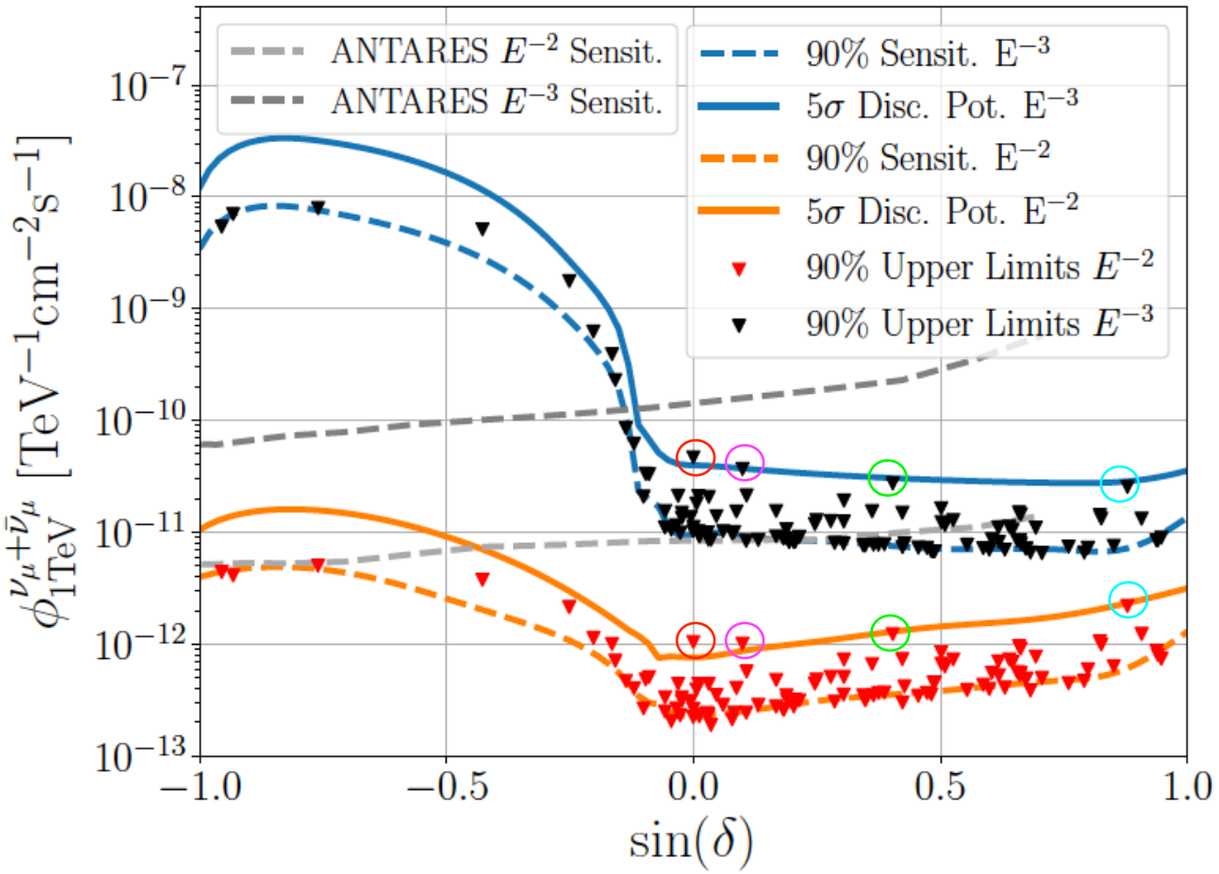
Severe energy cut on the downgoing tracks needed to reject background

POINT-LIKE SEARCHES IN ICECUBE WITH TRACKS

arXiv:1910.08488v1 18 October 2019

IC search for steady sources

10 years of IC data

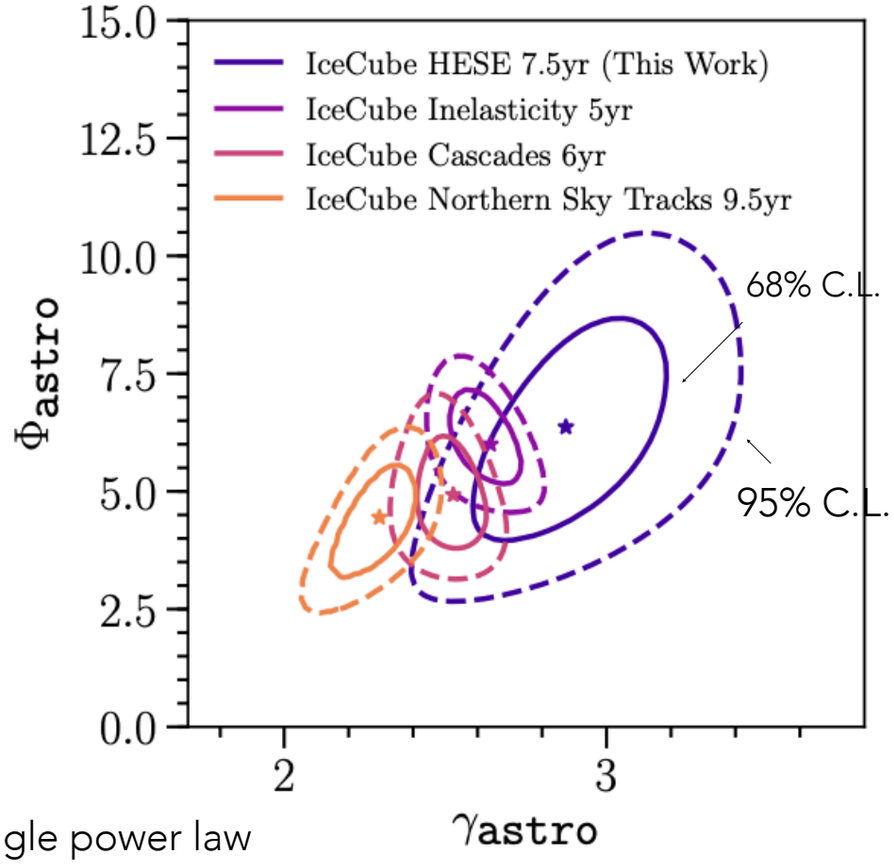


HOT SPOTS	Γ	PRE-TRIAL (SIGMA)
NGC 1068	3,2	4,7 👉 2.9 post-trial
TXS 0506+056	2,1	3,7
PKS 1424+240	3,9	2,8
GB6 J1542+6129	3,0	2,74

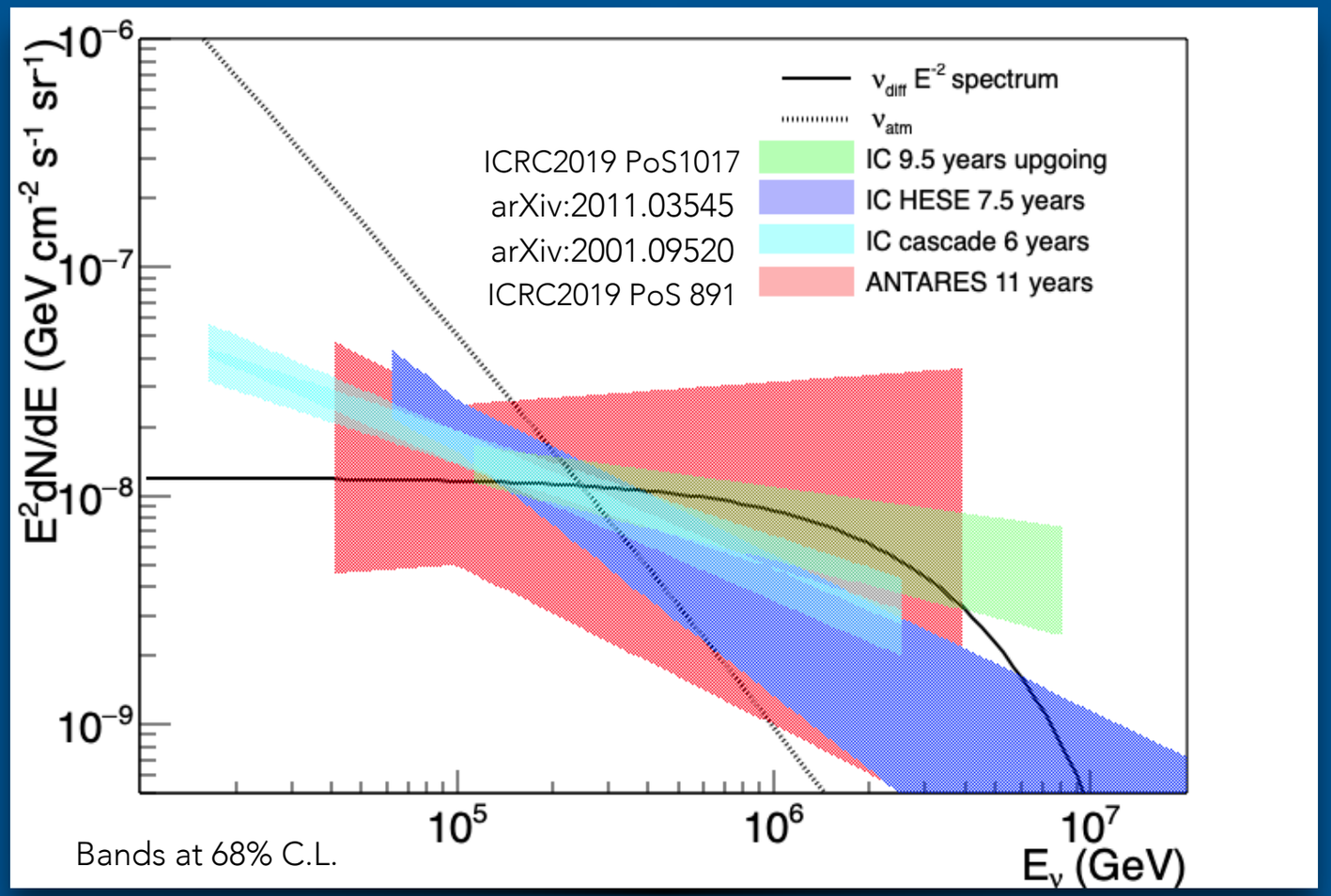
Compatible with background

DIFFUSE FLUX SEARCHES IN ICECUBE

From arXiv:2011.03545v1 6 Nov 2020



Single power law



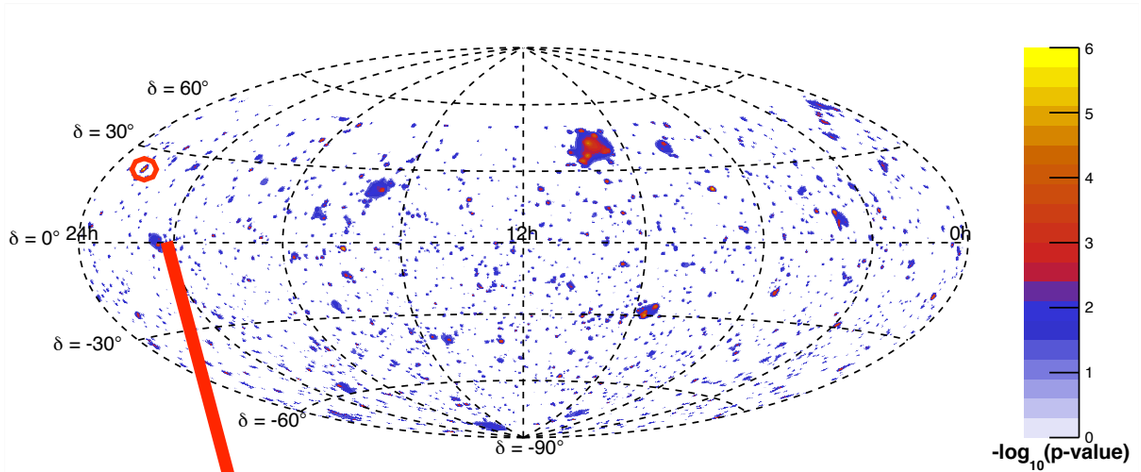
Bands at 68% C.L.

- Big uncertainties present in the data 👉 Results compatible within 95% CL contour
- Single power law? Statistics not enough to distinguish between different models. Currently no model is significantly preferred compared to a single power law
- Analysis based on track up-going indicates lower spectral index 👉 Different portion of sky observed with up-going tracks
- A multicomponent model to explain the different spectral indices? (A. Palladino and W. Winter arXiv:1801.07277)

ANTARES POINT-LIKE SEARCHES

ICRC2019 Pos 1177

11 years (3136 days of livetime) - track and cascade analysis



The most significant cluster

α=343.7° δ=+23.6°

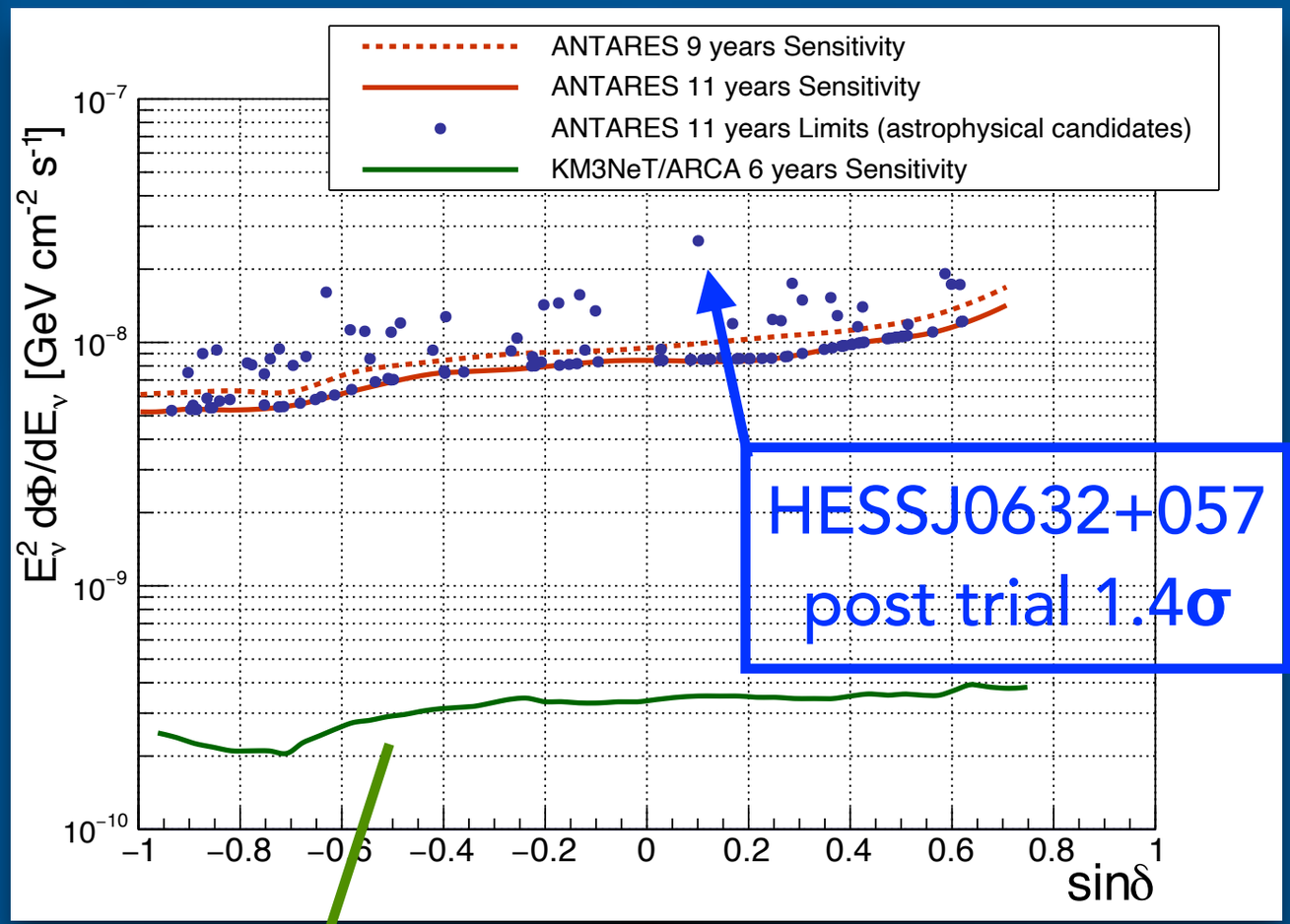
pre-trial 1.5 10^{-6} (4.8 σ)

post trial 0.23 (1.2 σ)

3 track events within 1°

15 tracks + 1 shower within 5°

upper limits and sensitivities



ICRC2019 POS 06

KM3NeT/ARCA
sensitivity after 6 years

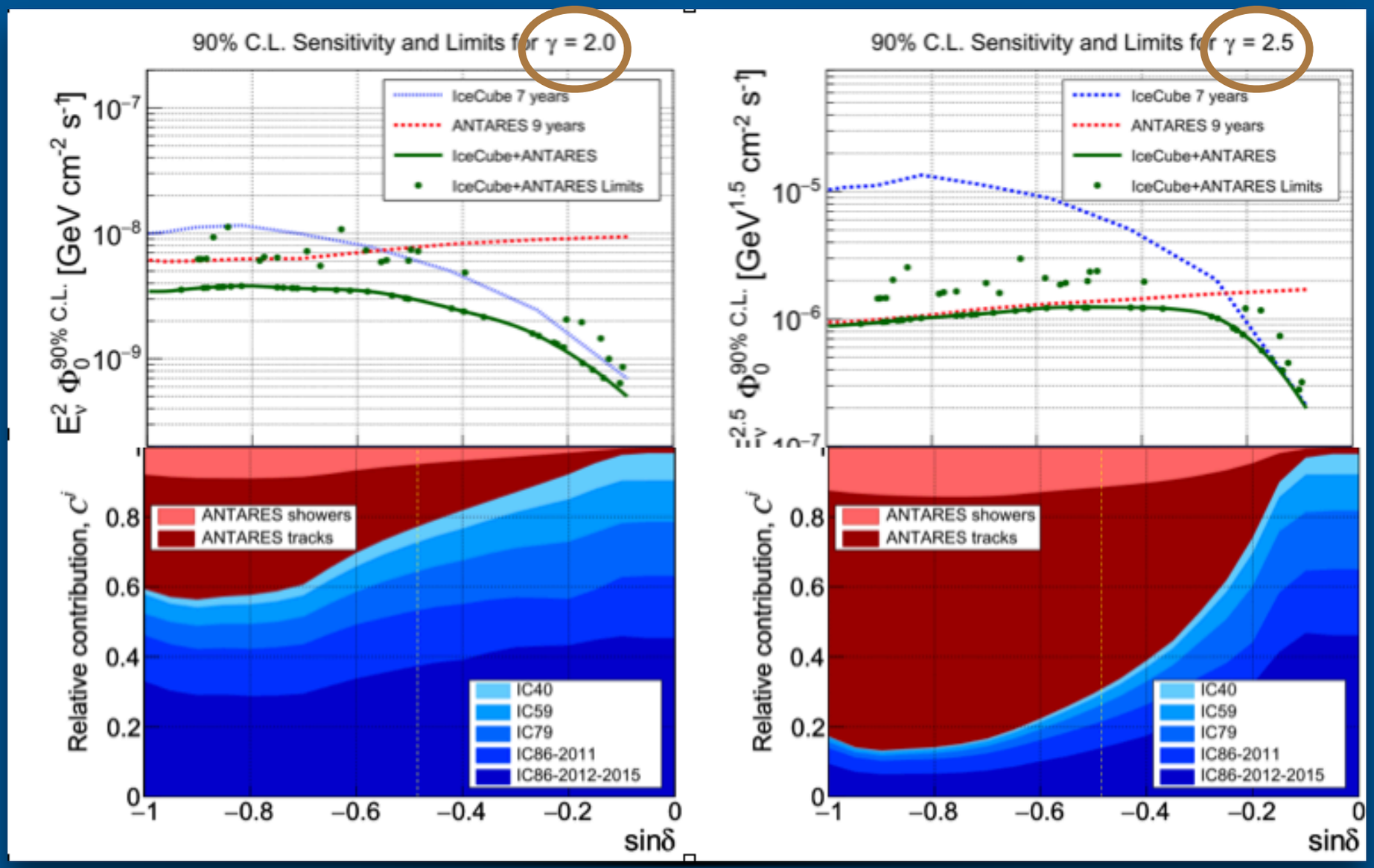
THE ANTARES & ICECUBE JOINT ANALYSIS

The Astrophysical Journal, 892:92, 2020 April 1

IC 7 years and ANTARES 9 years data to explore the Southern Sky

Data IC 👉 track events from APJ, 835 2017

ANTARES 👉 track+cascade from APJ, 786, 2014



Joint ANTARES/IC analysis also for:

- the Galactic diffuse emission arXiv:1808.03531
- dark matter from GC (Phys. Rev. D **102**, 082002 – 2020)

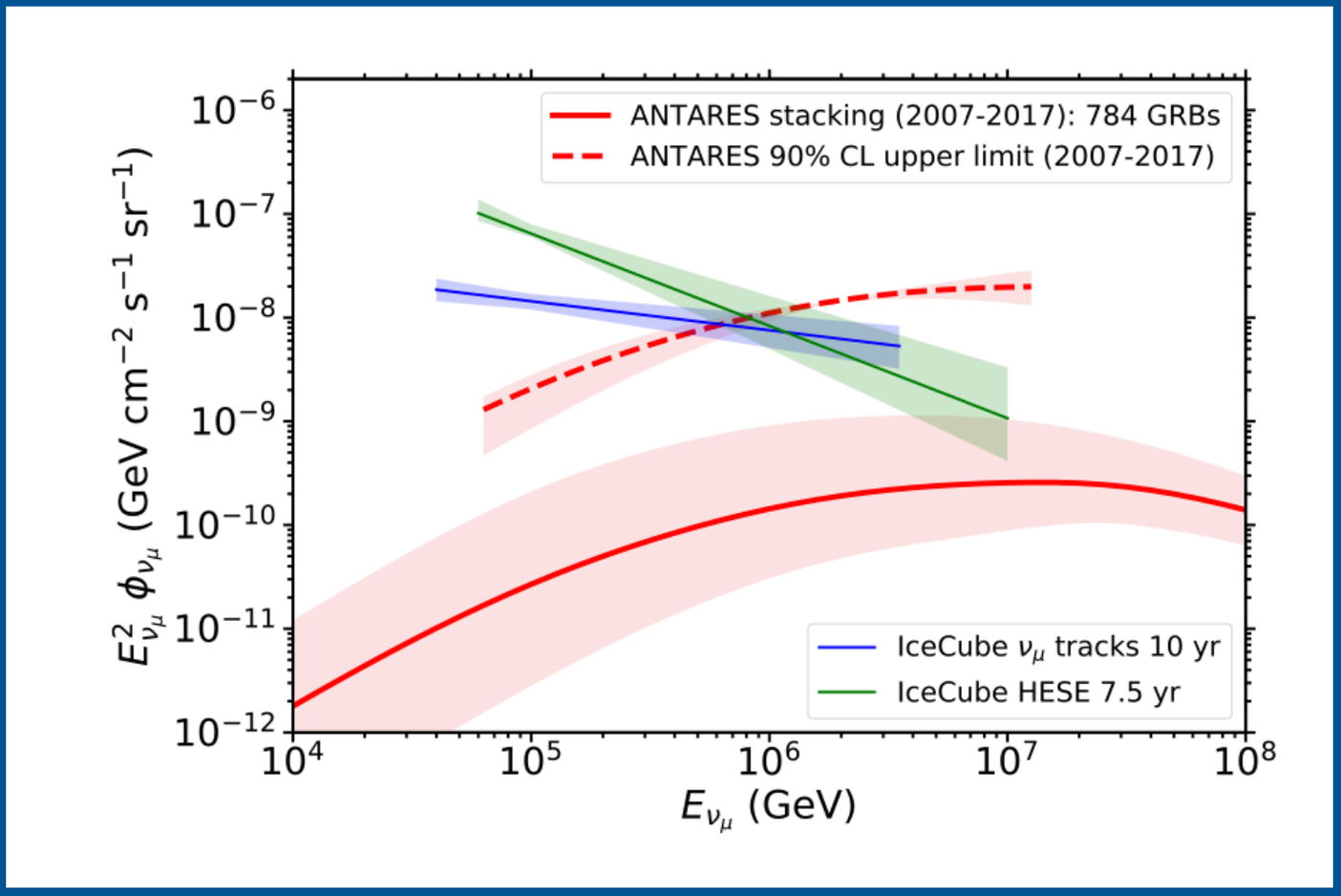
Sensitivity improved up to a factor ~2

THE ANTARES DATA: GRB

arXiv:2008.02127 6 Nov 2020

Neutrino searches in time - space coincidence with 784 GRB detected from 2007 to 2017
10 years of upgoing track events

No events survived the applied cuts and upper limits were set



GRB contribution less than 10% to the IC flux for E_ν<100TeV

See A. Zegarelli poster session

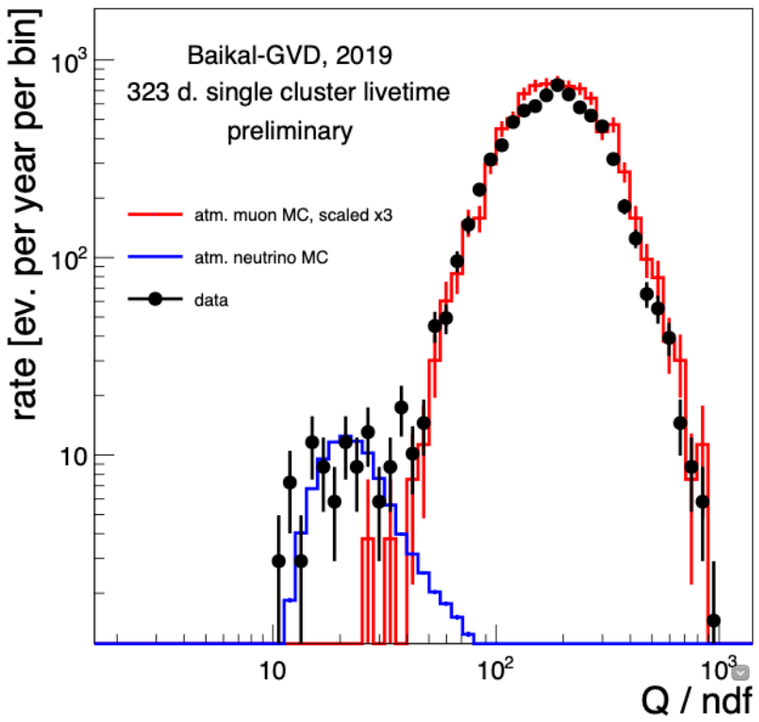
BAIKAL: FIRST RESULTS

arXiv:2011.09209 18 Nov 2020

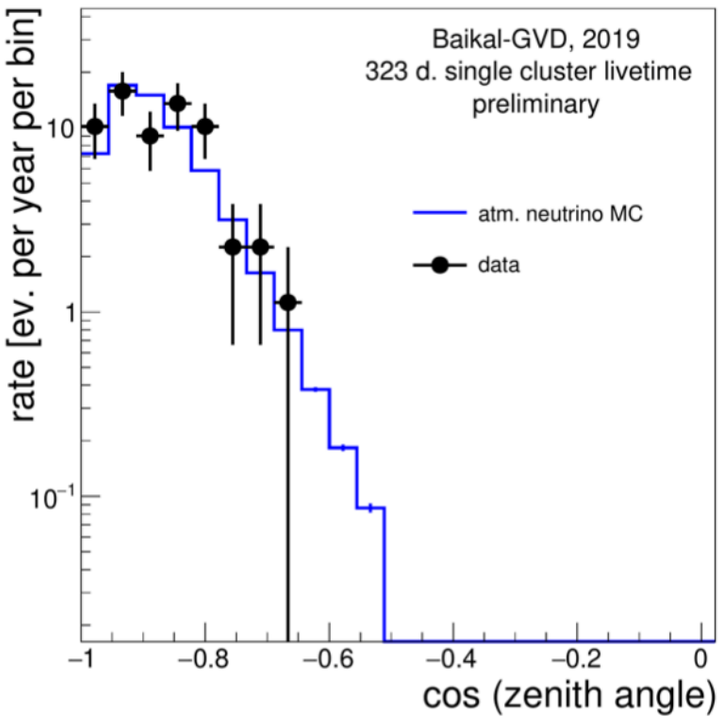
Single cluster upgoing tracks

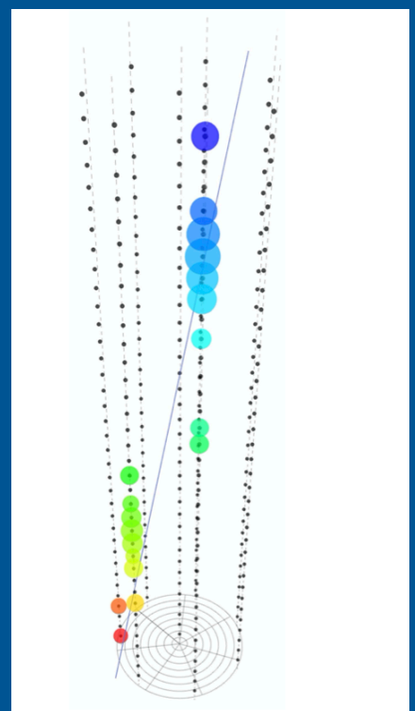
- 323 days of single cluster events
- neutrino candidates 52
- Angular resolution ~ 1°

Likelihood for upgoing tracks



Sample of candidate neutrinos





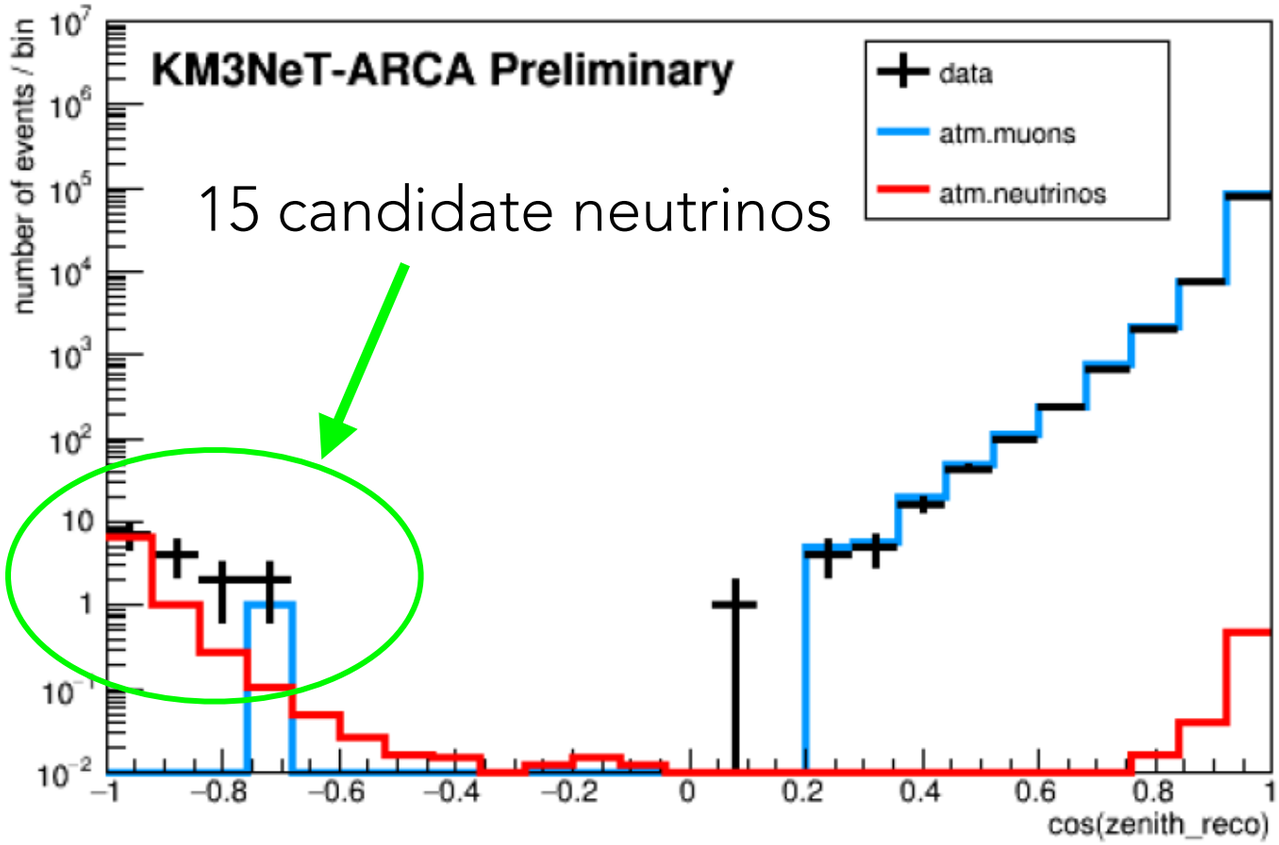
cluster 3, run 122
evt. 1549343
θ_{zenith} = 169.78°
$N_{strings}$ = 3
$N_{strings}$ = 19

Good selection between atmospheric neutrinos and atmospheric muons
Good Data/MC agreement

KM3NET/ARCA: FIRST RESULTS

https://nusoft.fnal.gov/nova/nu2020postersession/pdf/

Upgoing tracks



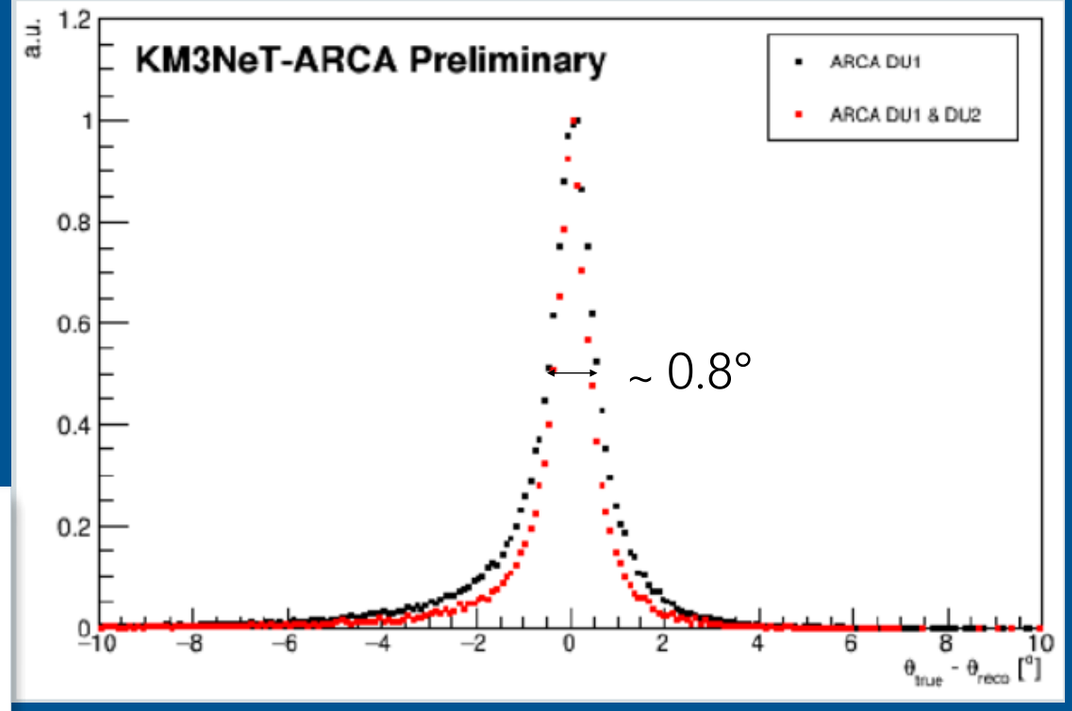
Selected 15 neutrino candidate events with energy > ~ 100 GeV with zenith angular resolution of ~ 0.8°

Good agreement data/MC

Data:

207 days ARCA 1 string + 53 days of ARCA 2 strings

Zenith angular resolution for the selected neutrinos

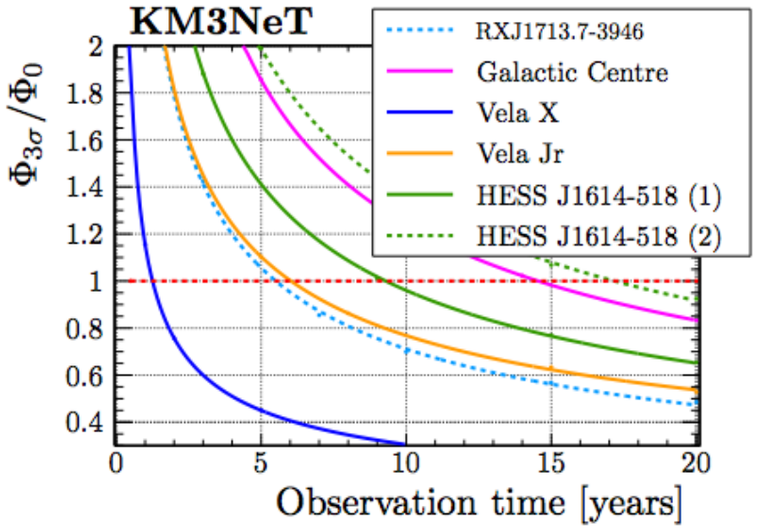


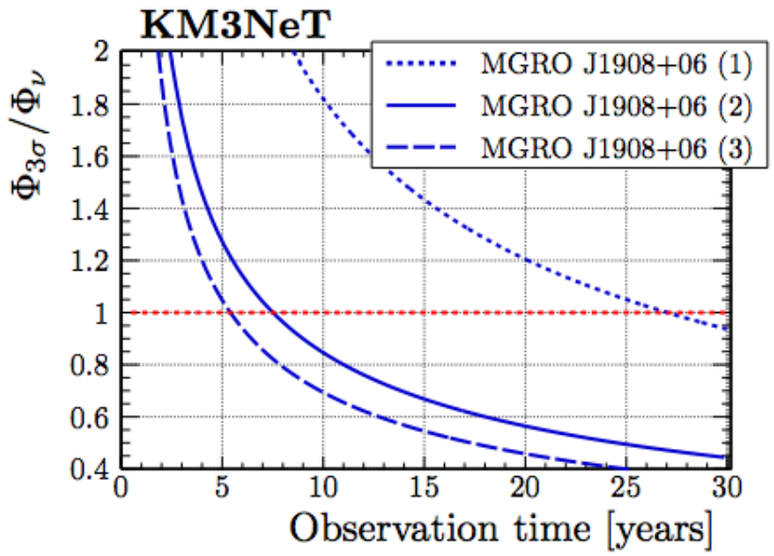
KM3NET/ARCA - GALACTIC SOURCES

KM3NeT coll. Astropart.Phys. 111 (2019) 100-110

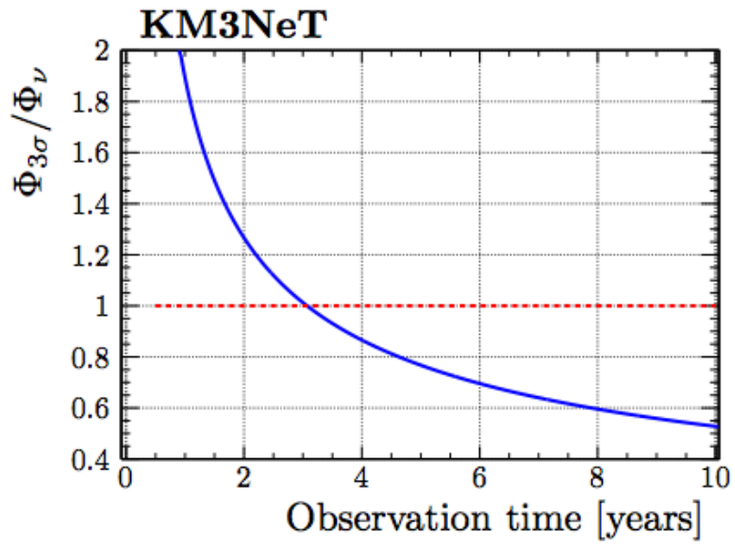
From TeVCat catalog selected intense Galactic sources measured up to the TeV region. Energy cut off and source extension taken into account

Upgoing track event selected





Stacked the RXJ1713 and Vela Jr.



Most of the sources considered can be observed within a few years if their **γ**-ray emission is of purely hadronic origin.

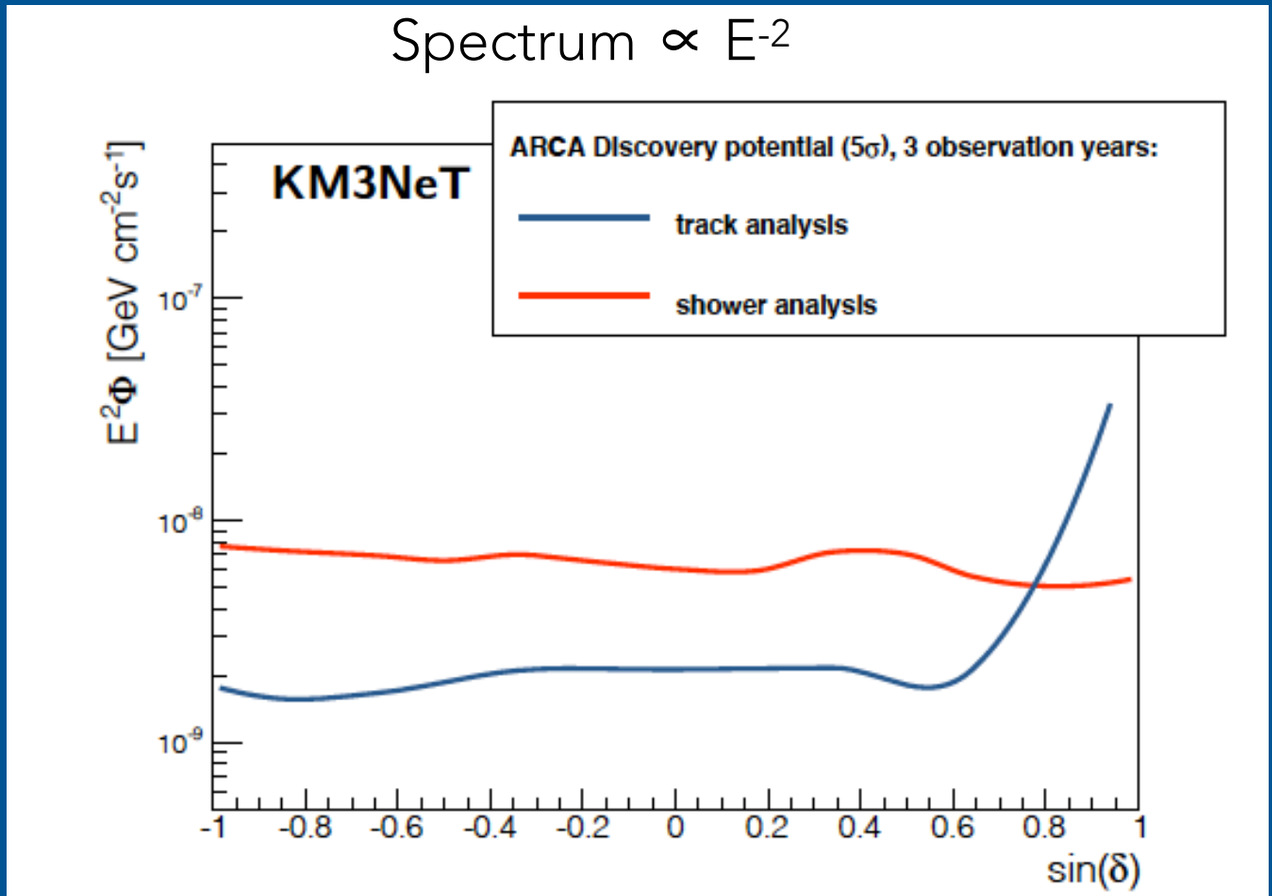
Vela Jr can be observed with a 3**σ** significance within 6 years,
and RX J1713.7-3946 within 5.5 years.

Stacking Vela Jr
and RX J1713.7-3946 👉 3**σ** significance within 3 years

KM3NET/ARCA - GENERIC POINT-LIKE SOURCES

KM3NeT LoI http://arxiv.org/abs/1601.07459

Search for a generic point like source done also with cascade events



Analysis with track events shows better discovery flux up to a factor ~ 4 in most of the sky

SUMMARY AND OUTLOOK

Track like event 👉 Better angular resolution and higher effective areas 👉 high quality sky maps and more precise multimessenger astronomy

Track like events: the golden channel in neutrino astronomy

More data needed from complementary detectors 👉 different field of view and different systematics

Joint analysis 👉 IceCube + KM3NeT/ANTARES + Baikal Global Neutrino Network (GNN) for a closer collaboration

https://www.globalneutrinonetwork.org