

HIGHLIGHTS FROM

# IceCube

J. A. Aguilar on behalf of IceCube

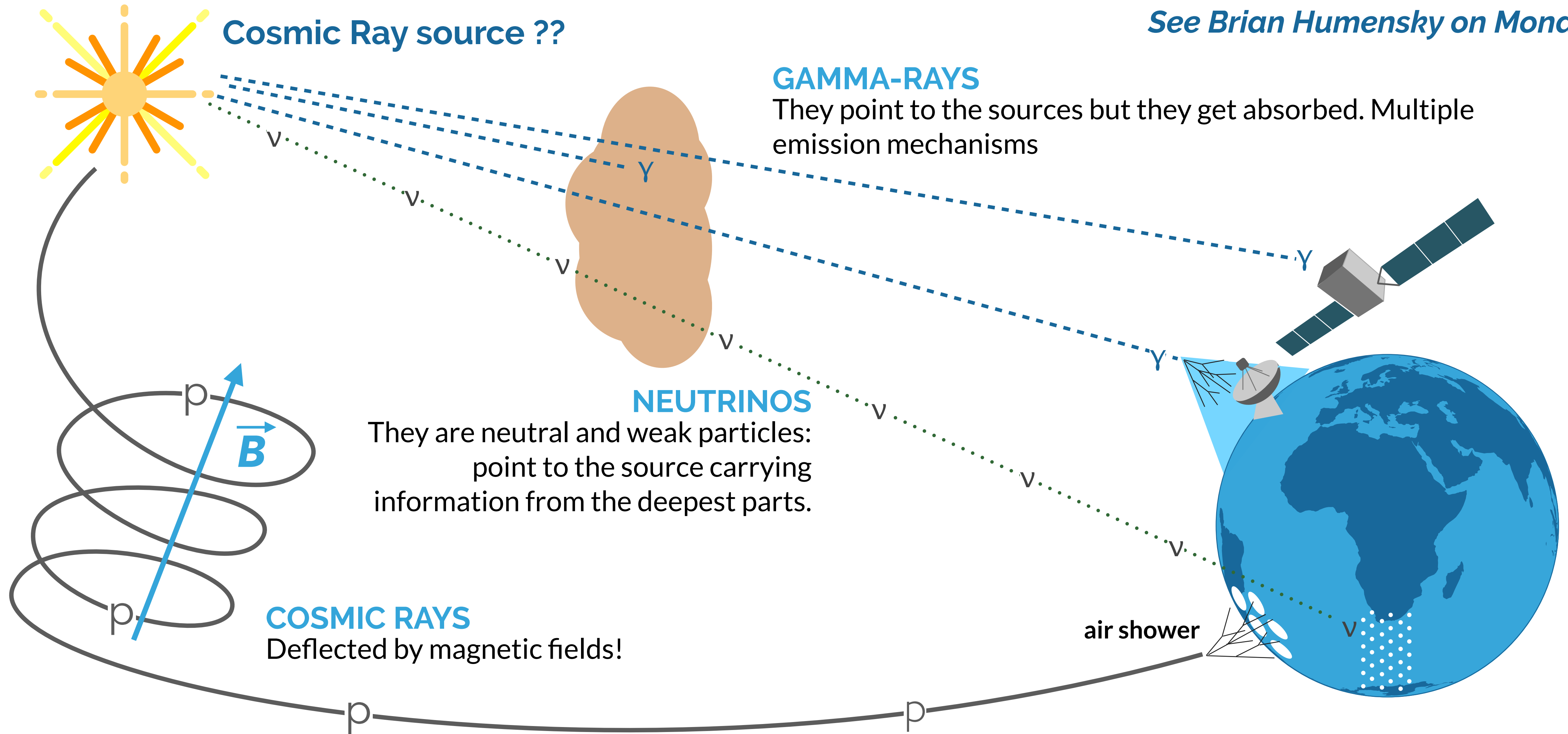
Photo: Ian Reese

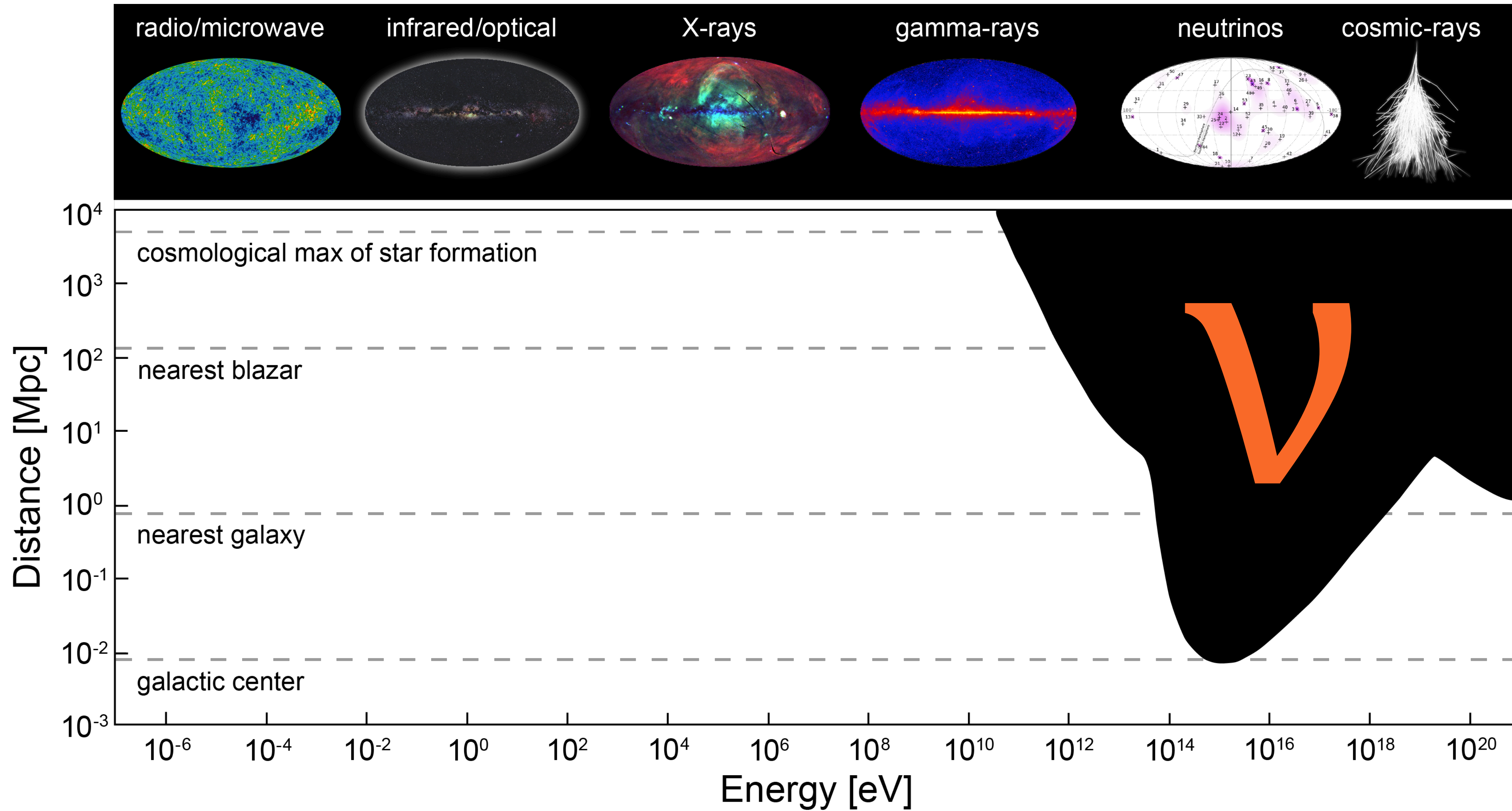
ULB

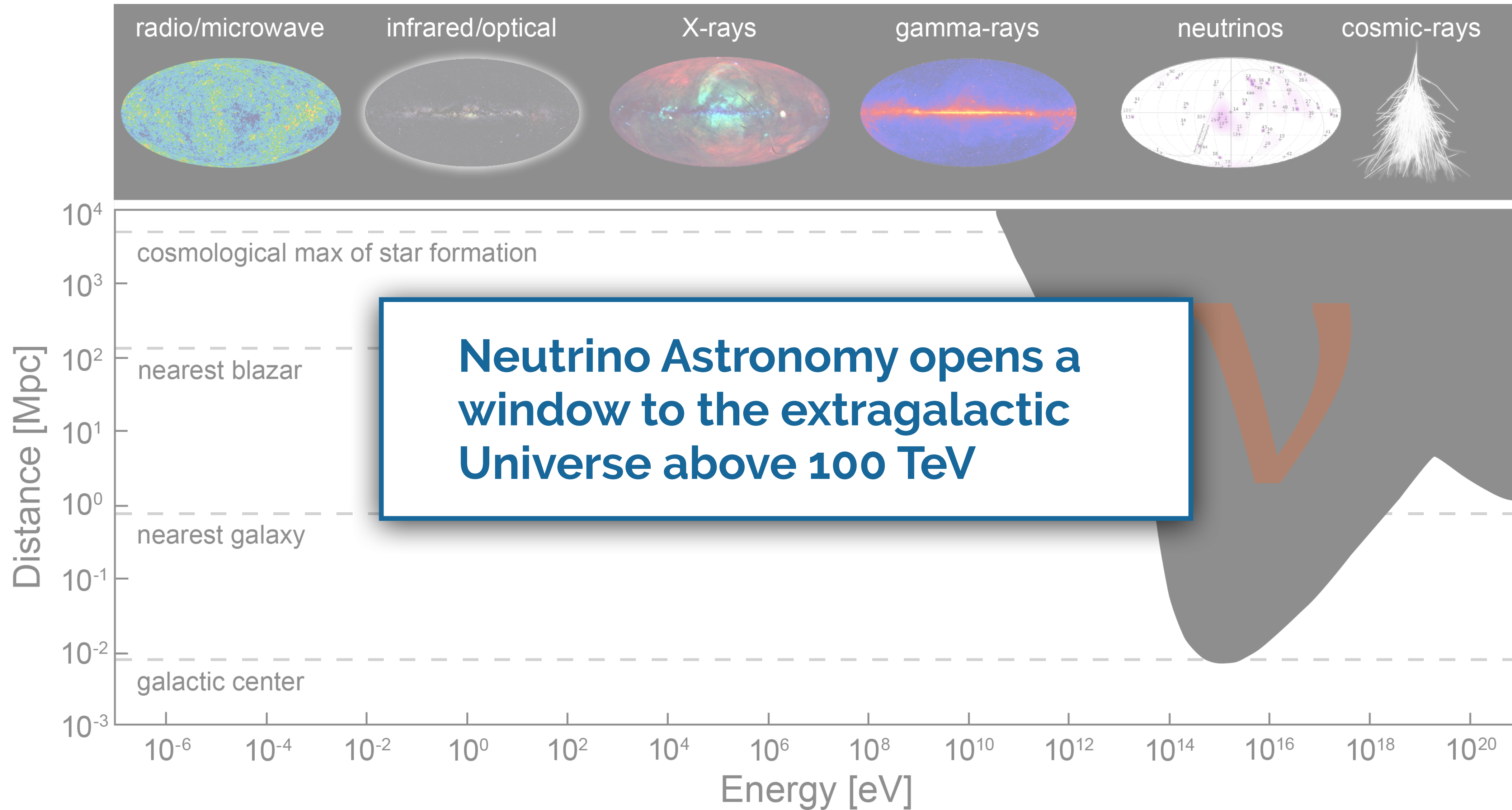
iihe

# Multimessenger Astronomy

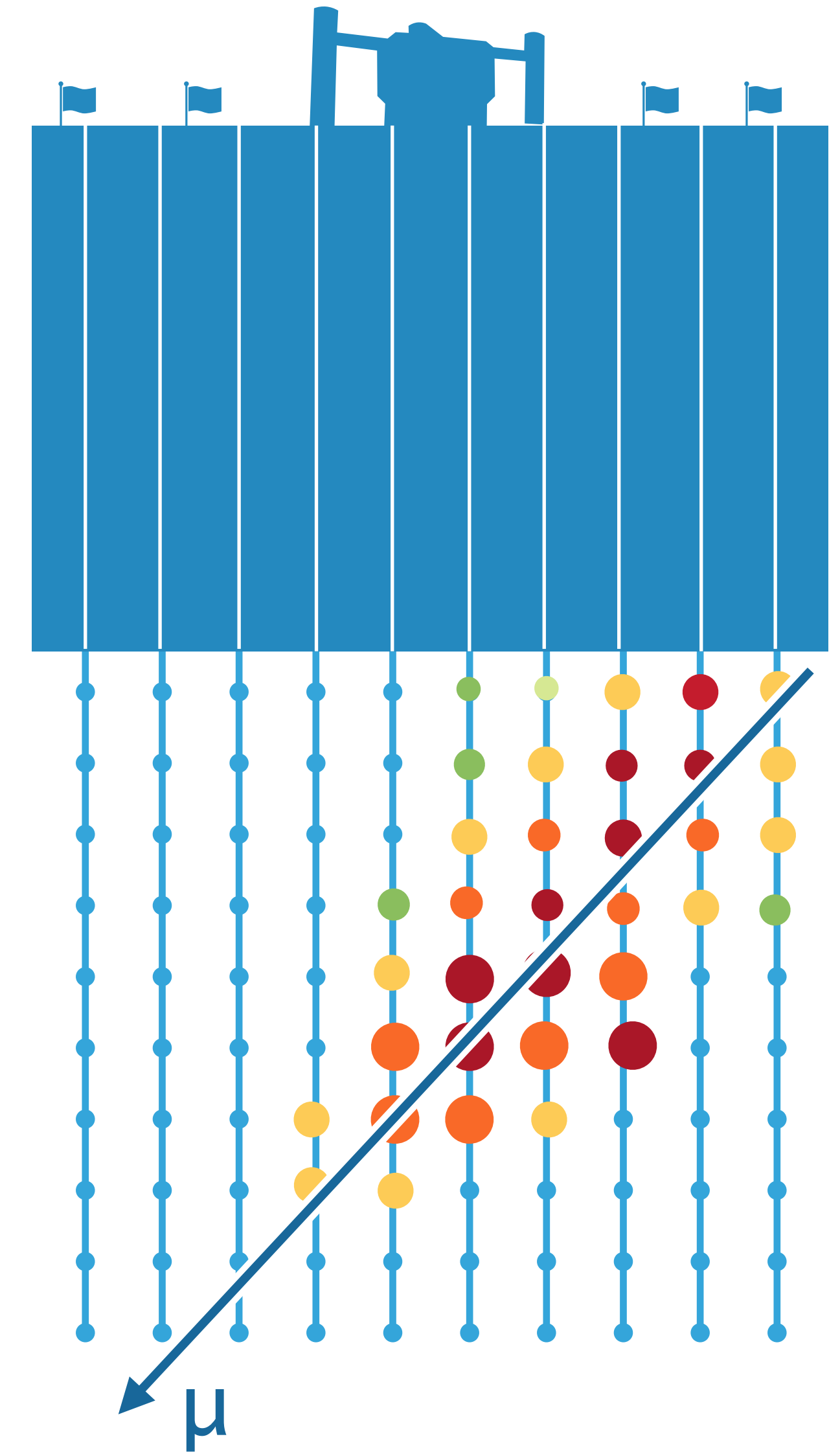
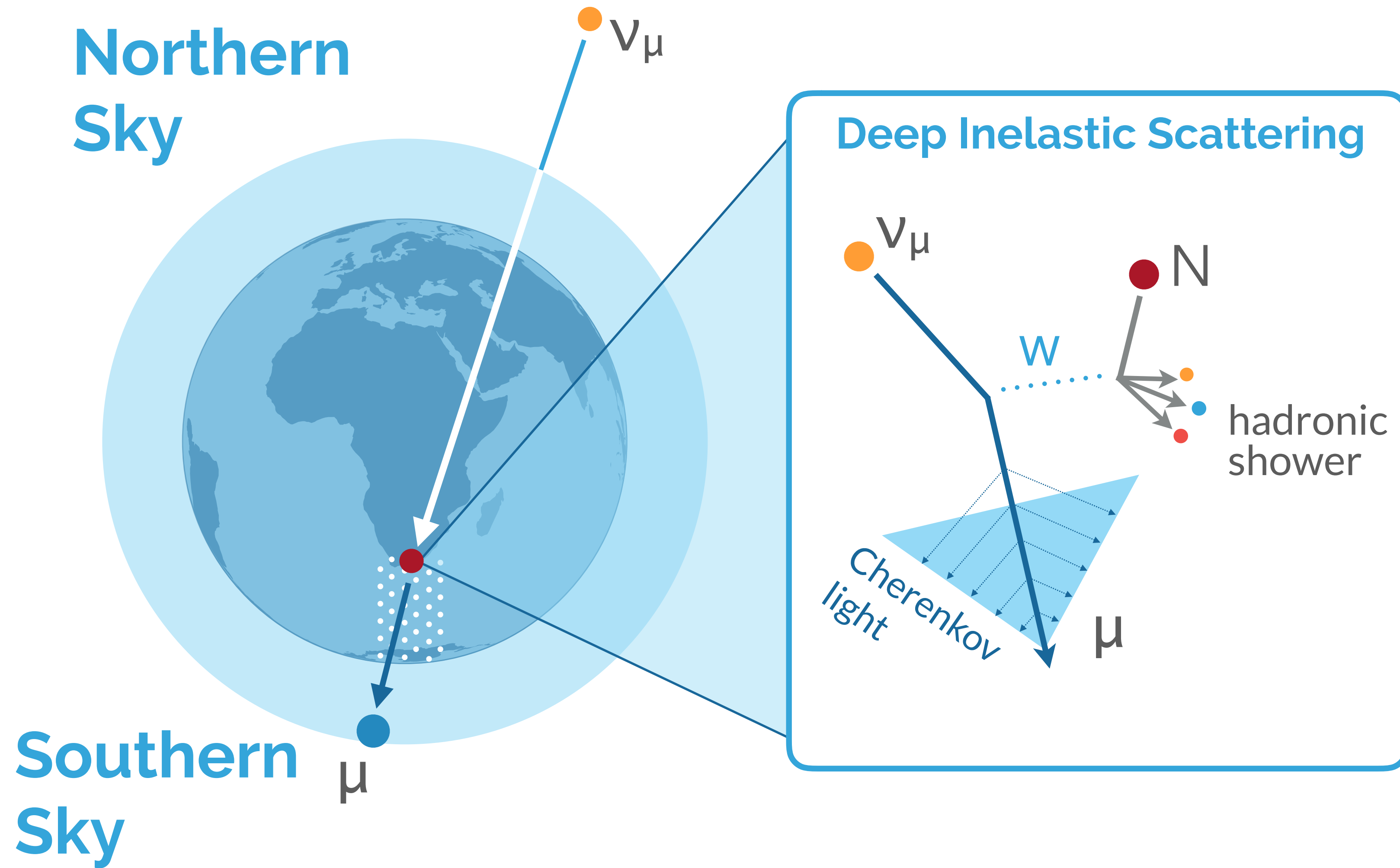
See Brian Humensky on Monday

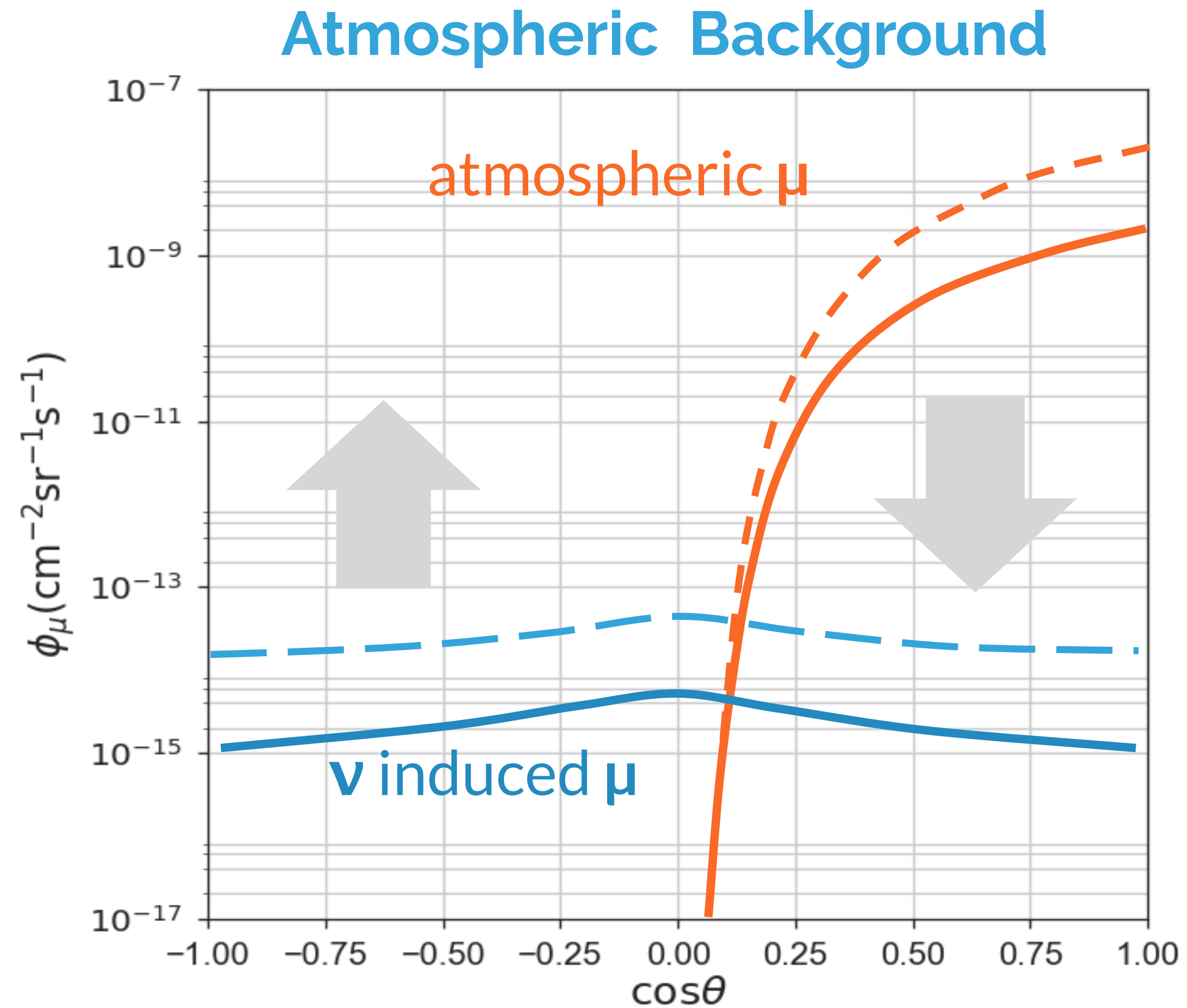
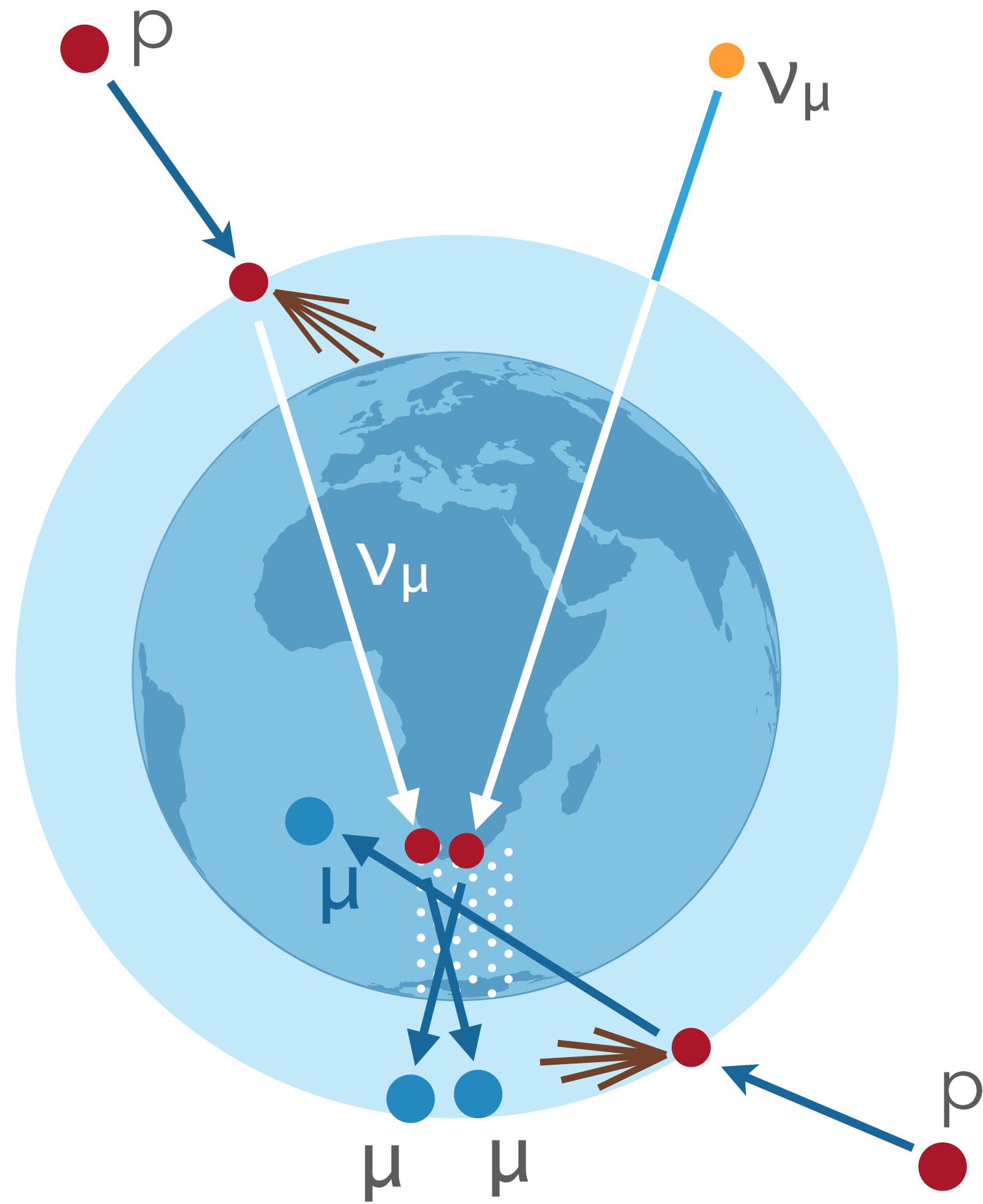






# Detection Principle

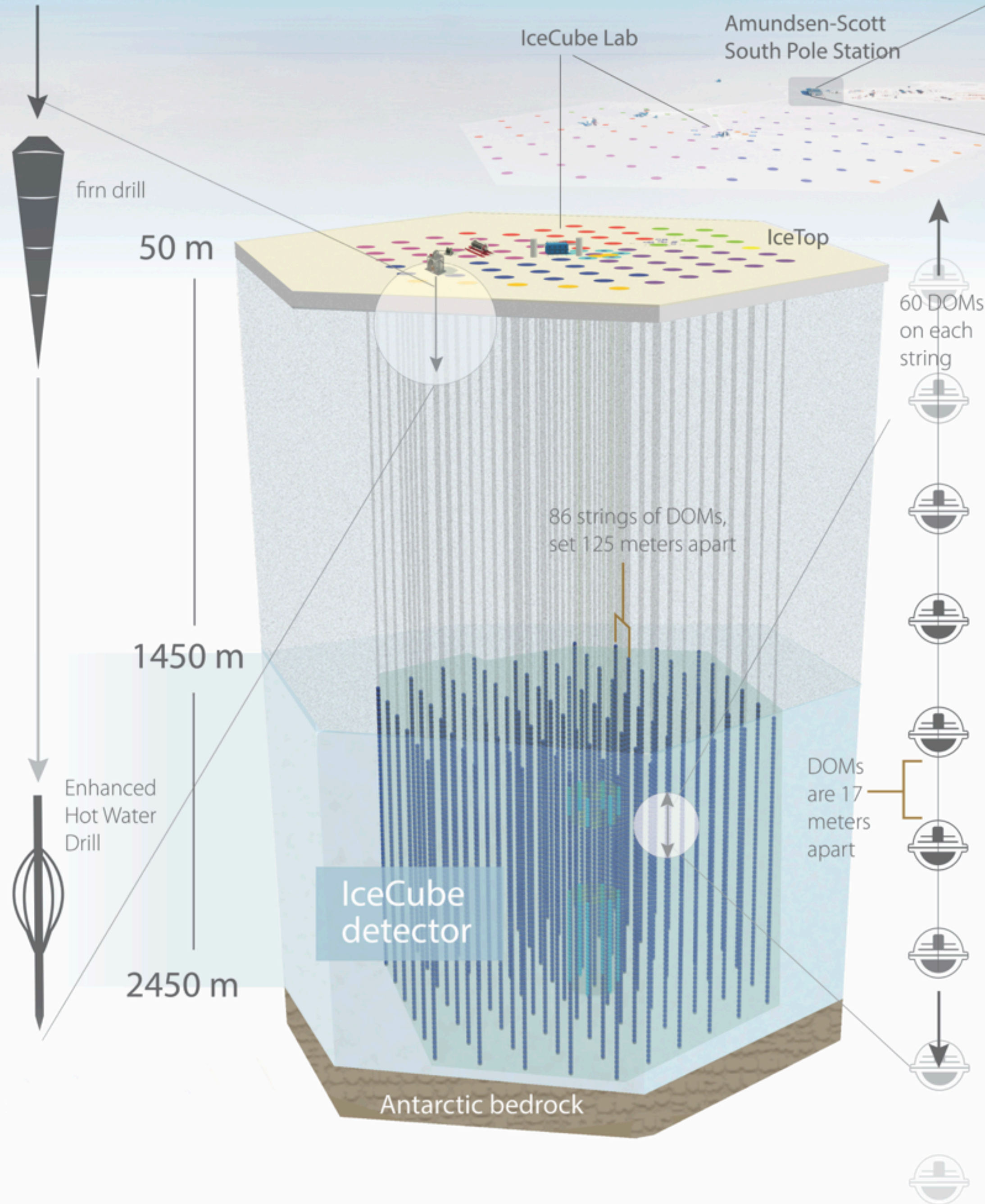




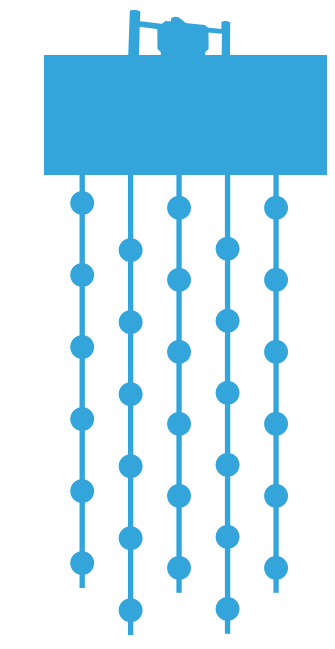
3kHz

2mHz

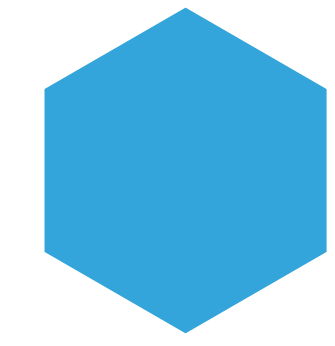
# IceCube Neutrino Observatory



5,160 Digital Optical Modules (DOMs)



86 string with 60 DOMs each. 6 denser strings called **DeepCore**



1 km<sup>2</sup> surface array with 324 DOMs: **IceTop**



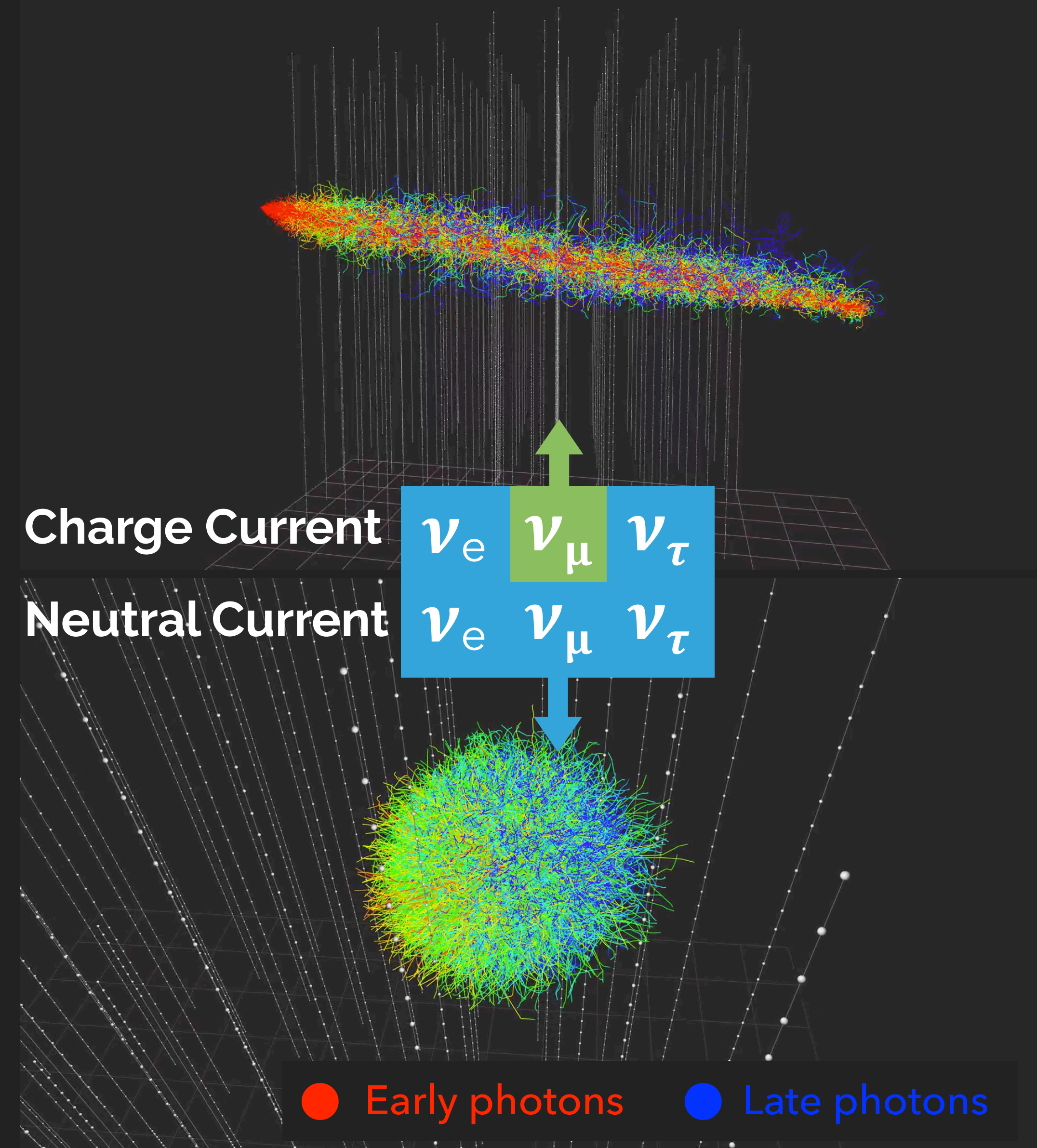
Completion with in **December 2010**

## Track topology

- Good angular resolution  $0.1^\circ - 1^\circ \rightarrow$   
**Neutrino Astronomy**
- Vertex can be outside the detector  $\rightarrow$   
**Increased effective volume**

## Cascade topology

- All flavors
- Fully active calorimeter  $\rightarrow$   
**Energy resolution  $\pm 15\%$**
- Angular reconstruction possible  $\rightarrow$   
 **$\sim 10^\circ @ E > 100 \text{ TeV}$**



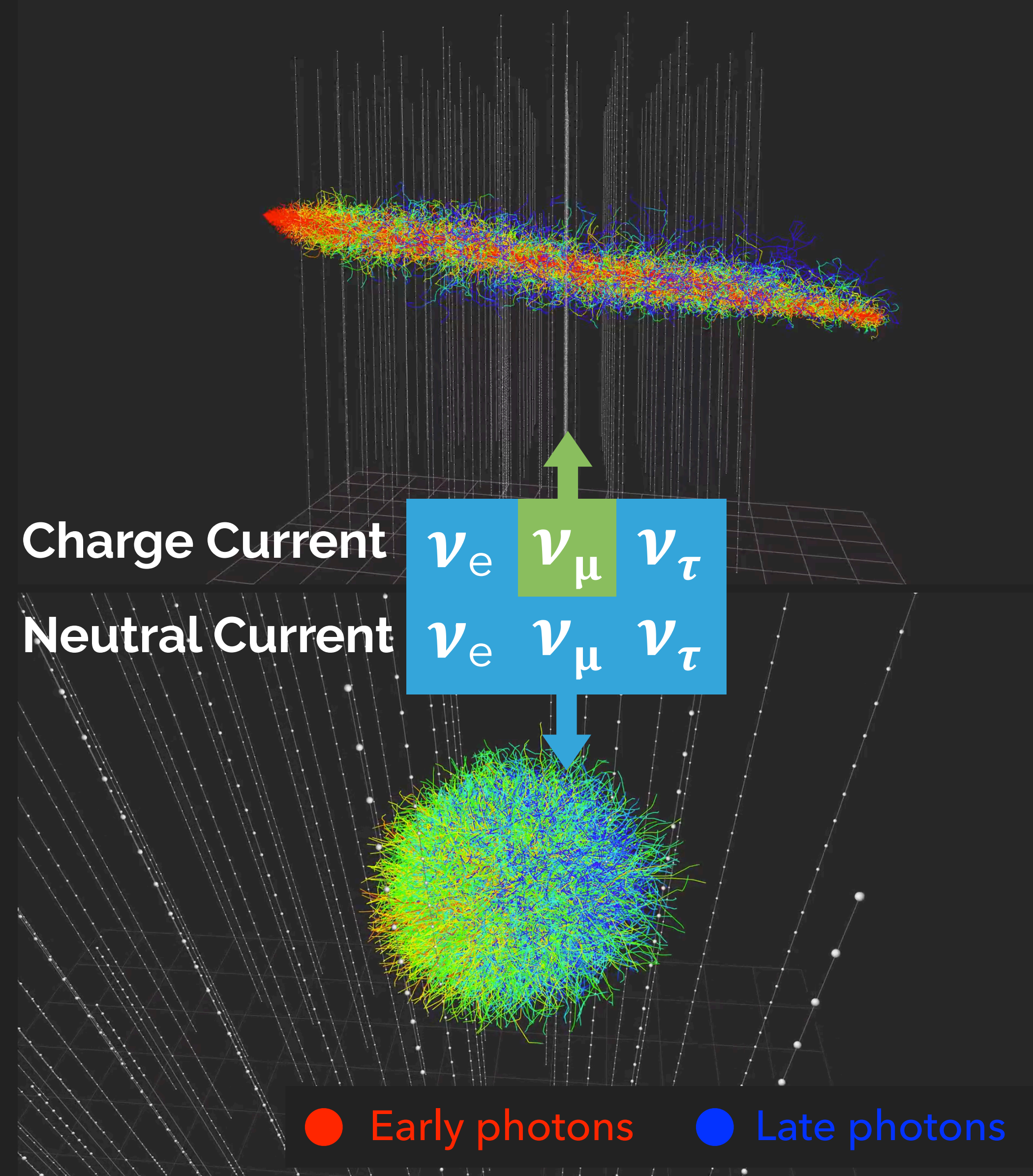


## Track topology

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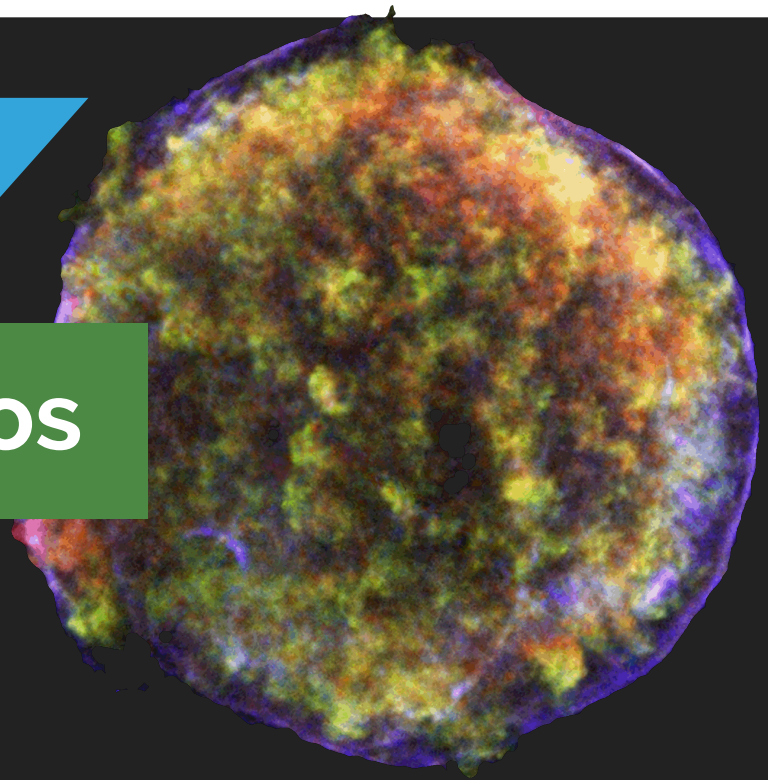
- All flavors
- Fully active calorimeter  $\rightarrow$   
**Energy resolution  $\pm 15\%$**
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 **$\sim 10^\circ @ E > 100 \text{ TeV}$**



# Neutrino Detectors **Scientific Scope**

And Cosmic Rays

SN Neutrinos



Astrophysical



MeV

GeV-TeV

<100 TeV

>100TeV

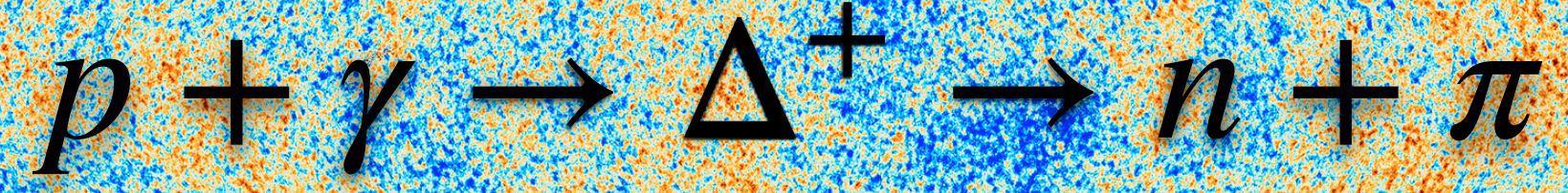
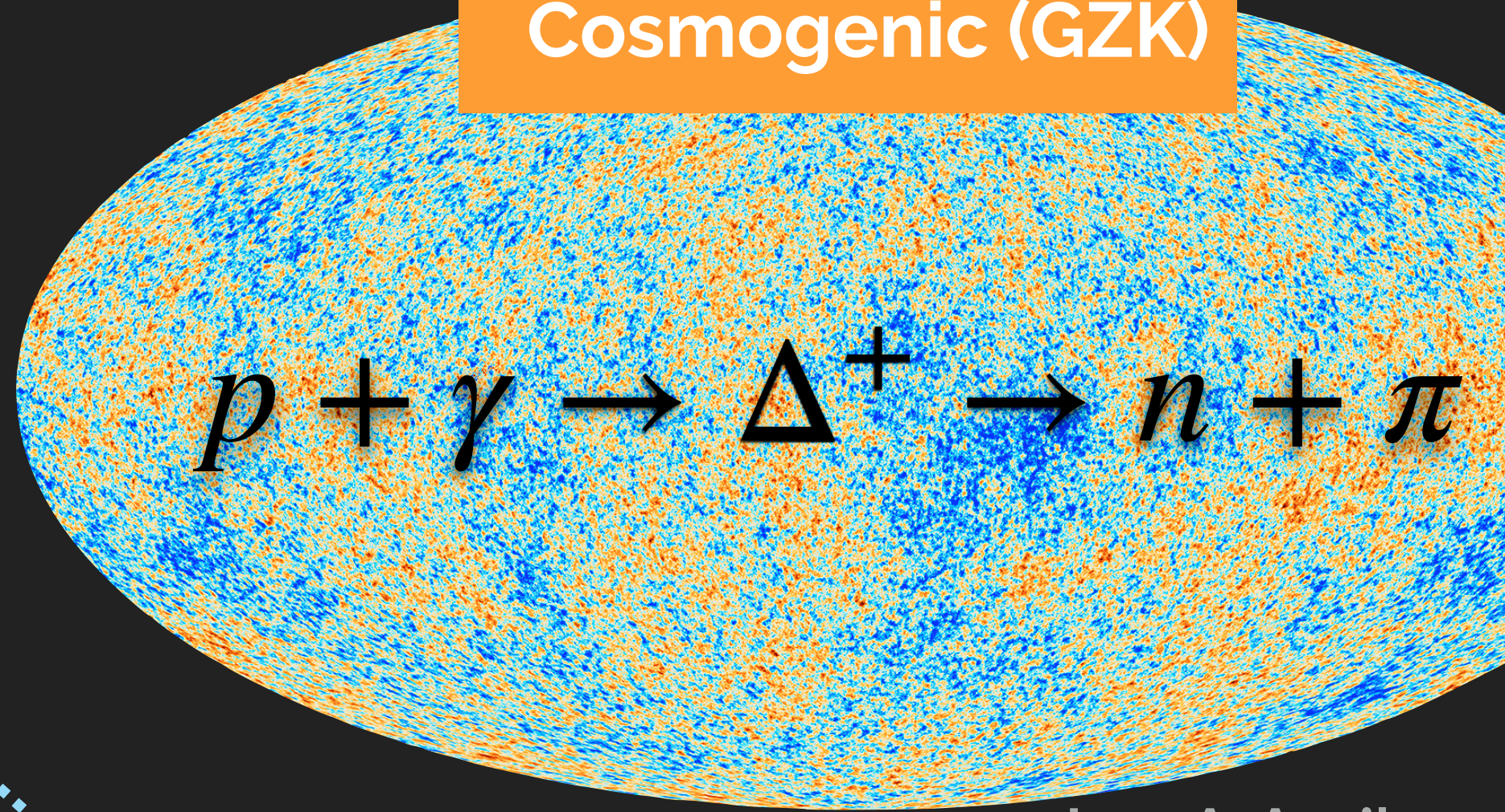
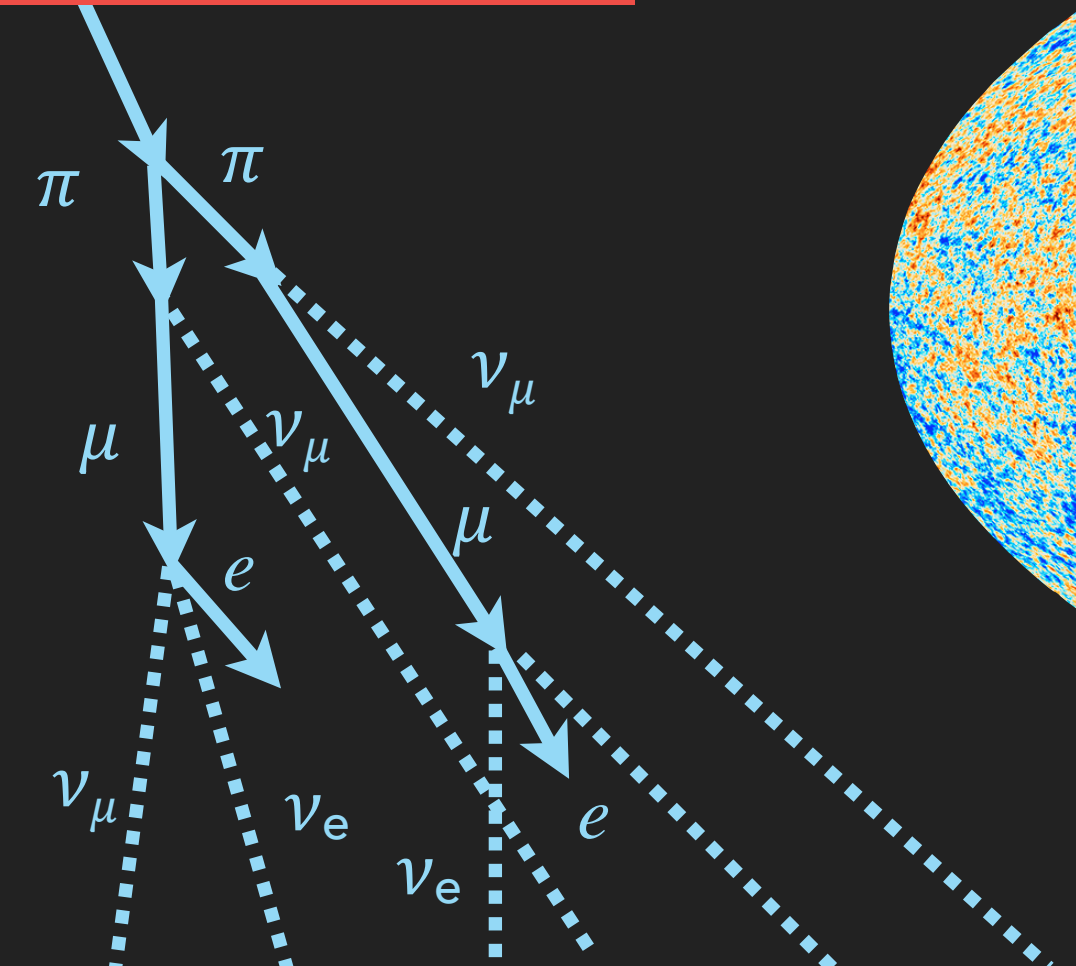
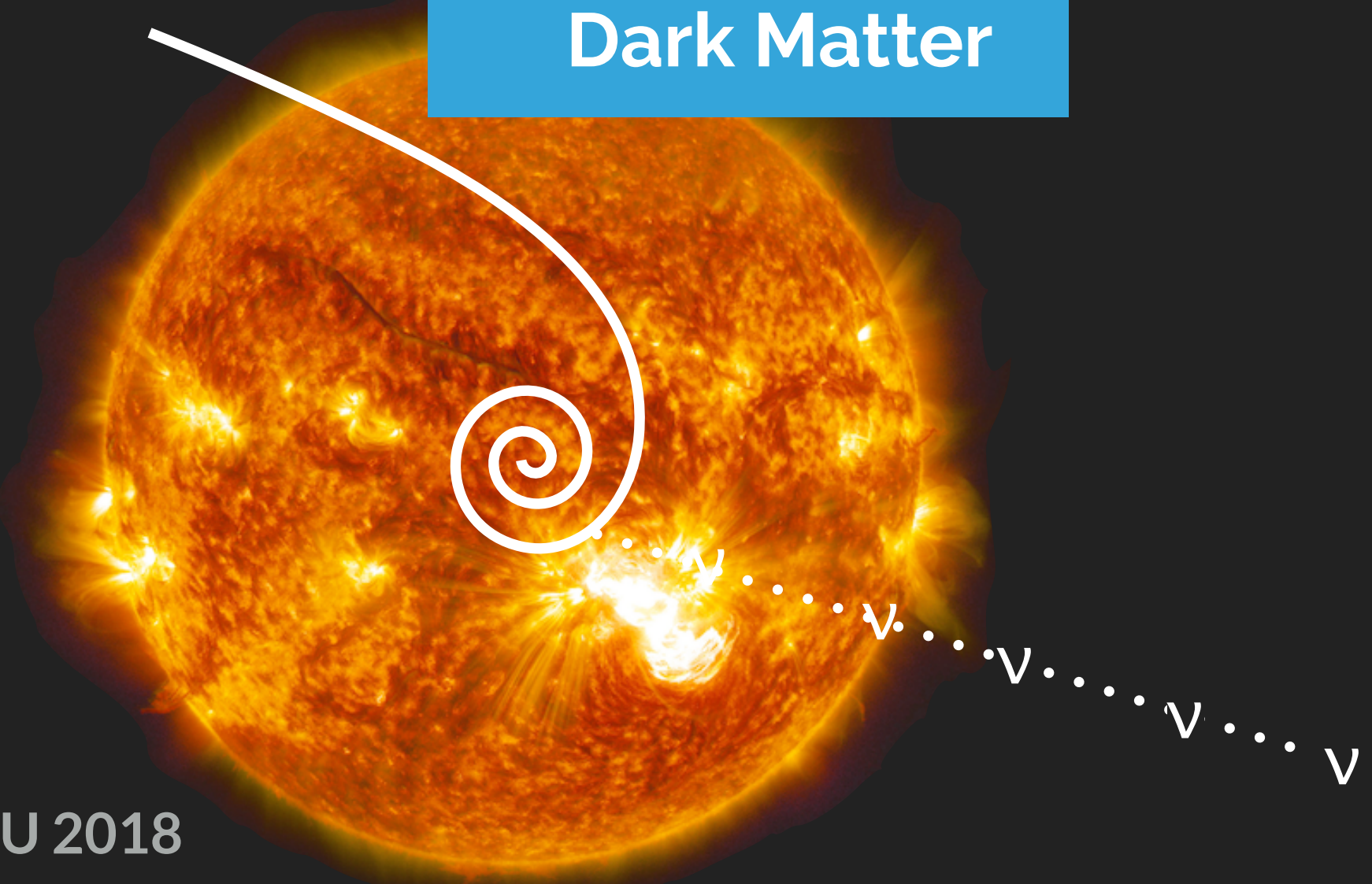
> 10<sup>6</sup> TeV

$\chi$

Dark Matter

Atmos: Oscillations, sterile  $\nu$ , Prompt

Cosmogenic (GZK)



# Neutrino Detectors **Scientific Scope**

And Cosmic Rays

SN Neutrinos

Astrophysical

MeV

GeV-TeV

<100 TeV

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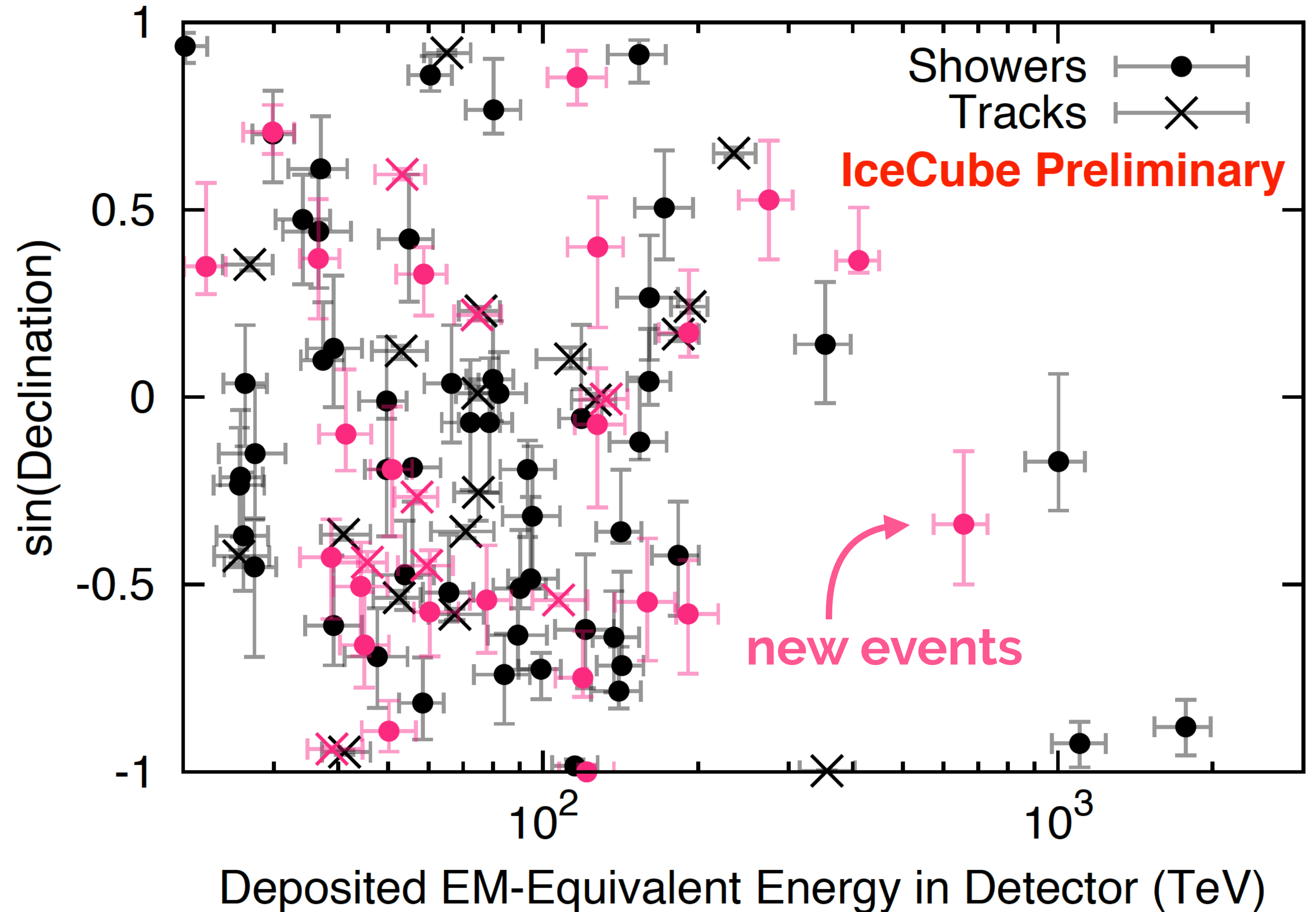
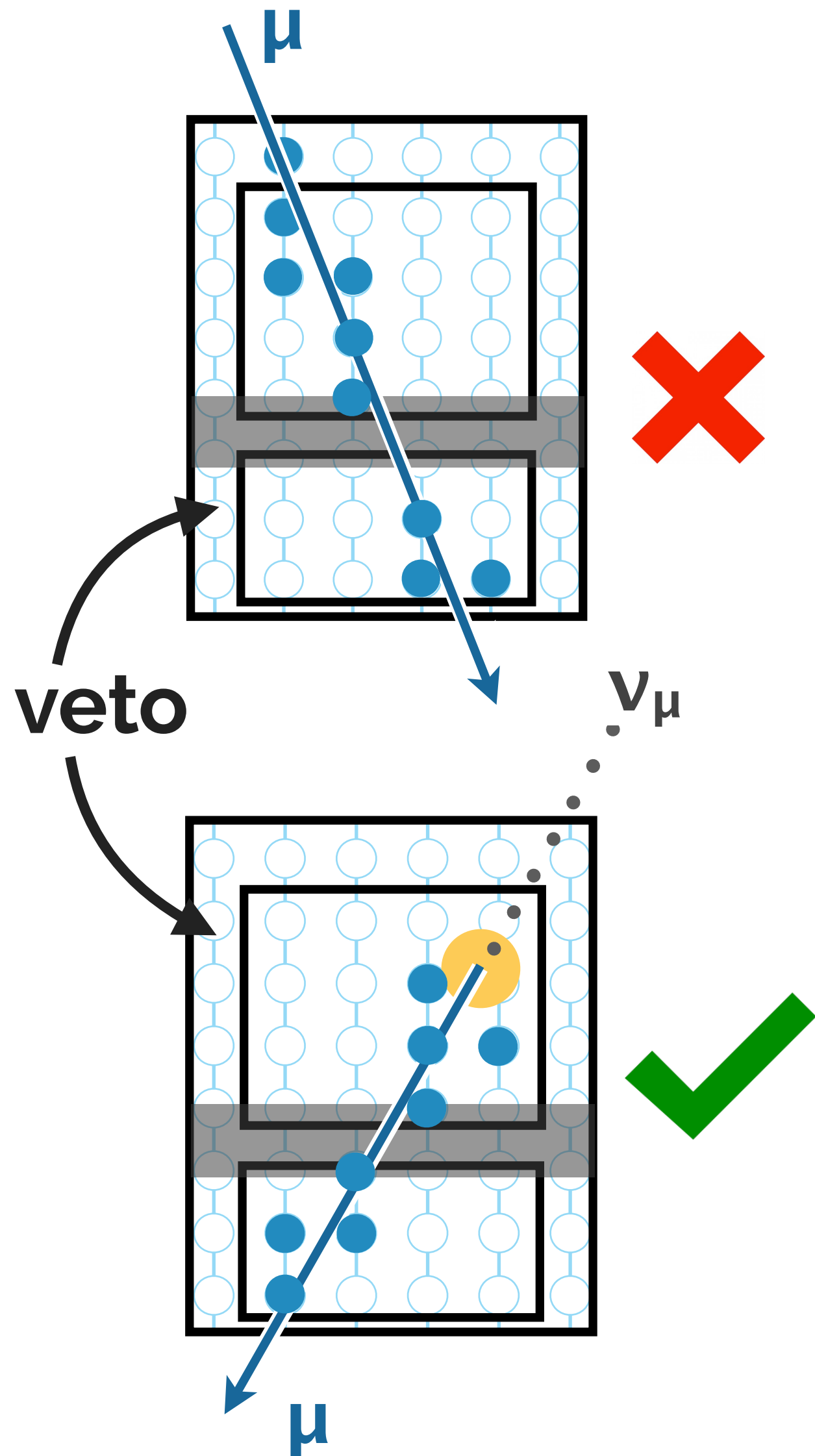
> 10<sup>6</sup> TeV

Dark Matter

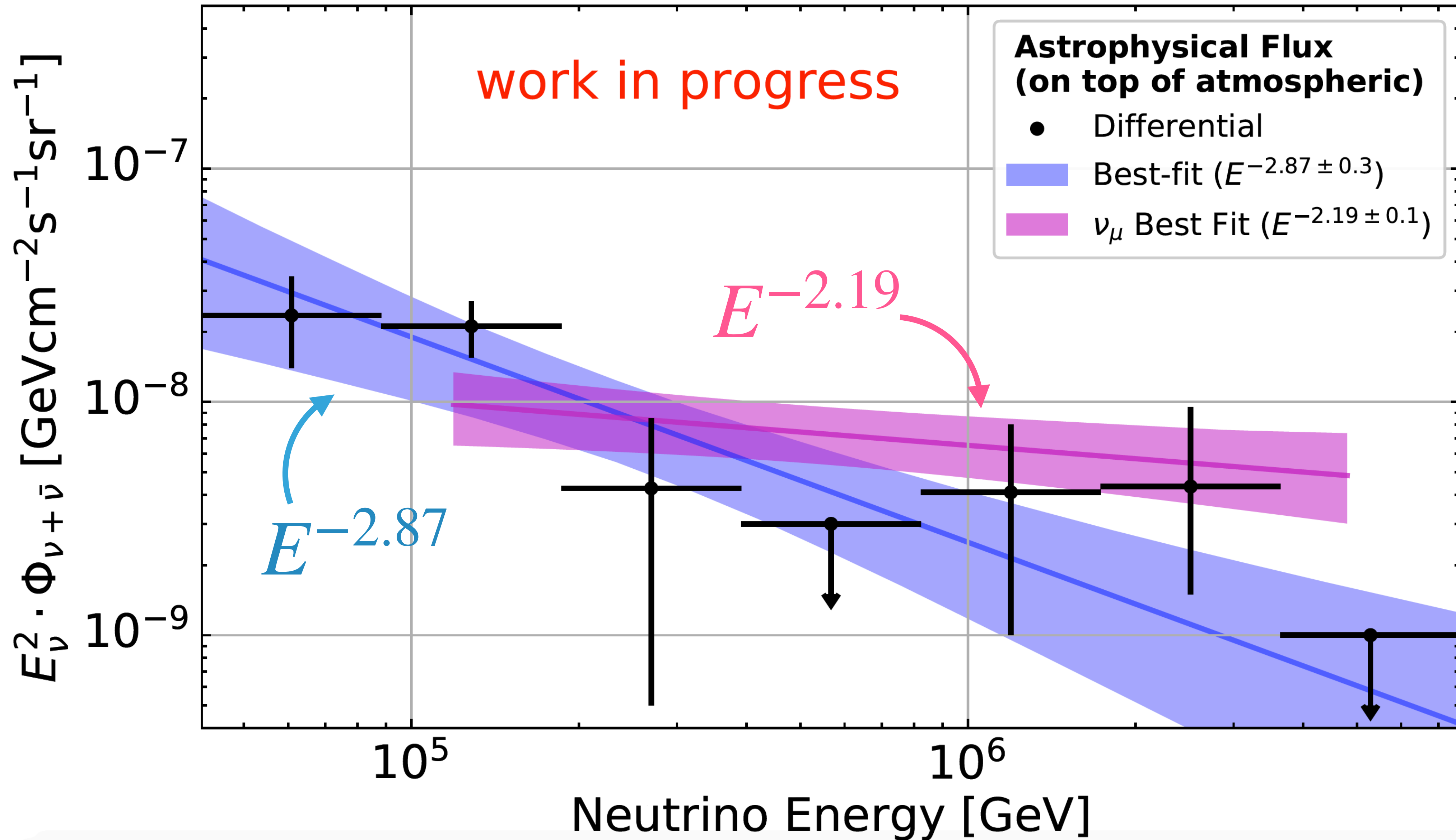
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Wandkowsky et al. (IceCube) Neutrino 2018

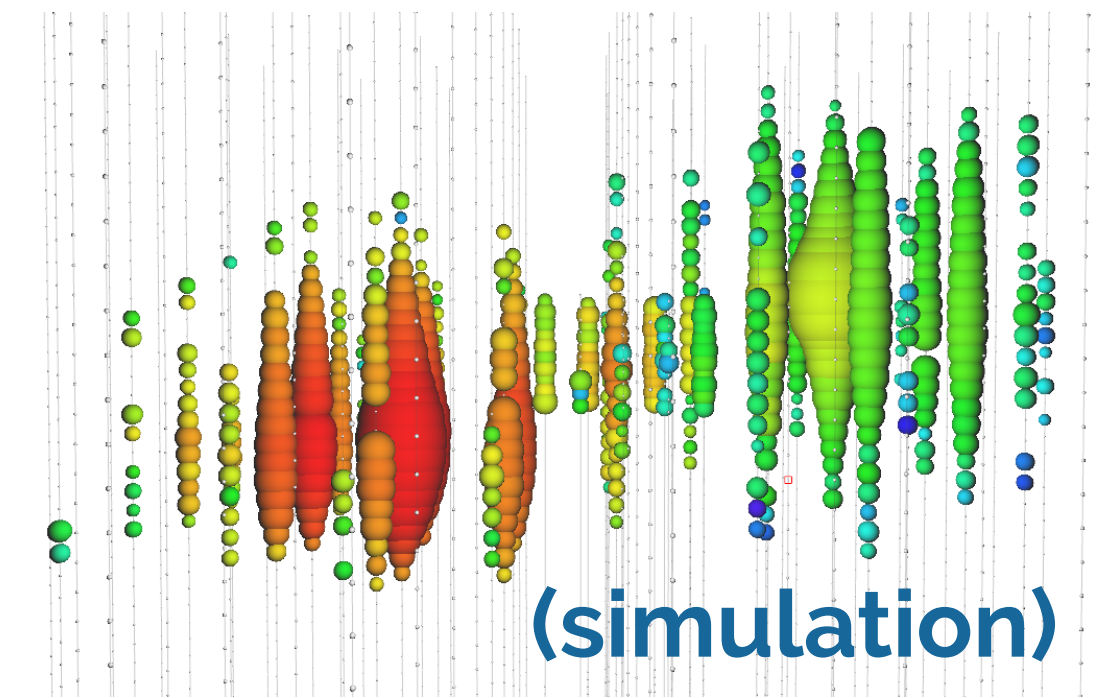
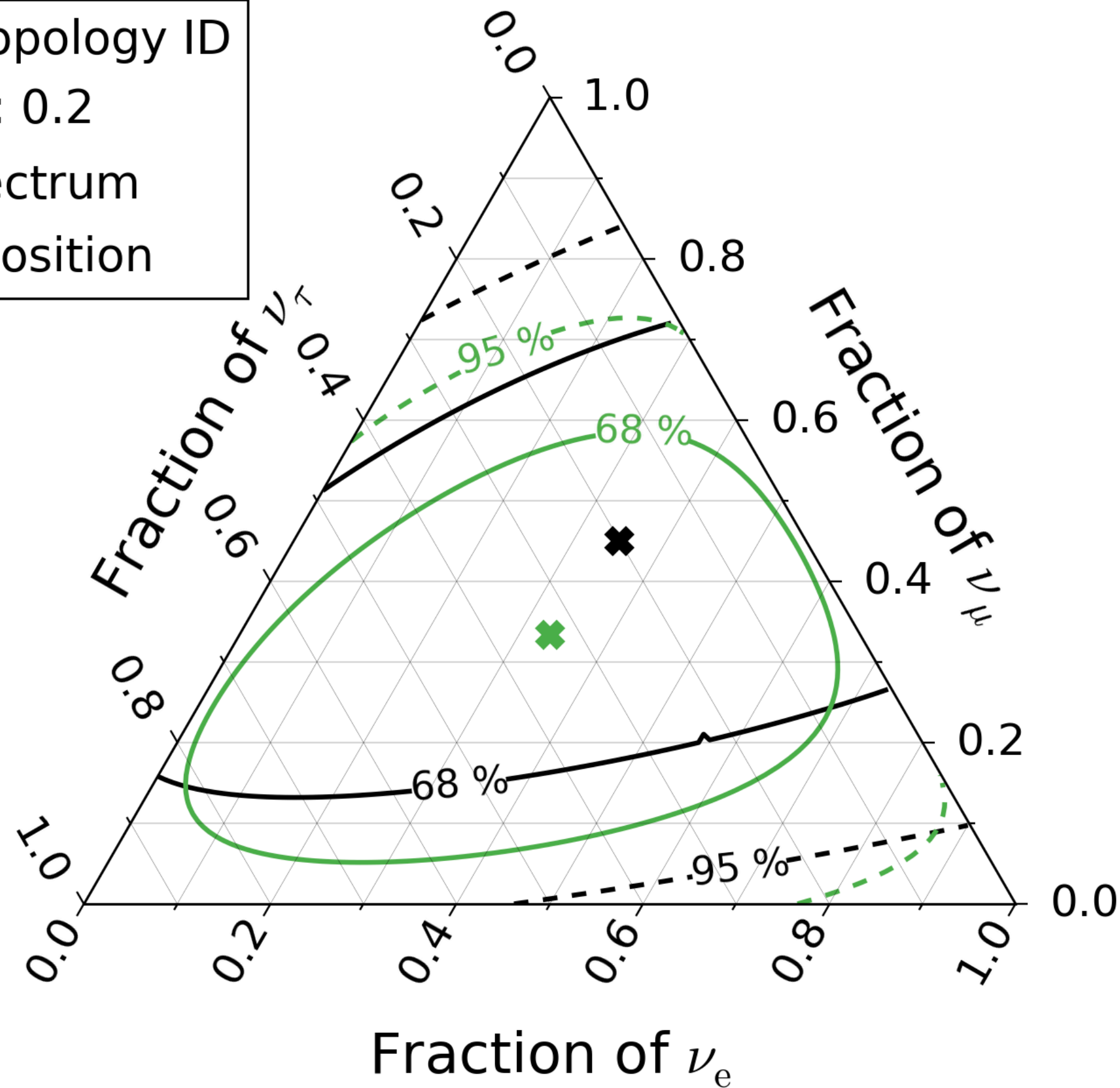


Wandkowsky et al. (IceCube) Neutrino 2018

Source (1:2:0)  $\nu_e$   $\nu_\mu$   $\nu_\tau$  Earth (1:1:1)

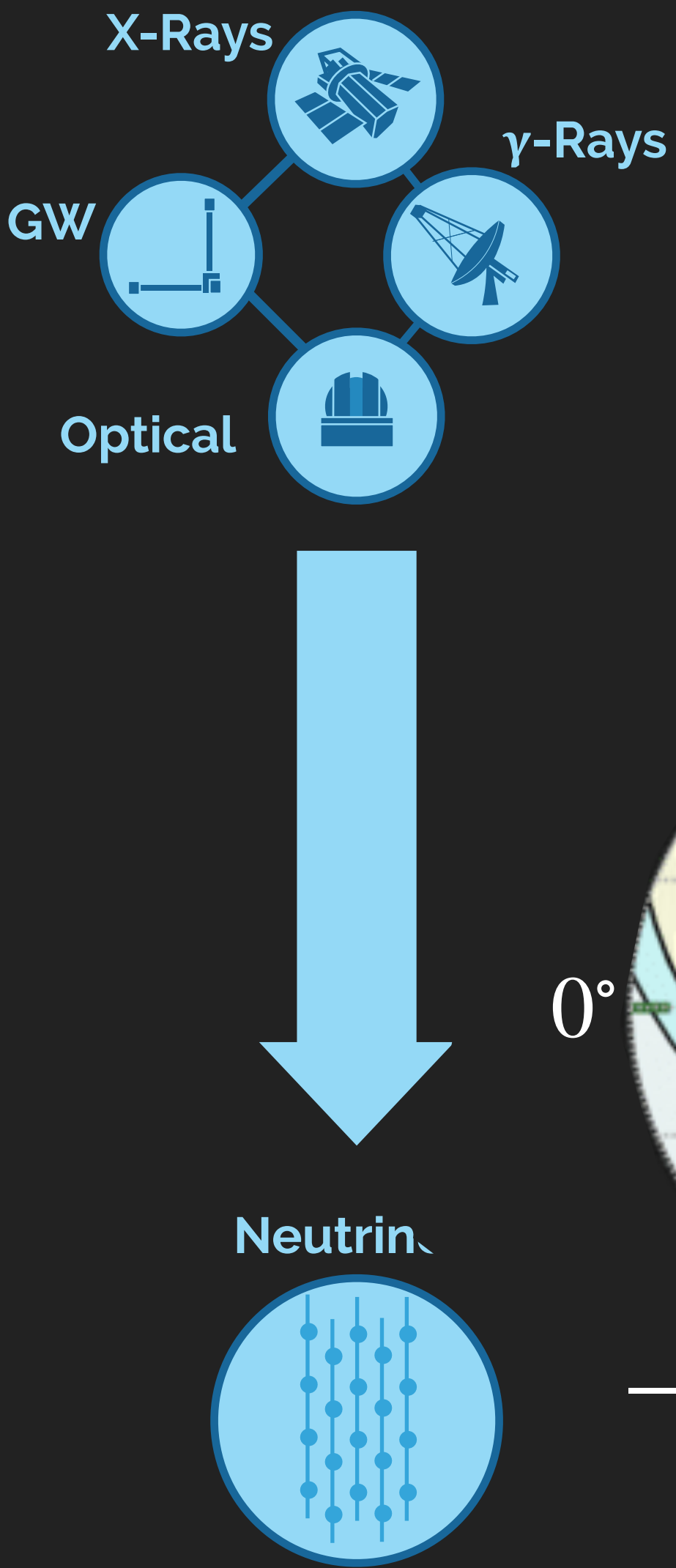
— HESE with ternary topology ID  
 ✱ best fit: 0.35 : 0.45 : 0.2  
 — Sensitivity,  $E^{-2.9}$  spectrum  
 ✱ 1 : 1 : 1 flavor composition

**WORK IN PROGRESS**

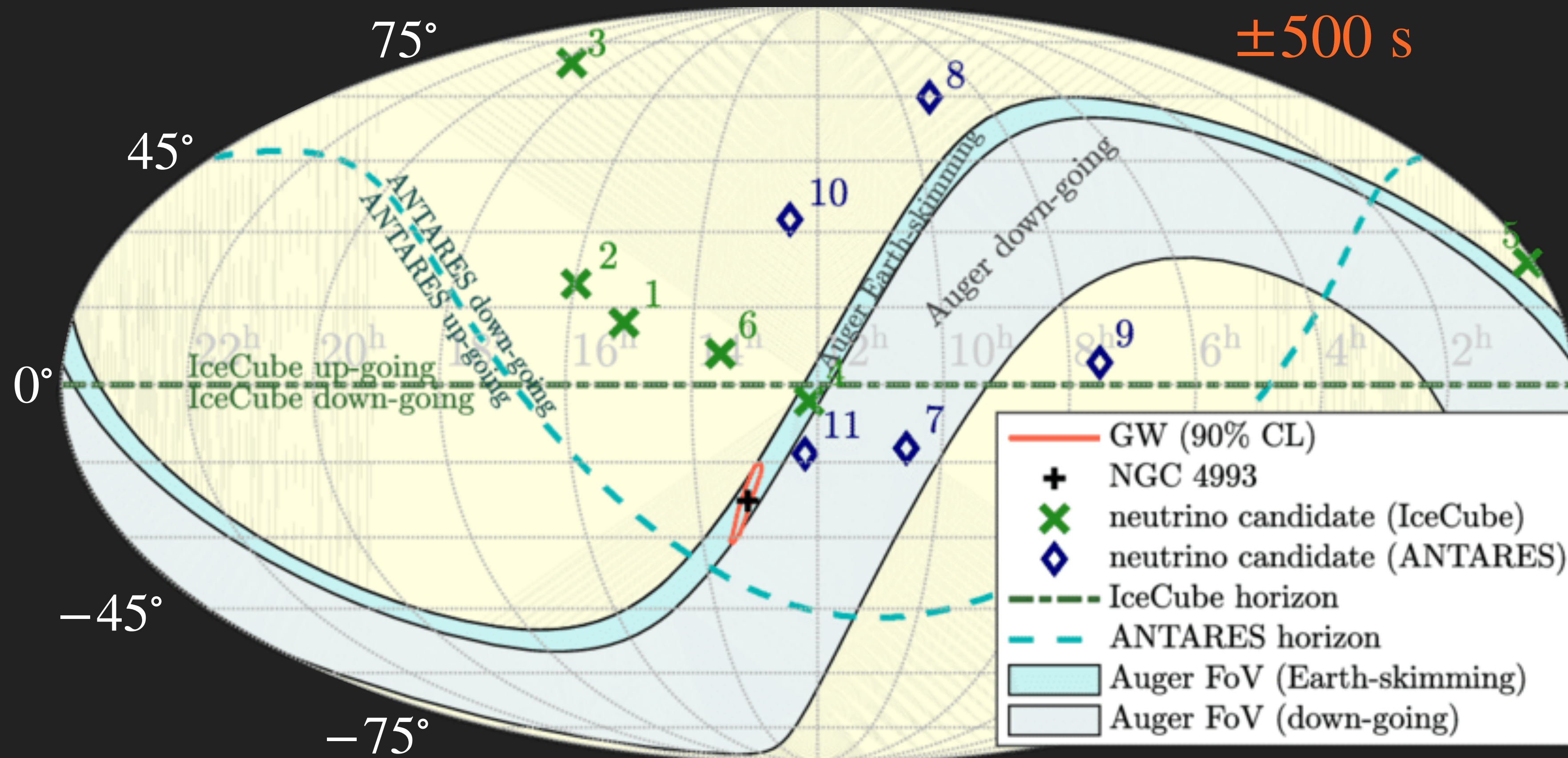


- **Two tau candidates** events found (expected  $\sim 2.1$ )
- One is an unambiguous double-cascade
- Best fit composition **(1.05:1.35:0.6)**

Stachurska et al. (IceCube) Neutrino 2018

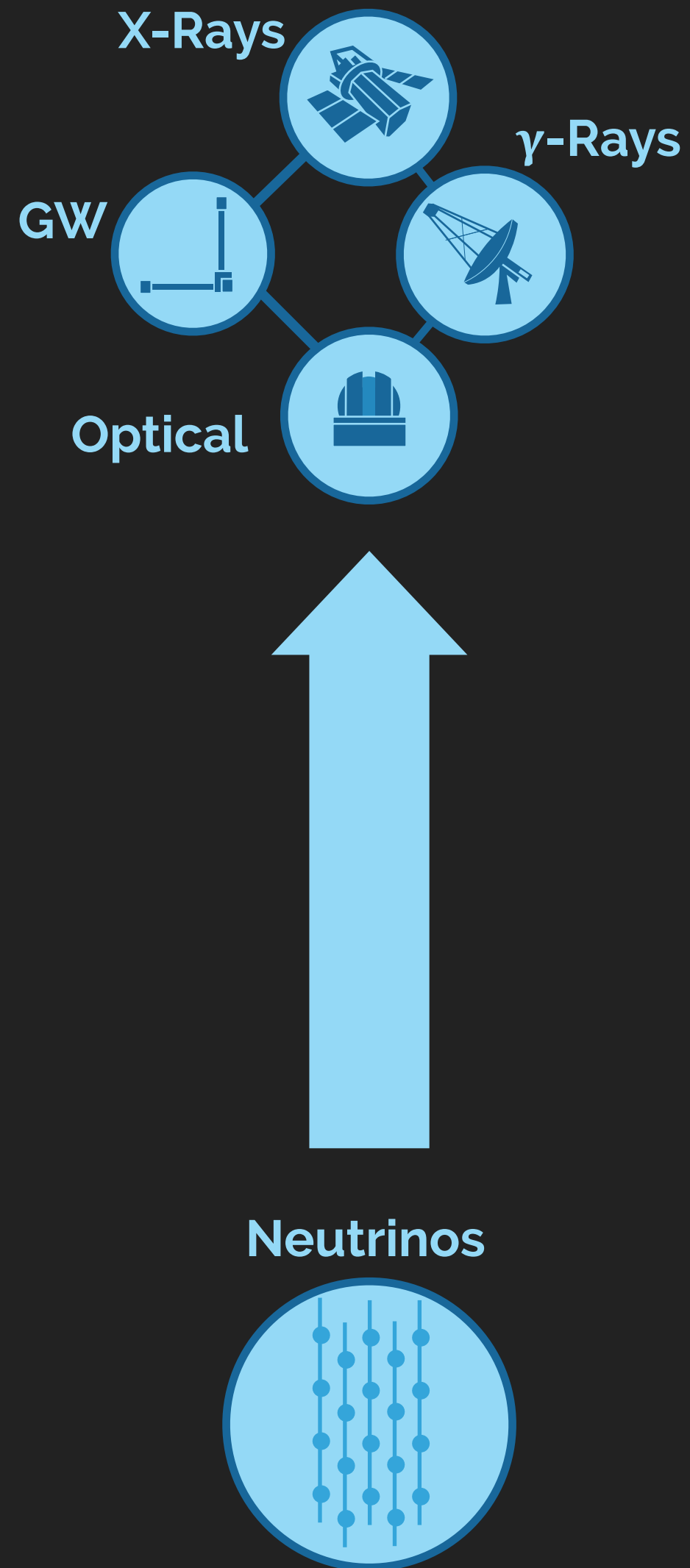


- On August 17 2017 at 12:41:04 UTC the signal from a **binary neutron star** was detected by LIGO & Virgo
- Short GRB detection 2 seconds after by Fermi



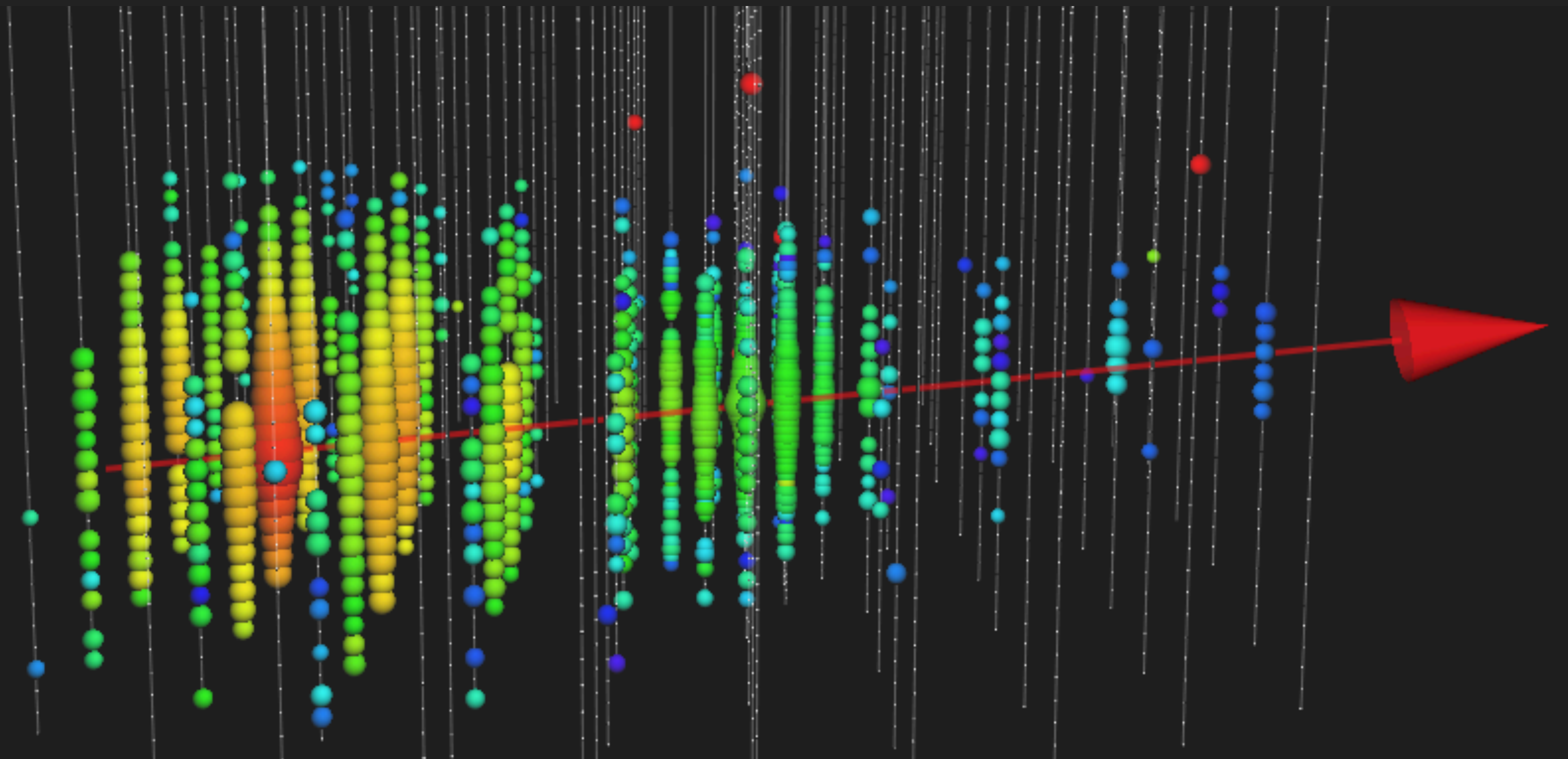
A vertical stack of three logos on the right side of the slide. From top to bottom: the IceCube logo (a circular image of the detector array), the ANTARES logo (a circular image of the detector array), and the Pierre Auger Observatory logo (a rectangular image of the detector array).

ANTARES, IceCube, Auger arXiv:1710.05839

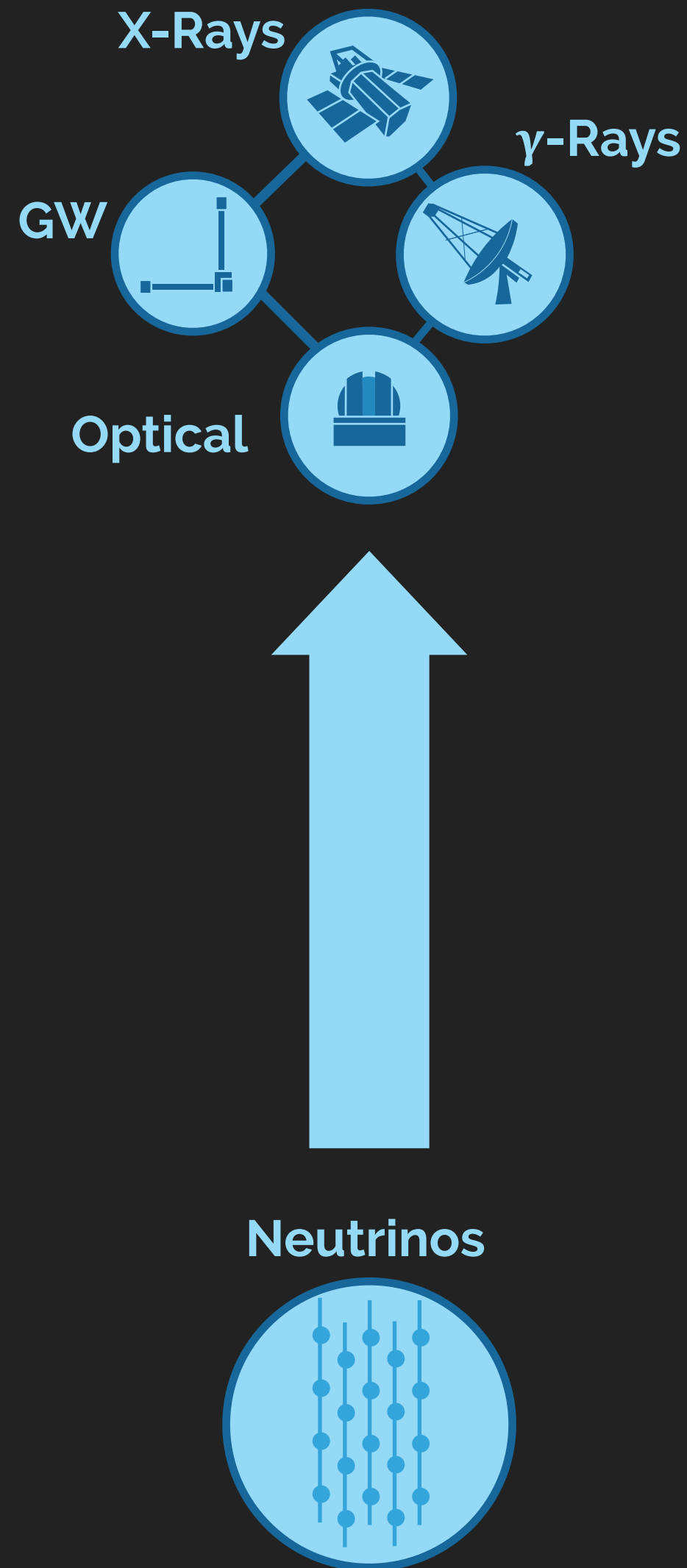


- An alert system based on HESE track-like events and Extreme High Energy events
- Operating since **April 2016**.
- **6-8 alerts** per year
- Below the first event alert sent **IC160427A**

*Astropart. Phys. 92 (2017) 30*







- Sep 22 2017: An alert on was sent corresponding to the event **IC170922A**
- 28 Sep 2017: Four days later Fermi-LAT reported a flaring blazar **TXS 0506+056** inside the error region.
- 4 Oct 2017: Magic detected **VHE gamma-rays** from the same location

**Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.**

ATel #10791; **Yasuyuki T. Tanaka (Hiroshima University), Sara Buson (NASA/GSFC), Daniel Kocevski (NASA/MSFC) on behalf of the Fermi-LAT Collaboration**  
on 28 Sep 2017; 10:10 UT

Credential Certification: David J. Thompson (David.J.Thompson@nasa.gov)

Subjects: Gamma Ray, Neutrinos, AGN

Referred to by ATel #: 10792, 10794, 10799, 10801, 10817, 10830, 10844, 10845, 10861, 10890, 10942, 11419, 11430, 11489

We searched for Fermi-LAT sources inside the extremely high-energy neutrino event error region (<https://gcn.gsfc.nasa.gov/gcn3/21916.html>) with all-sky survey data from the Large Area Telescope (LAT) on-board the Fermi Gamma Space Telescope. We found that one Fermi-LAT source, TXS 0506+056, was located inside the IceCube error region. The FAVA (Fermi All-sky Above 800 MeV) shows a significant excess of photons at energies above 800 MeV (<https://fermi.gsfc.nasa.gov/ssc/data/access/lat/FAVA/SourceReports.html>).

**First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A**

ATel #10817; **Razmik Mirzoyan for the MAGIC Collaboration**  
on 4 Oct 2017; 17:17 UT

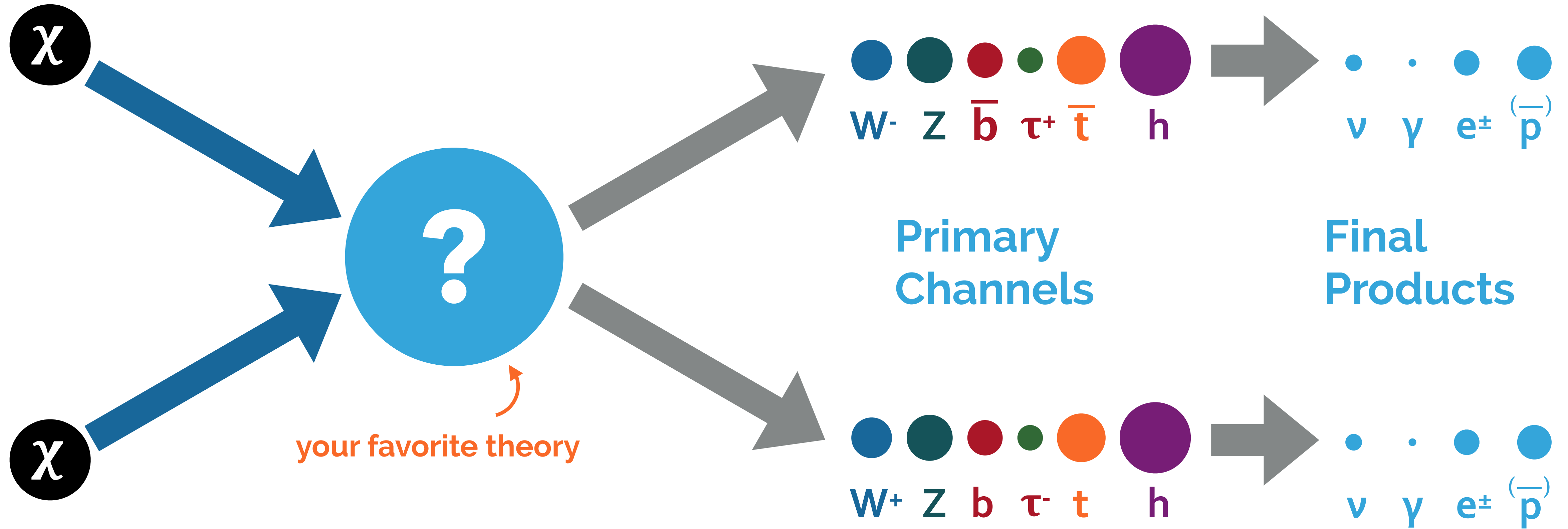
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Optical, Gamma Ray, >GeV, TeV, VHE, UHE, Neutrinos, AGN, Blazar

Referred to by ATel #: 10830, 10833, 10838, 10840, 10844, 10845, 10942

After the IceCube neutrino event EHE 170922A detected on 22/09/2017 (GCN circular #21916), Fermi-LAT measured enhanced gamma-ray emission from the blazar TXS 0506+056 (05 09 25.96370, +05 41 35.3279 (J2000), [Lani et al., Astron. J., 139, 1695-1712 (2010)]), located 6 arcmin from the EHE 170922A estimated direction (ATel #10791). MAGIC observed this source under good weather conditions and a 5 sigma detection above 100 GeV was achieved after 12 h of observations from September 28th till October 3rd. This is the first time that VHE gamma rays are measured from a direction consistent with a detected neutrino event. Several follow up observations

See Eric Charles on Tuesday



- No need of specialized detectors: **Gamma-ray telescopes, neutrino detectors, CR-experiments**
- Search for products of dark matter annihilation processes: **Focus on large reservoirs of dark matter**

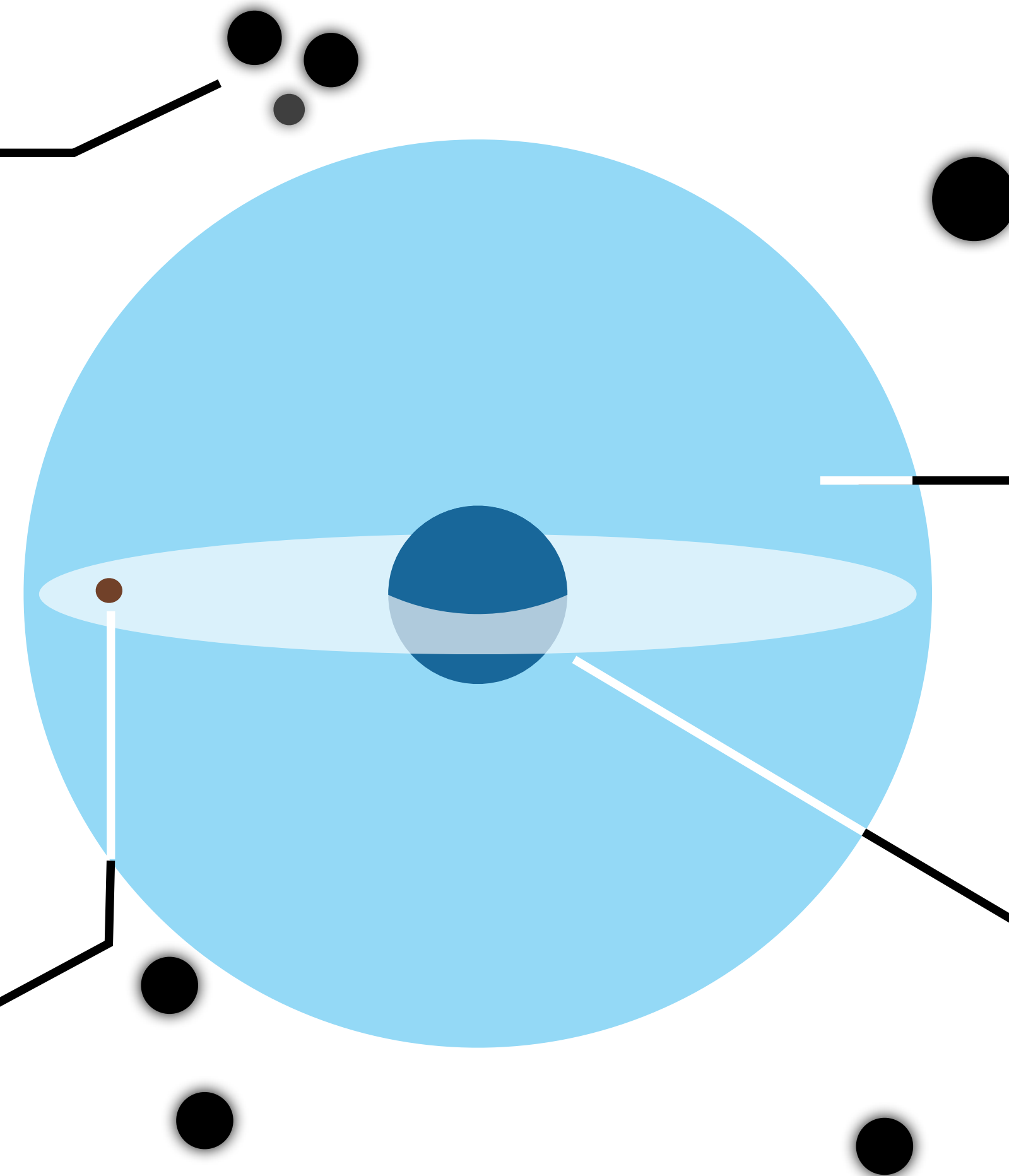
*See Aldo Morselli on Monday  
See Eric Charles on Tuesday*

**Dwarf spheroidal Galaxies  
Cluster of Galaxies**

Probe velocity-averaged DM  
annihilation cross section  $\langle v\sigma_A \rangle$

**Local Sources (Sun, Earth)**

Only accessible with neutrinos  
Under equilibrium they can  
probe  $\sigma_{SI}$  and  $\sigma_{SD}$



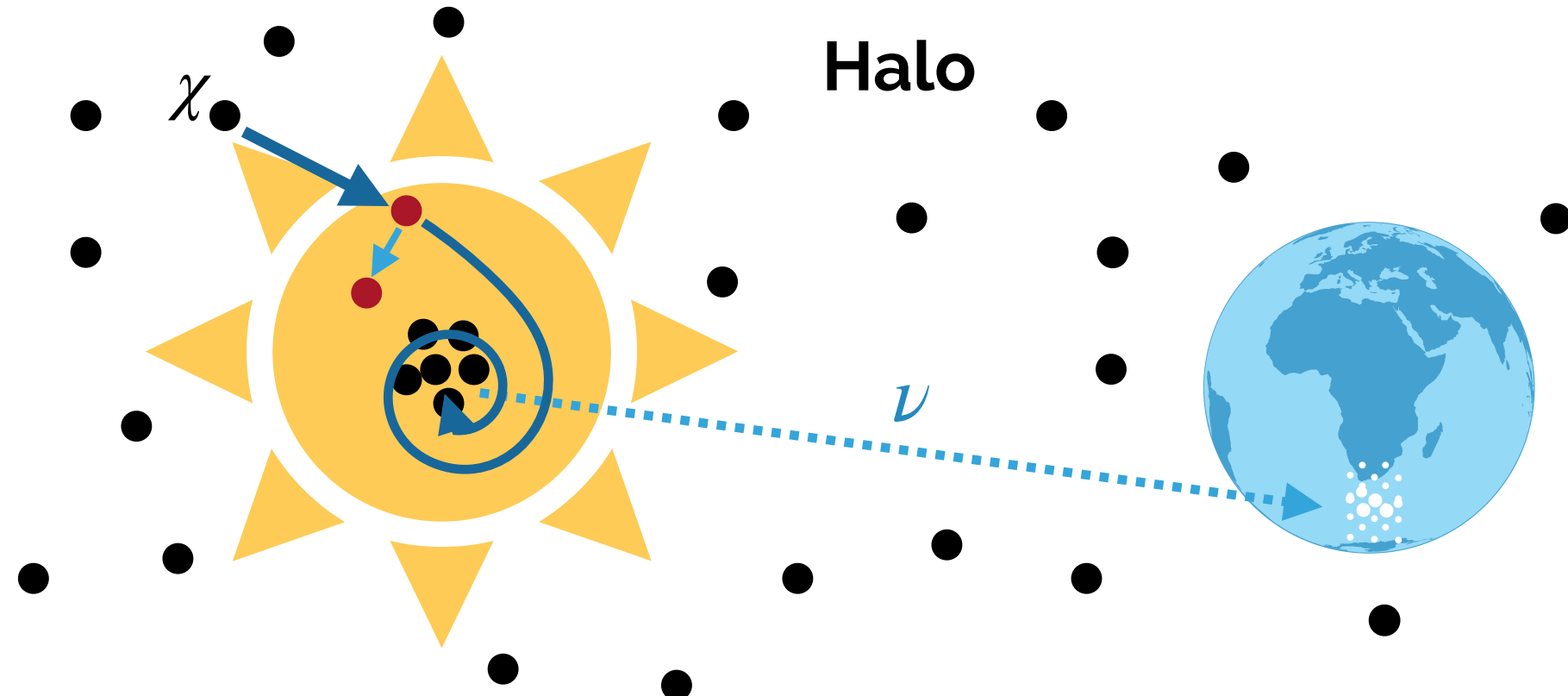
**Galactic Halo**

Probe velocity-averaged DM  
annihilation cross section  $\langle v\sigma_A \rangle$

**Galactic Center**

Probe velocity-averaged DM  
annihilation cross section  $\langle v\sigma_A \rangle$

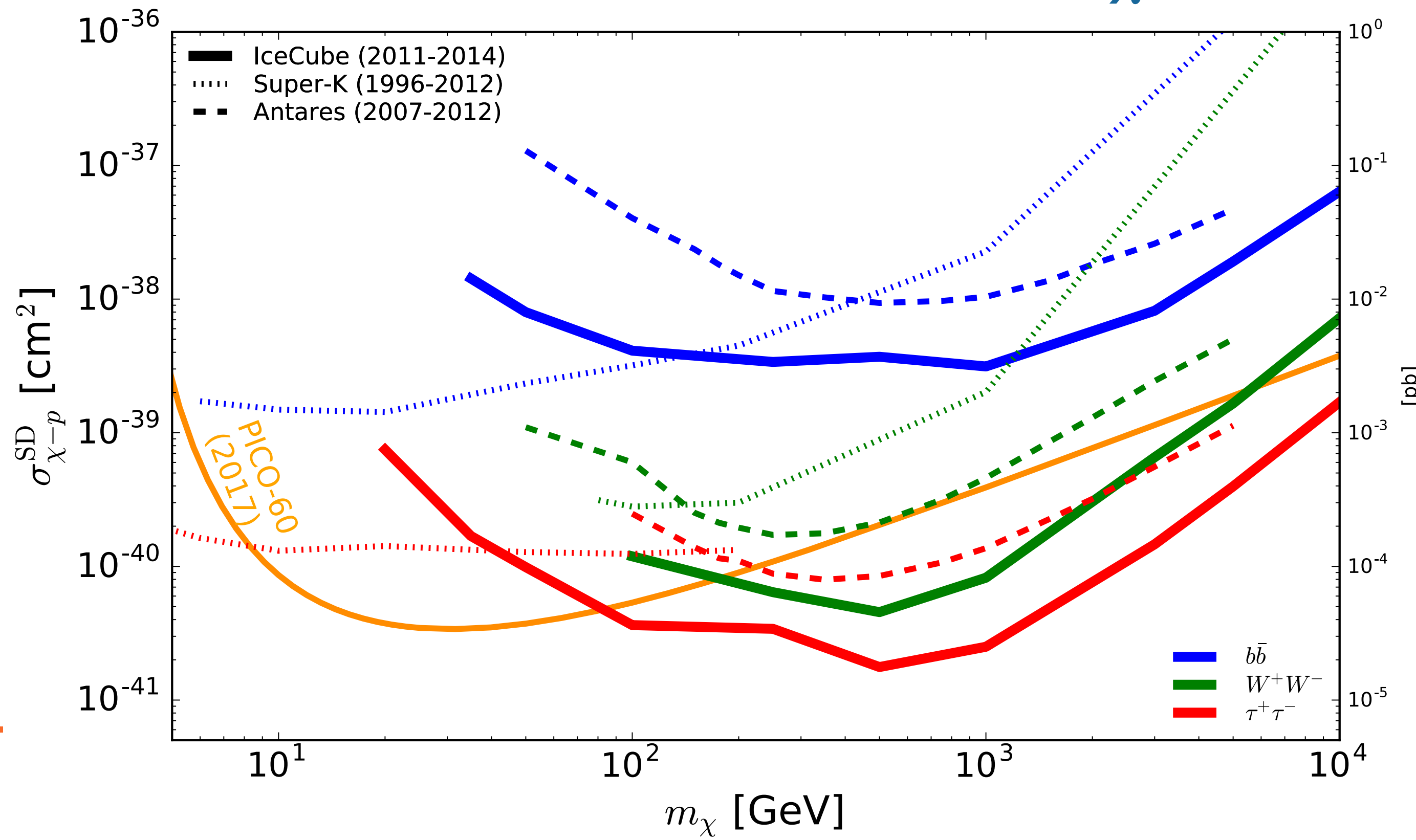
See Aaron Vincent on Monday



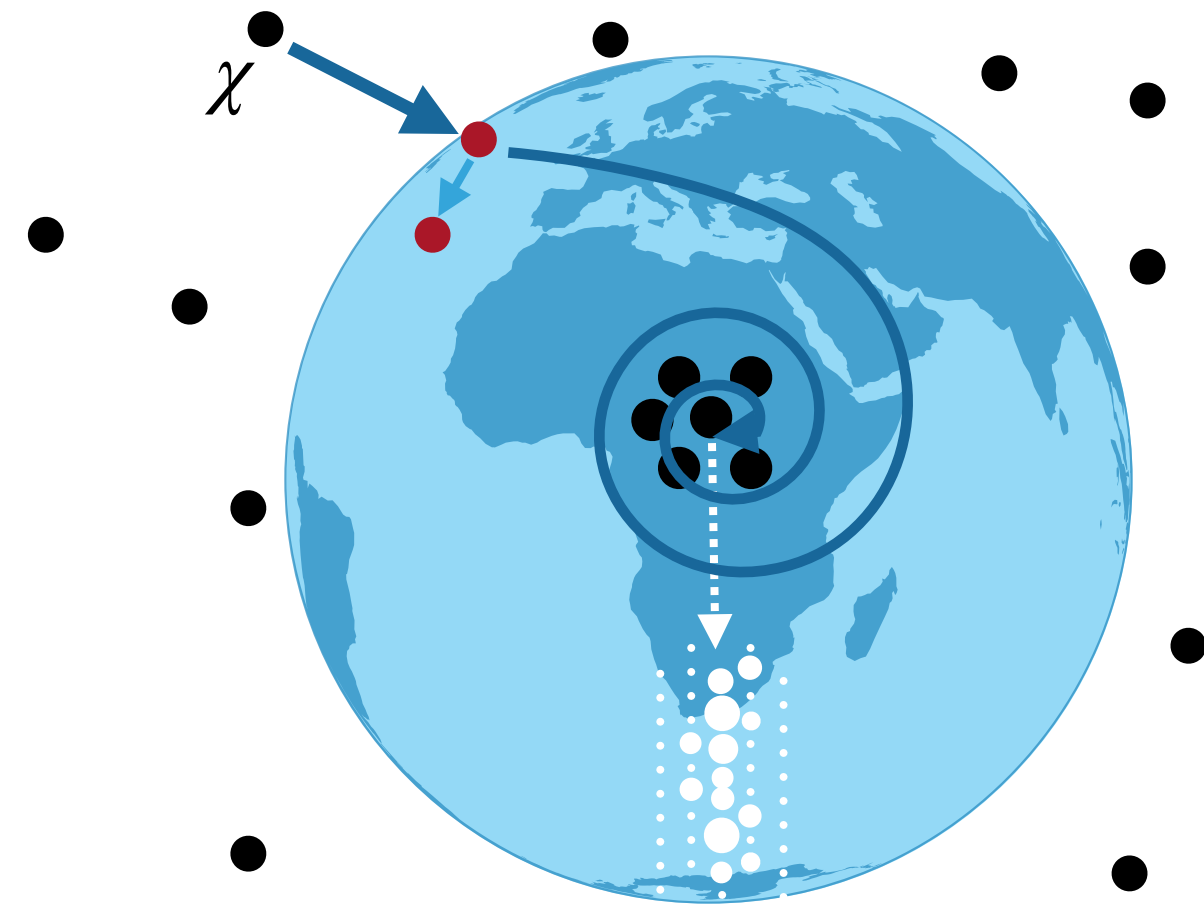
**equilibrium!**

$$\Phi_\nu \rightarrow \Gamma_A \rightarrow C_c \rightarrow \sigma_{\chi N}$$

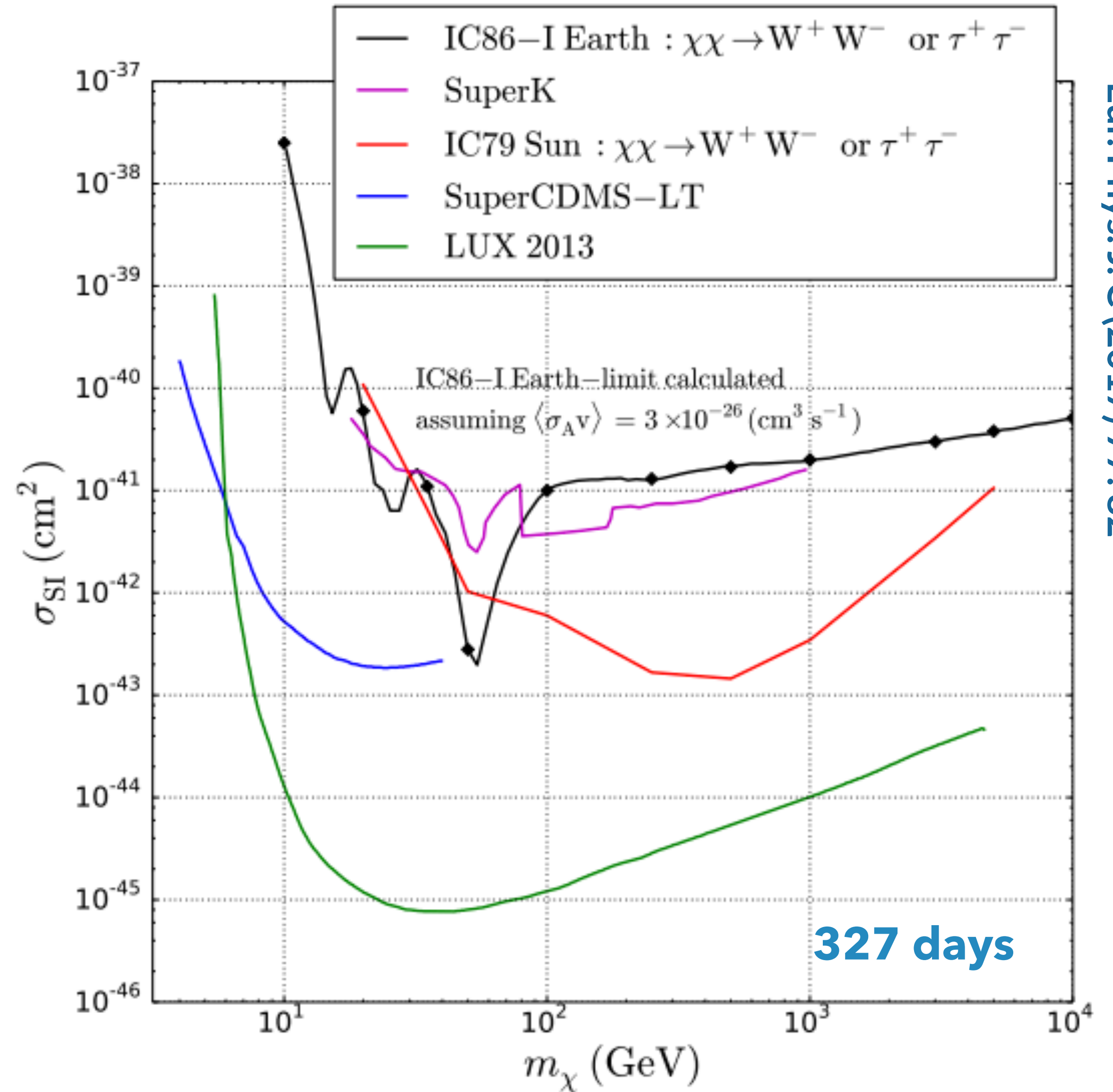
- Only events when Sun is below the horizon: **532 days of livetime**
- The mean free path of TeV neutrinos smaller than the Sun radius: **Low energy analysis**
- Limit driven by capture on H: **SD cross-section**



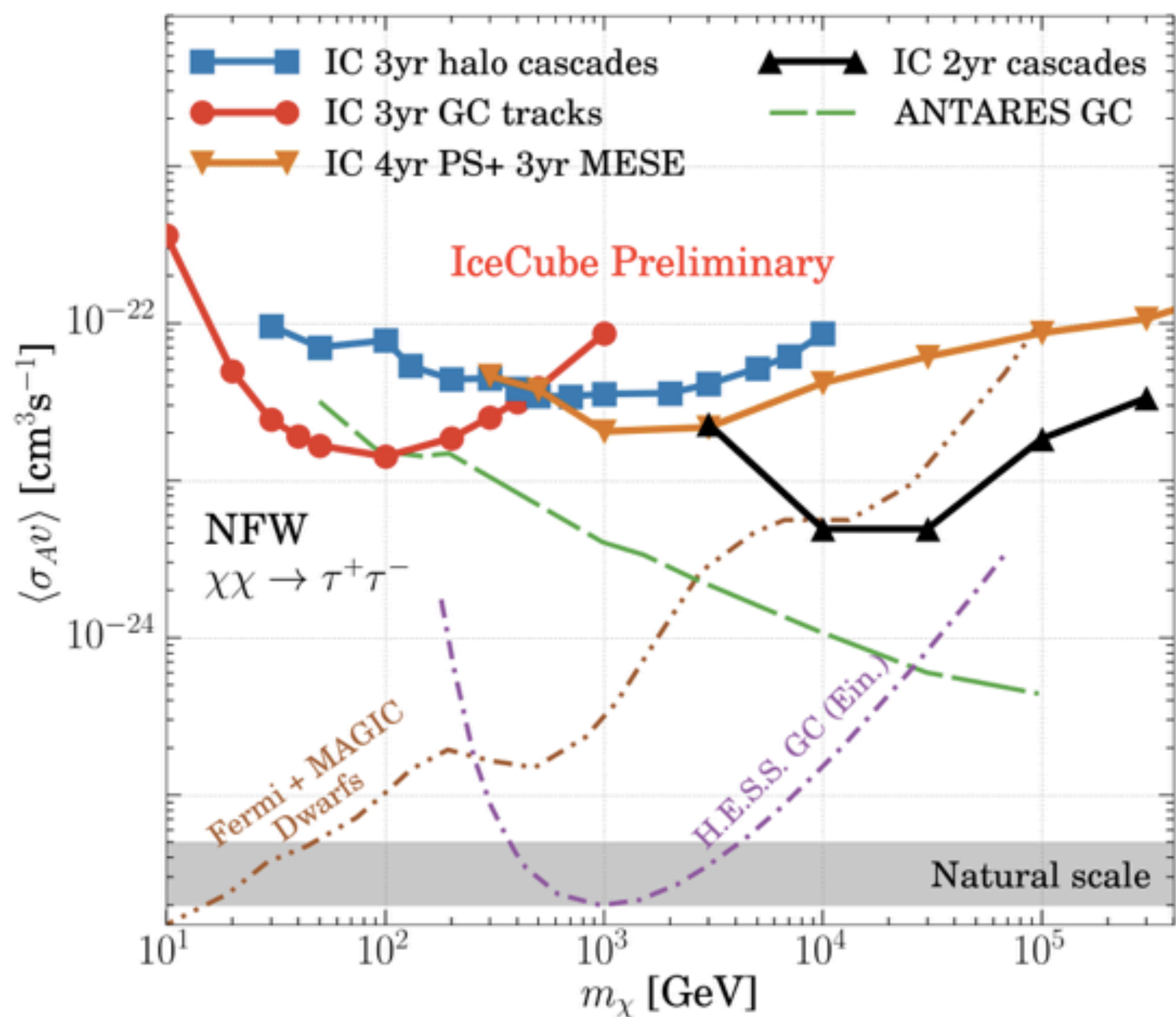
EPJ C 77 146 (2017) [arXiv:1612.05949]



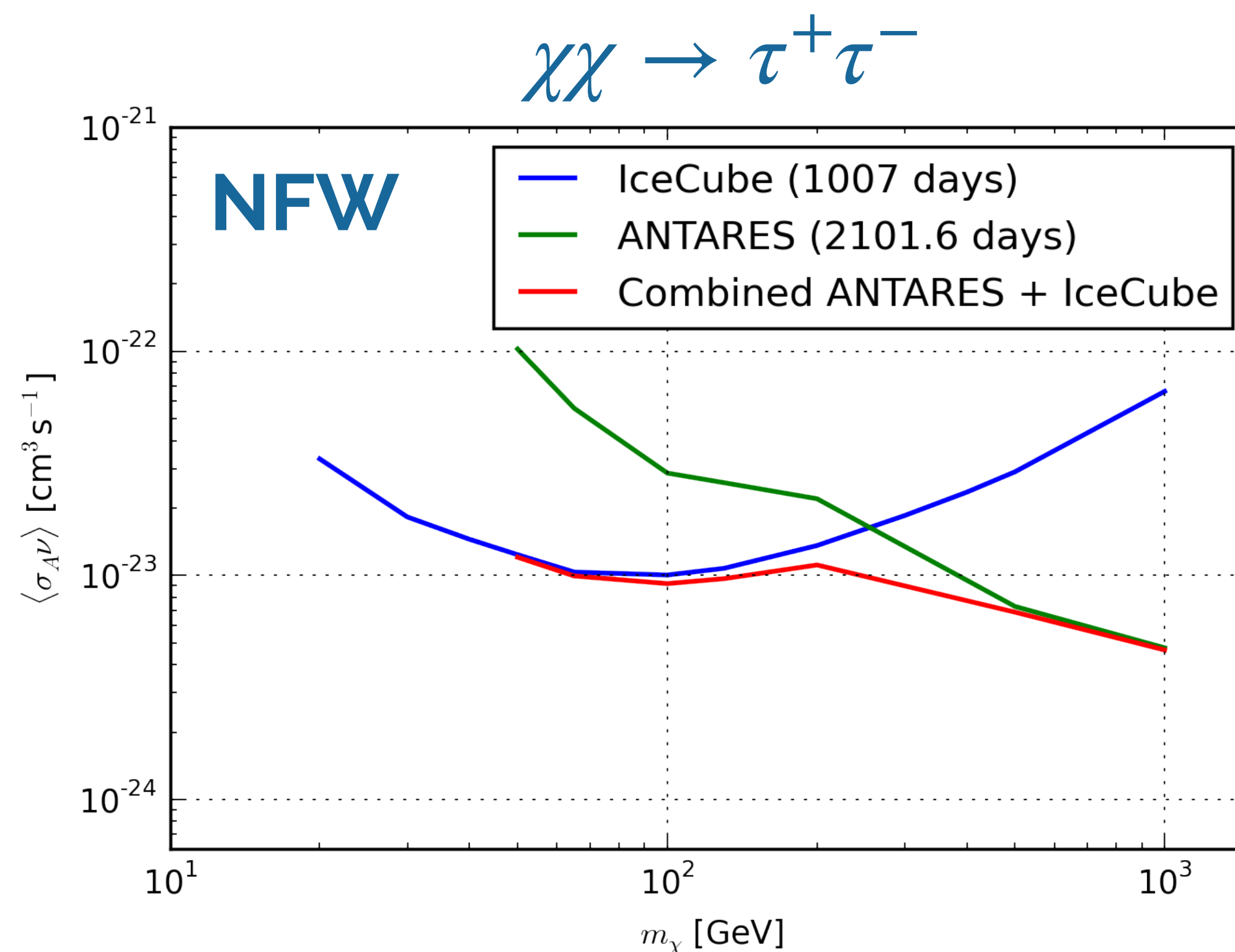
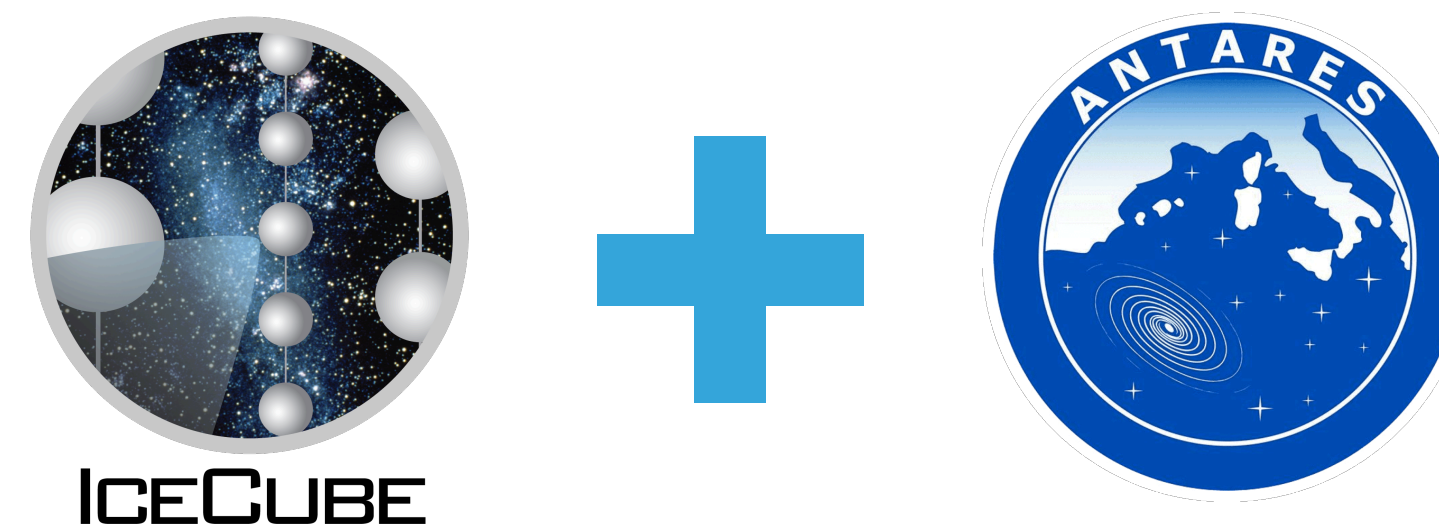
- Background needs to be very well understood: **Earth has an unique position in the sky.**
- Analysis with large uncertainties... (dark disc, velocity distribution)
- **No thermal equilibrium** assumption on the annihilation cross-section



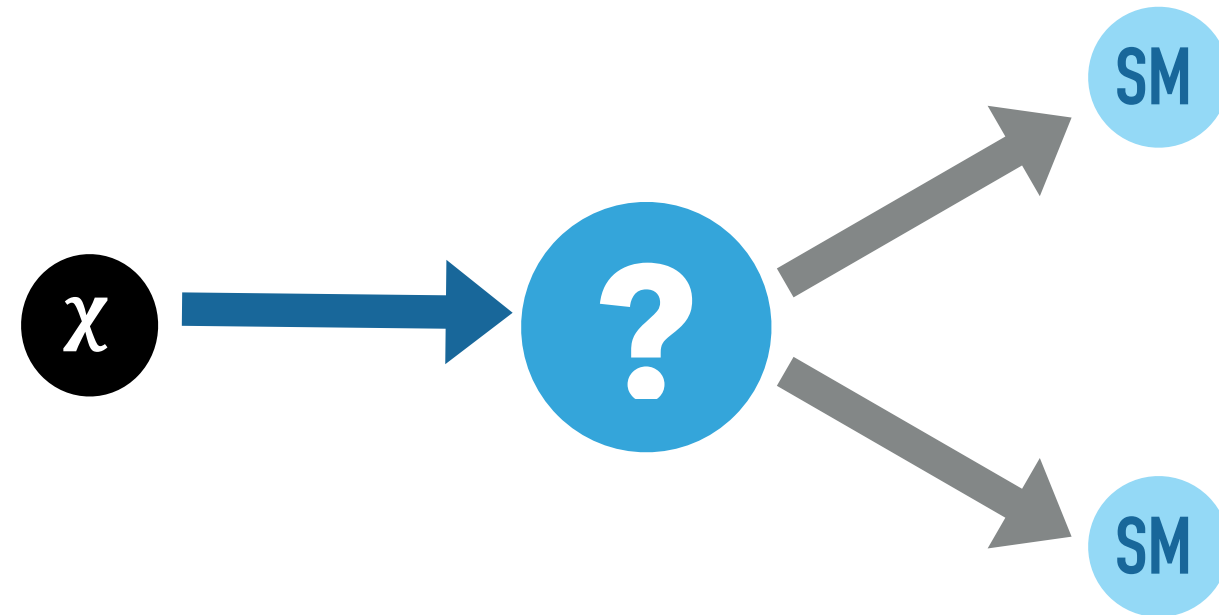
Eur. Phys. J. C (2017) 77:82



Eur. Phys. J. C (2017) 77: 627

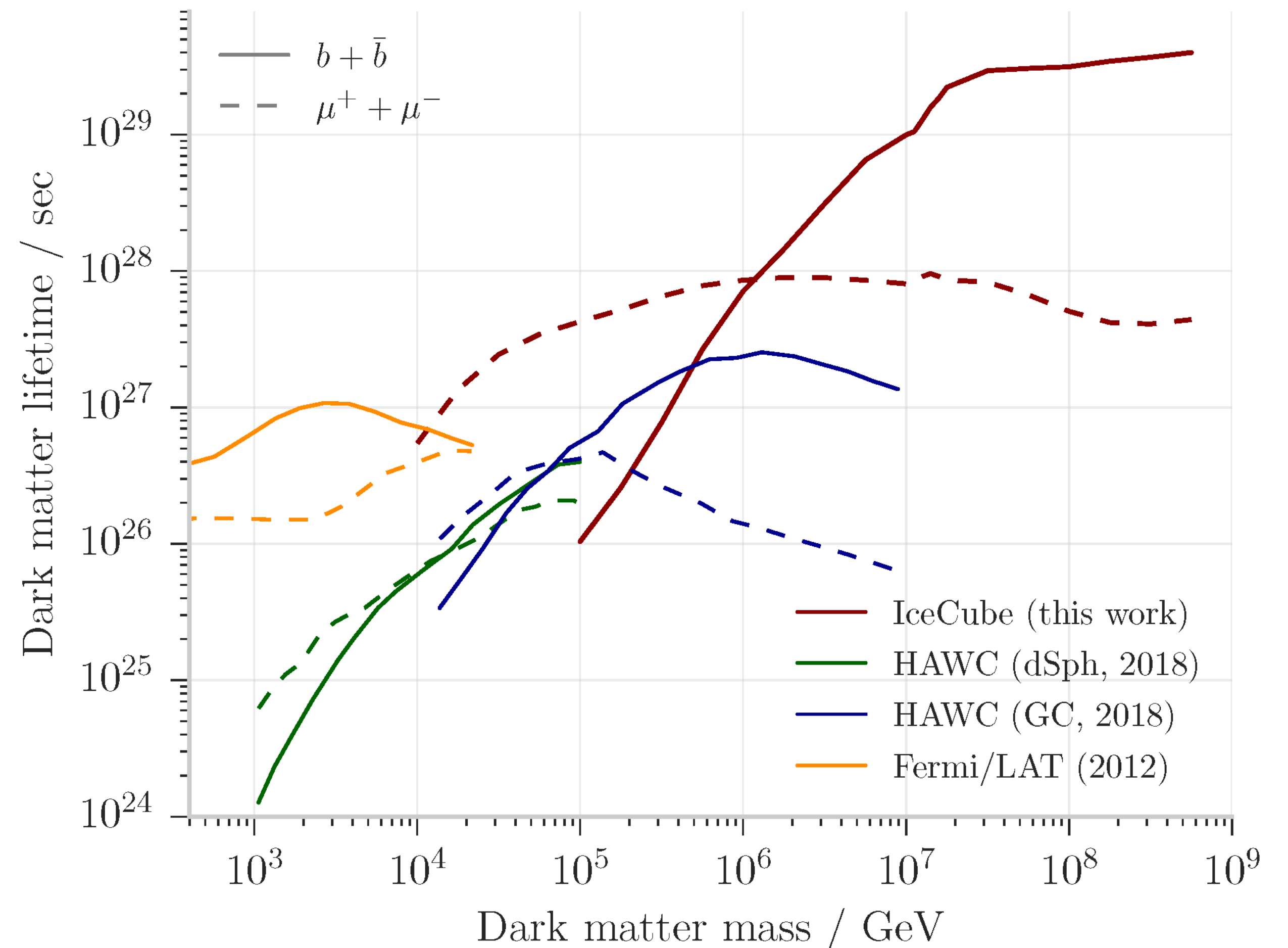


ICRC17 arXiv:1710.01197



- Two IceCube independent data samples:
  - Track-like with six years of data
  - Cascade-like with two years of data
- Dark Matter alone cannot explain IceCube neutrino flux.
- Best limits  $> 10$  TeV

IceCube Collaboration arXiv:1804.03848



- The future exploration of the high energy Universe belongs to the **Multimessenger Astronomy**.
- IceCube has started to characterize the observed **astrophysical neutrino flux** including the flavor composition
- IceCube is actively interconnected in the **realtime network** sending and receiving alerts to other observatories.
- **Indirect detection of Dark Matter** with neutrino telescopes provides complementarity to other techniques due to different backgrounds and systematics
- IceCube has a **lively program of Dark Matter searches**, with very competitive results.






## THE ICECUBE COLLABORATION

 **AUSTRALIA**  
University of Adelaide

 **BELGIUM**  
Université libre de Bruxelles  
Universiteit Gent  
Vrije Universiteit Brussel

 **CANADA**  
SNOLAB  
University of Alberta–Edmonton

 **DENMARK**  
University of Copenhagen

 **GERMANY**  
Deutsches Elektronen-Synchrotron  
ECAP, Universität Erlangen-Nürnberg  
Humboldt-Universität zu Berlin  
Ruhr-Universität Bochum  
RWTH Aachen University  
Technische Universität Dortmund  
Technische Universität München  
Universität Mainz  
Universität Wuppertal  
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 **NEW ZEALAND**  
University of Canterbury

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Stockholms Universitet  
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Technology

Southern University  
and A&M College  
Stony Brook University  
University of Alabama  
University of Alaska Anchorage  
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University of California, Irvine  
University of Delaware  
University of Kansas  
University of Maryland  
University of Rochester  
University of Texas at Arlington

University of Wisconsin–Madison  
University of Wisconsin–River Falls  
Yale University

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(FWO-Vlaanderen)

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Deutsches Elektronen-Synchrotron (DESY)

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Swedish Polar Research Secretariat

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