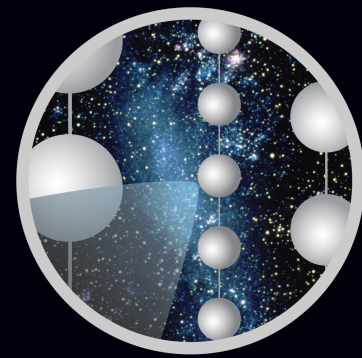


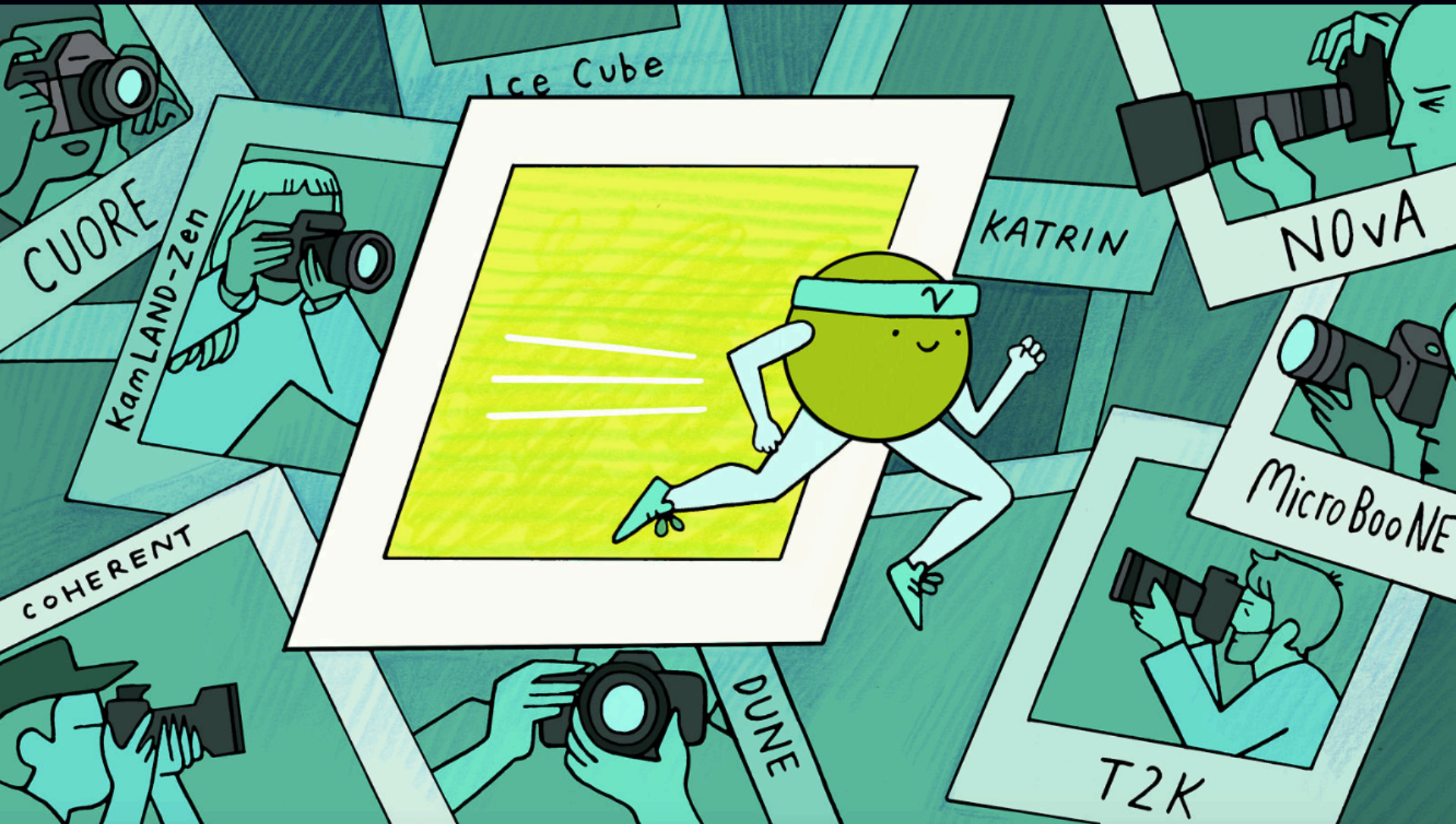


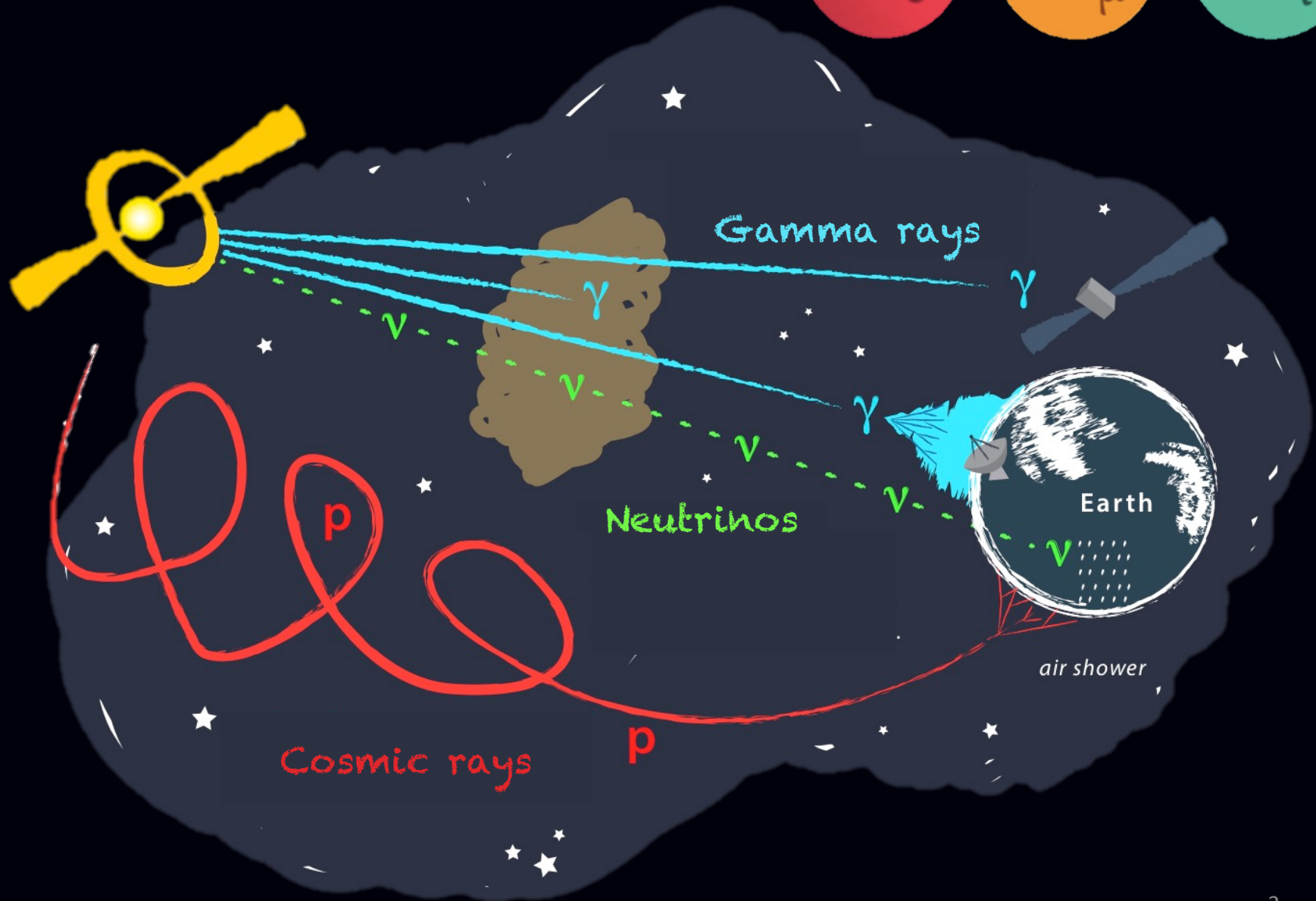
VRIJE  
UNIVERSITEIT  
BRUSSEL



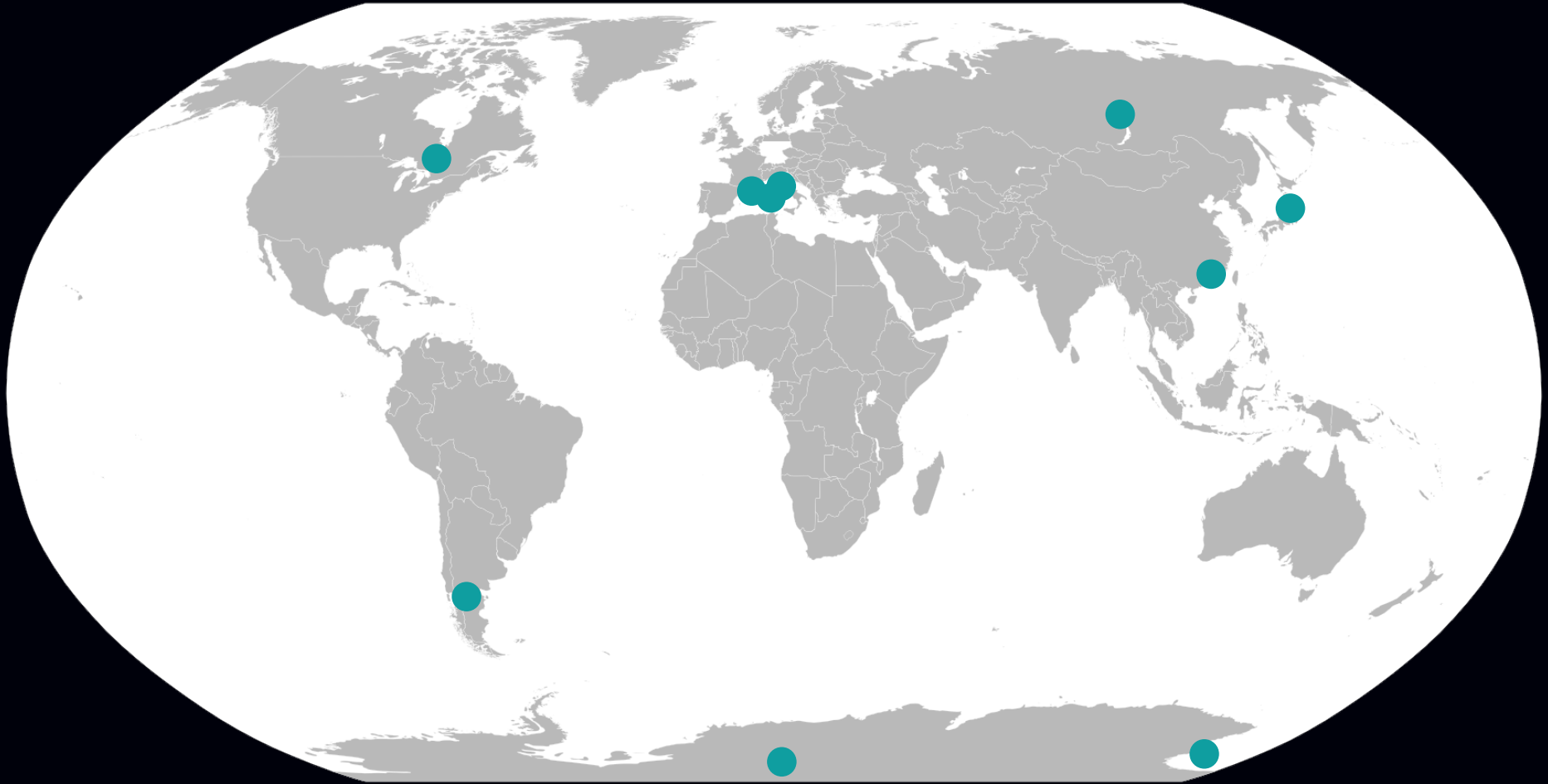
ICECUBE

# Neutrino Astronomy: From GeV to PeV

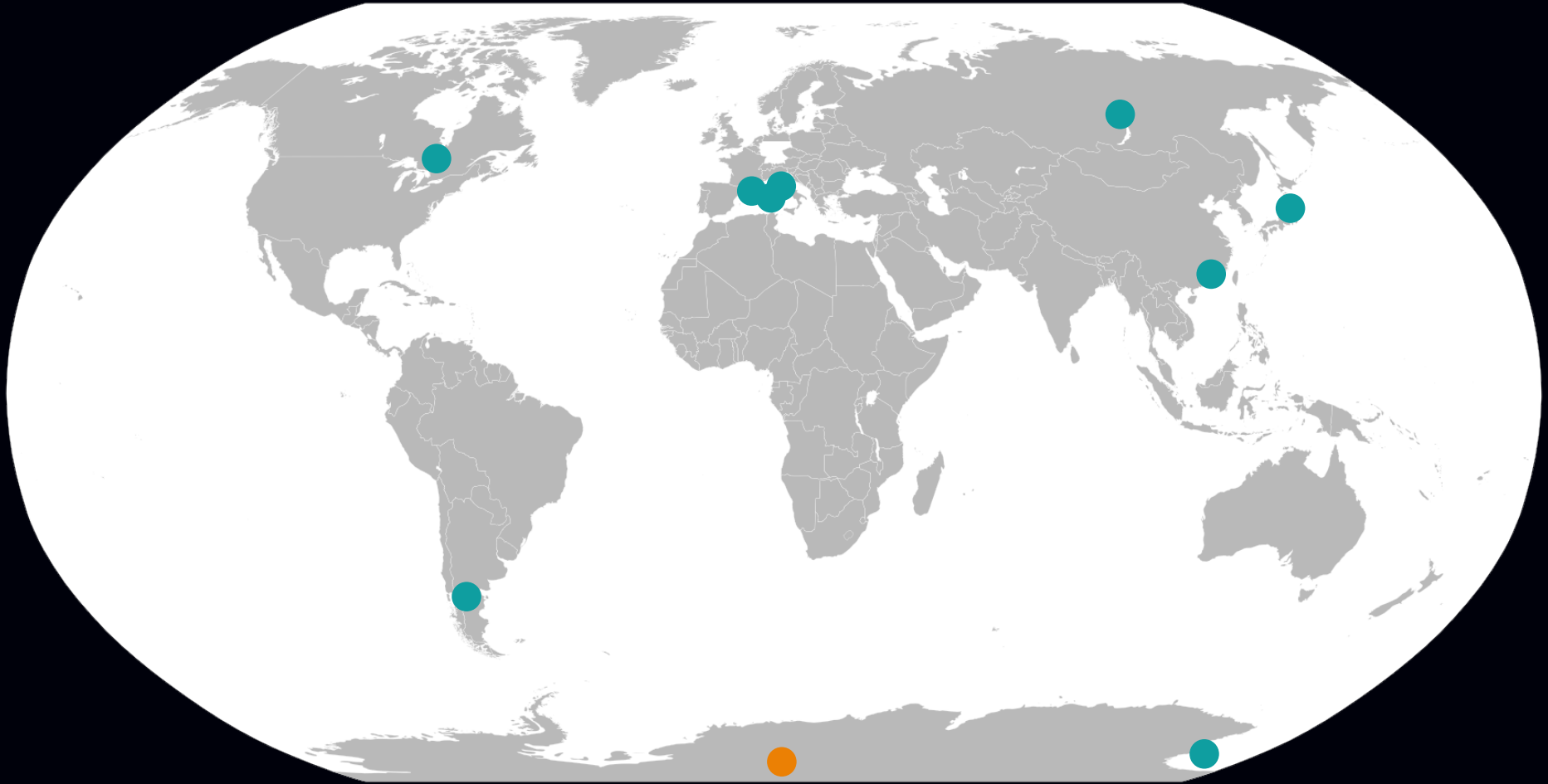




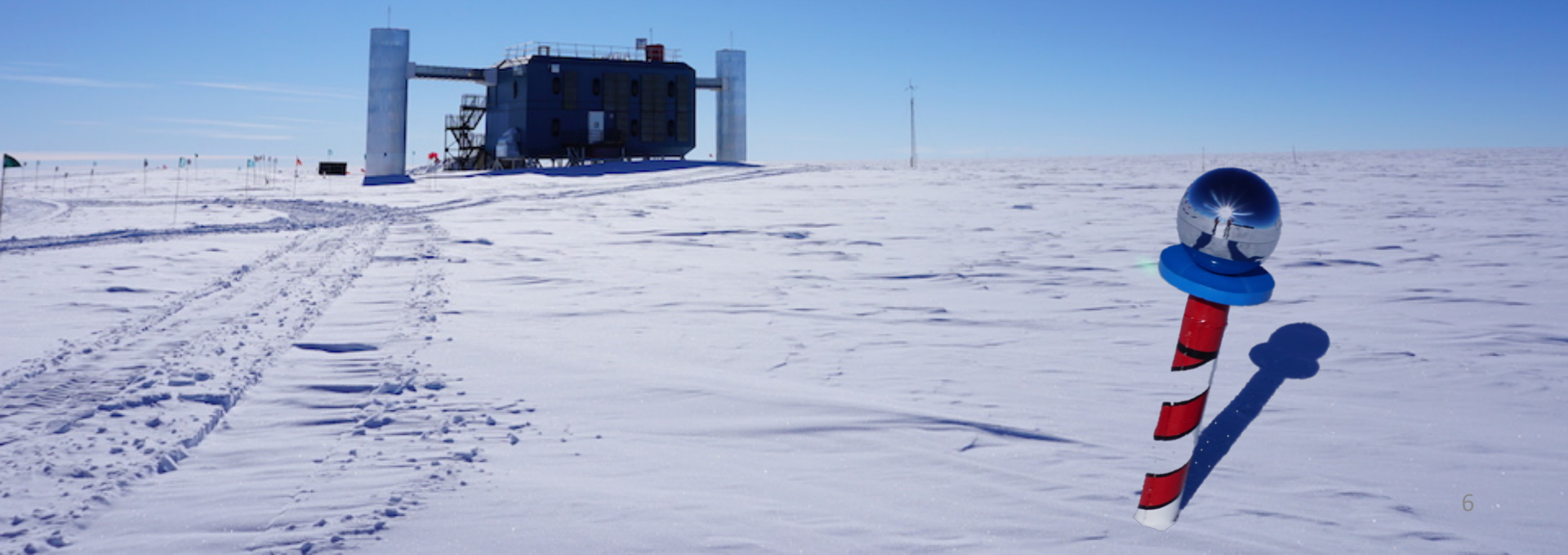
# Neutrino Telescopes



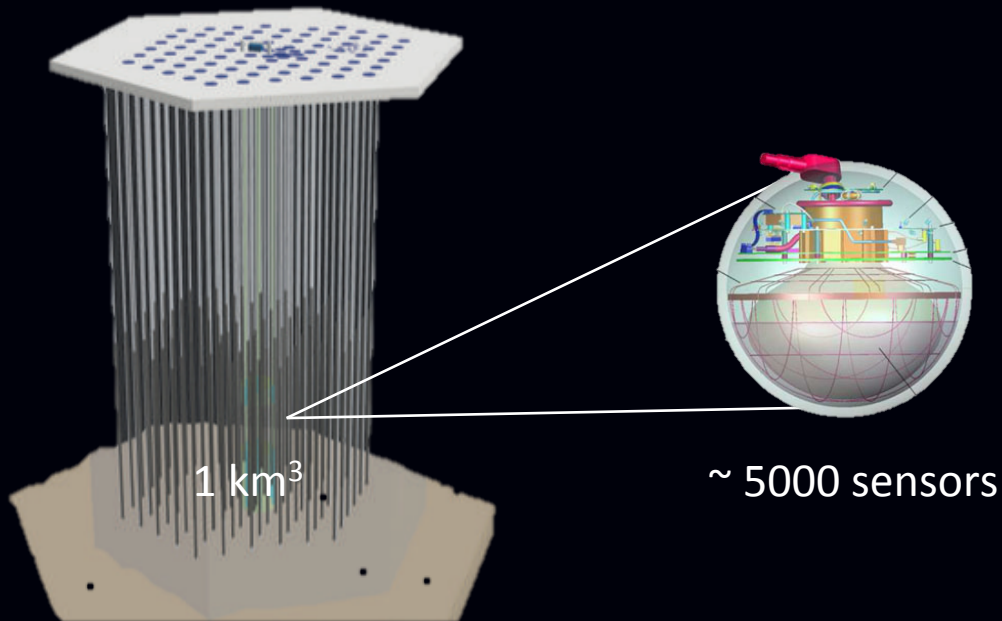
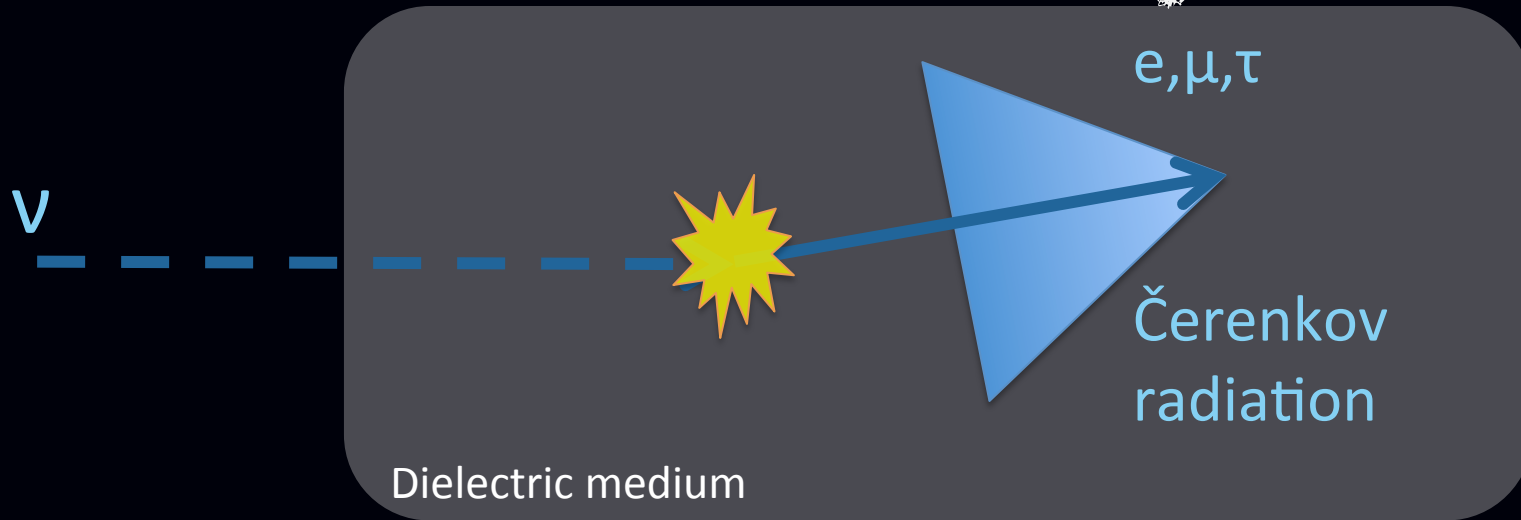
# Neutrino Telescopes



# IceCube Neutrino Observatory South Pole, Antarctica

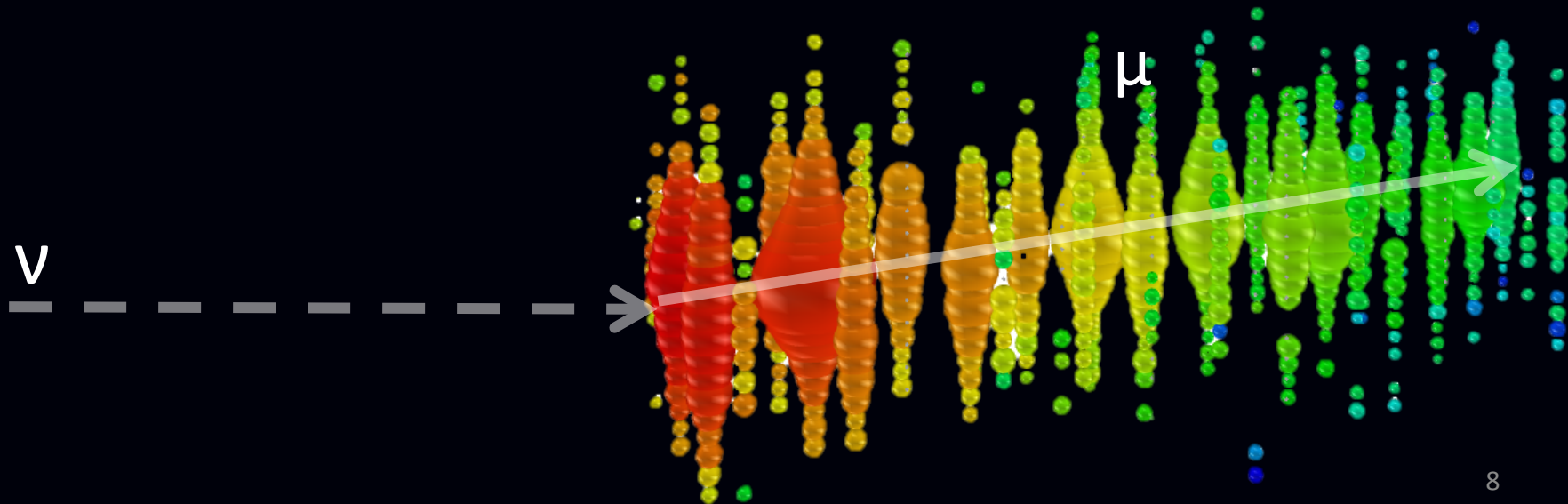
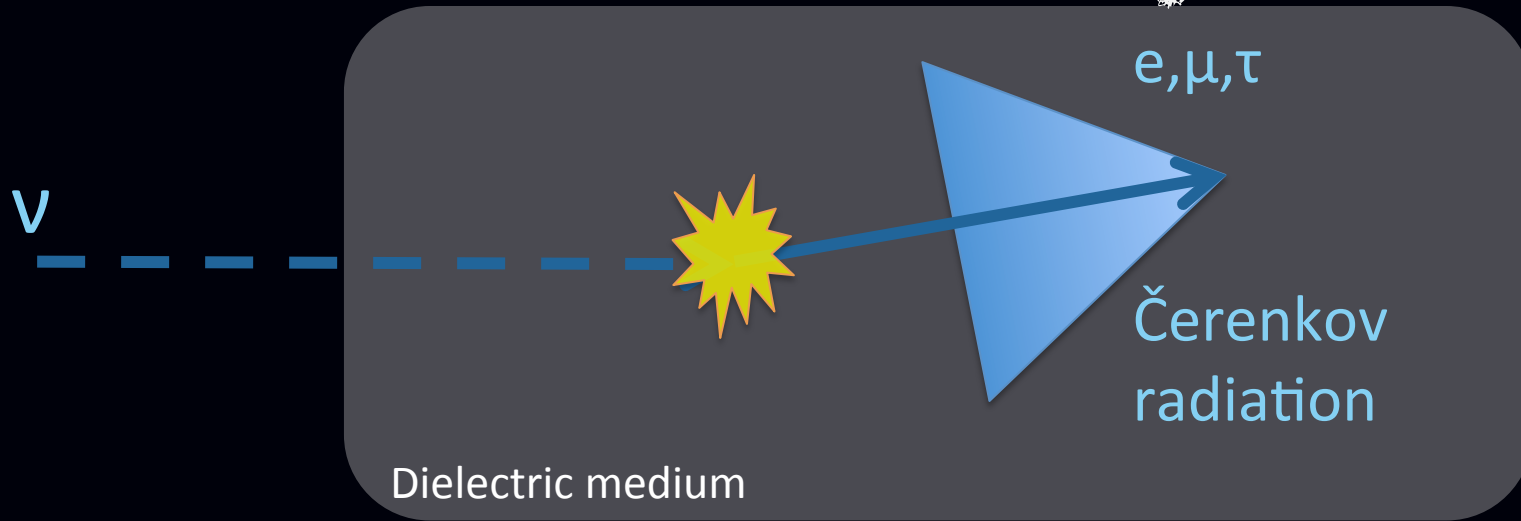


# How to detect high-energy neutrinos?



High-energy = between GeV and PeV

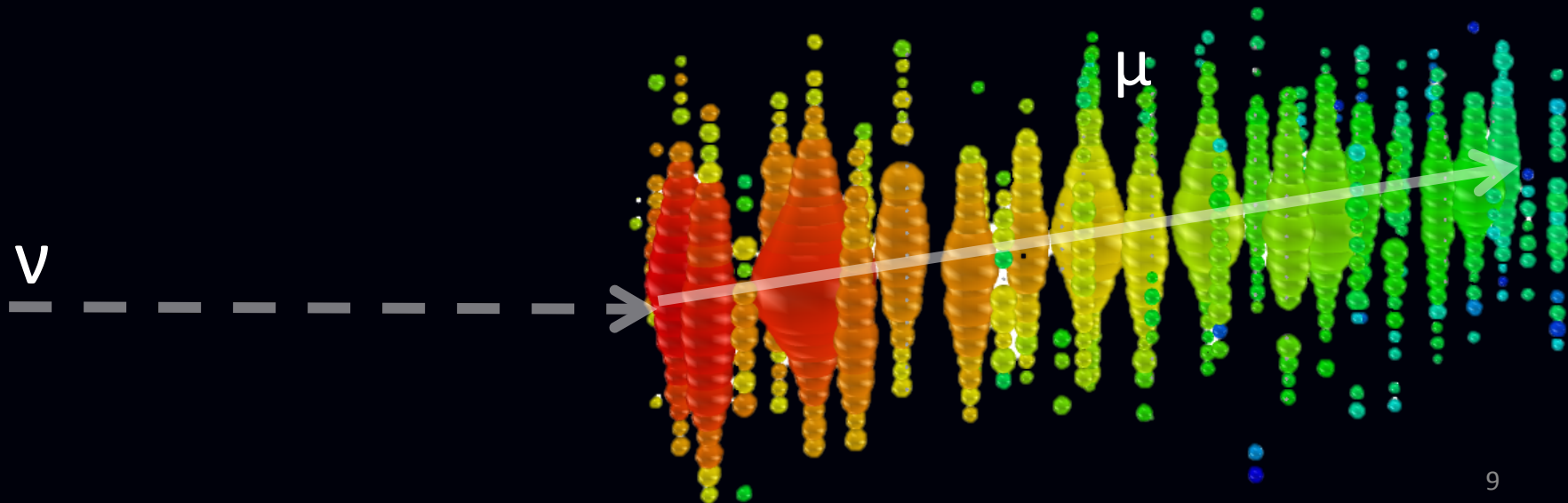
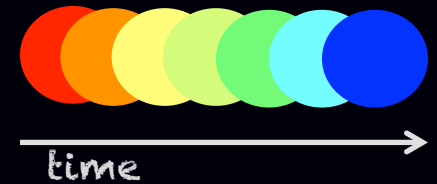
# How to detect high-energy neutrinos?



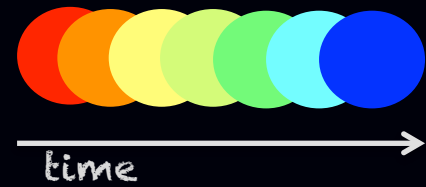


# Which information can we get?

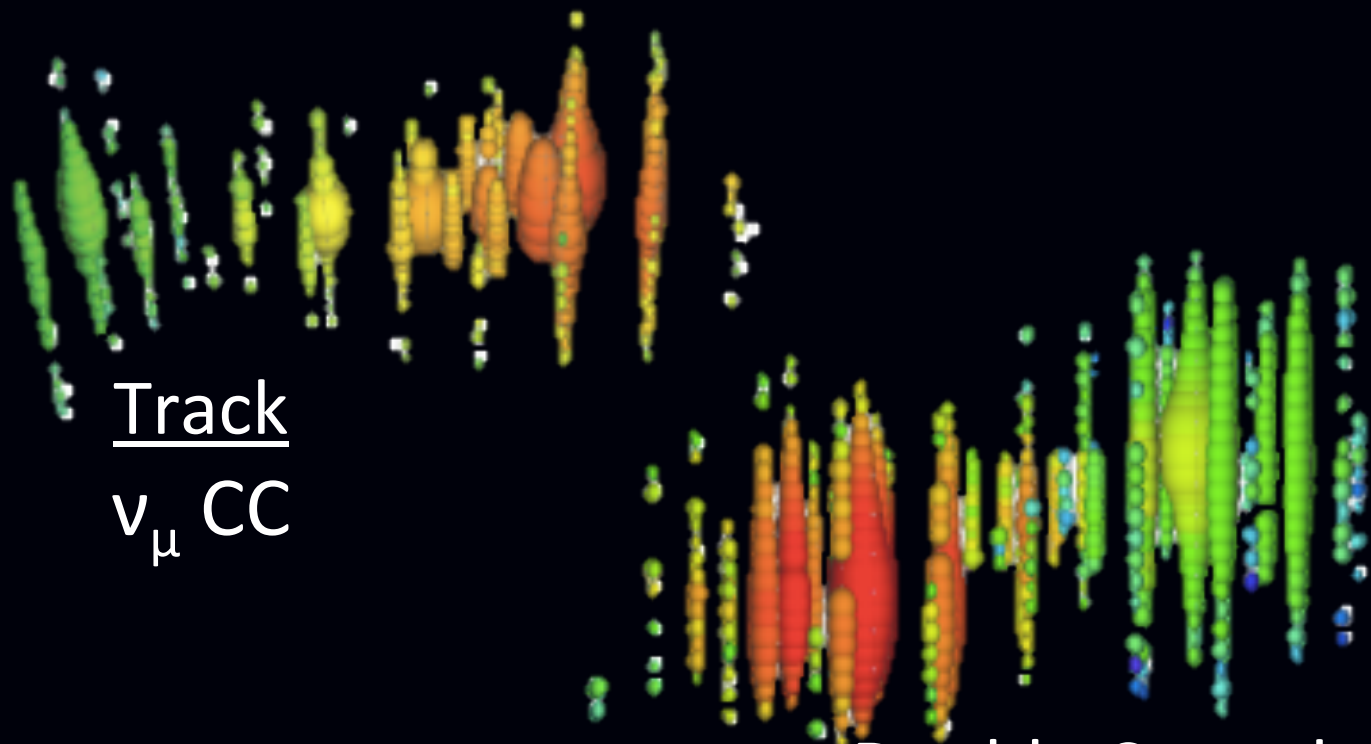
- Amount of light -> Energy
- Timeline -> Direction
- Topology -> Interaction type



# Event topology



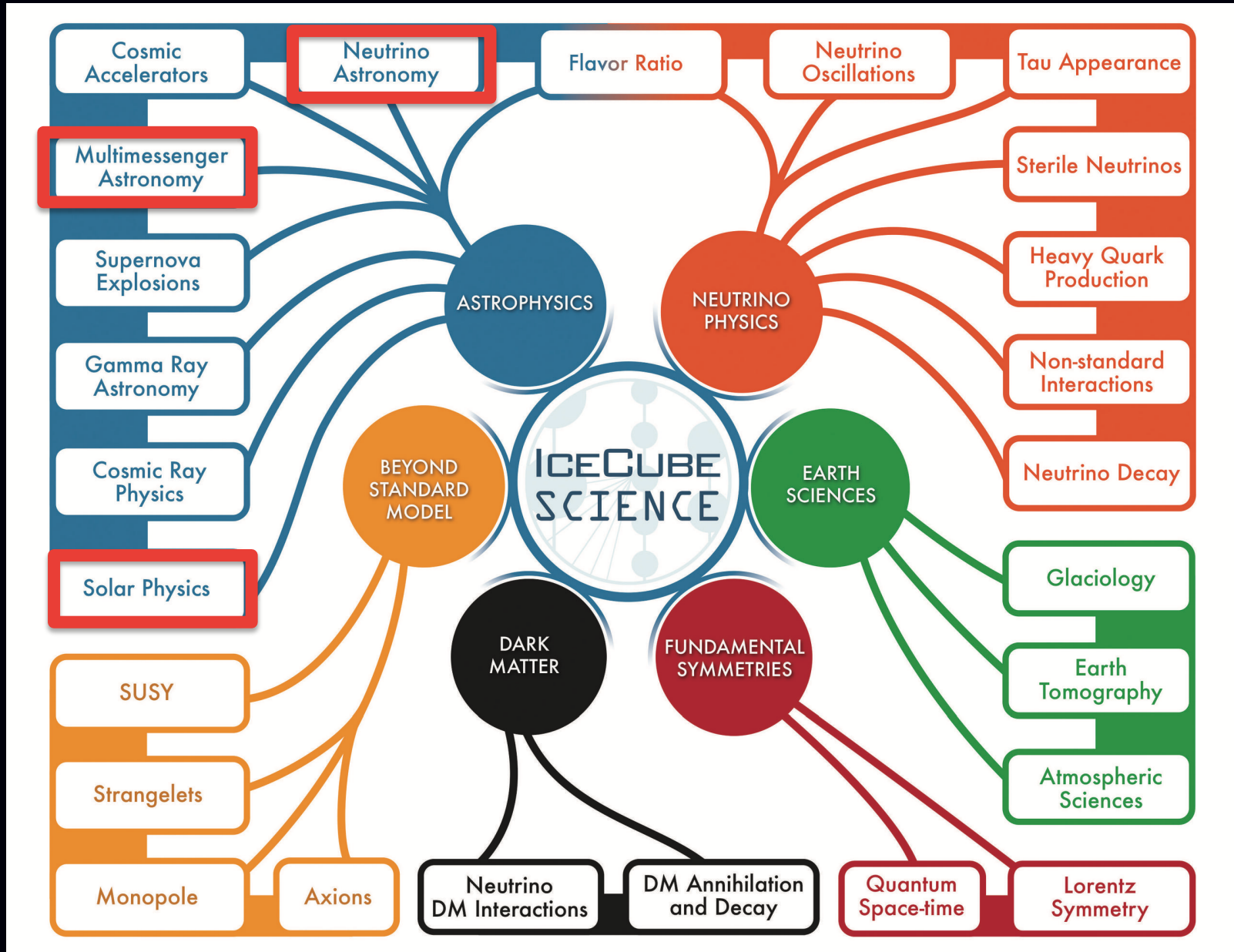
Cascade  
NC or  $\nu_e$  CC



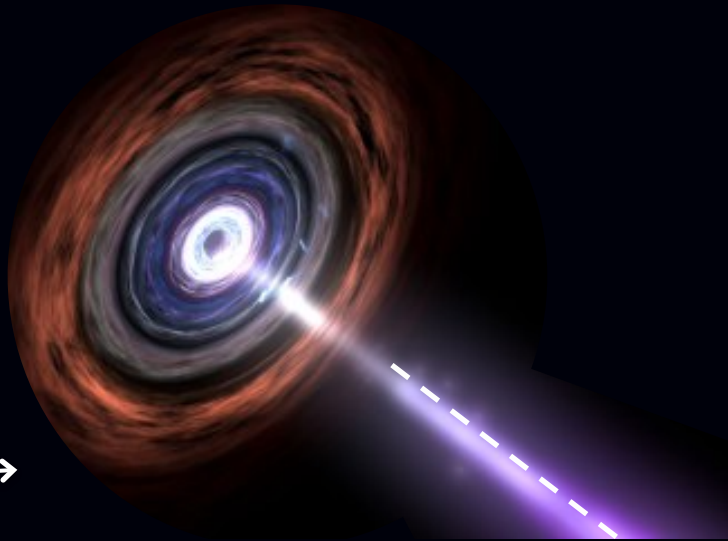
Track  
 $\nu_\mu$  CC

Double Cascade  
 $\nu_\tau$  CC

# What do we learn?



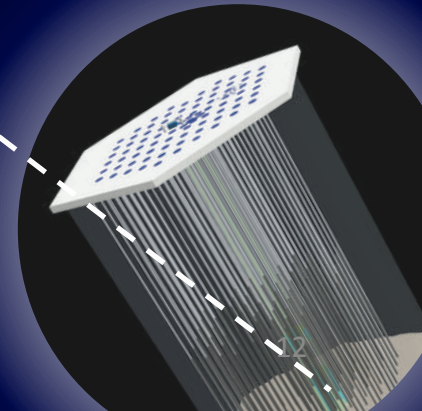
# What do we learn?



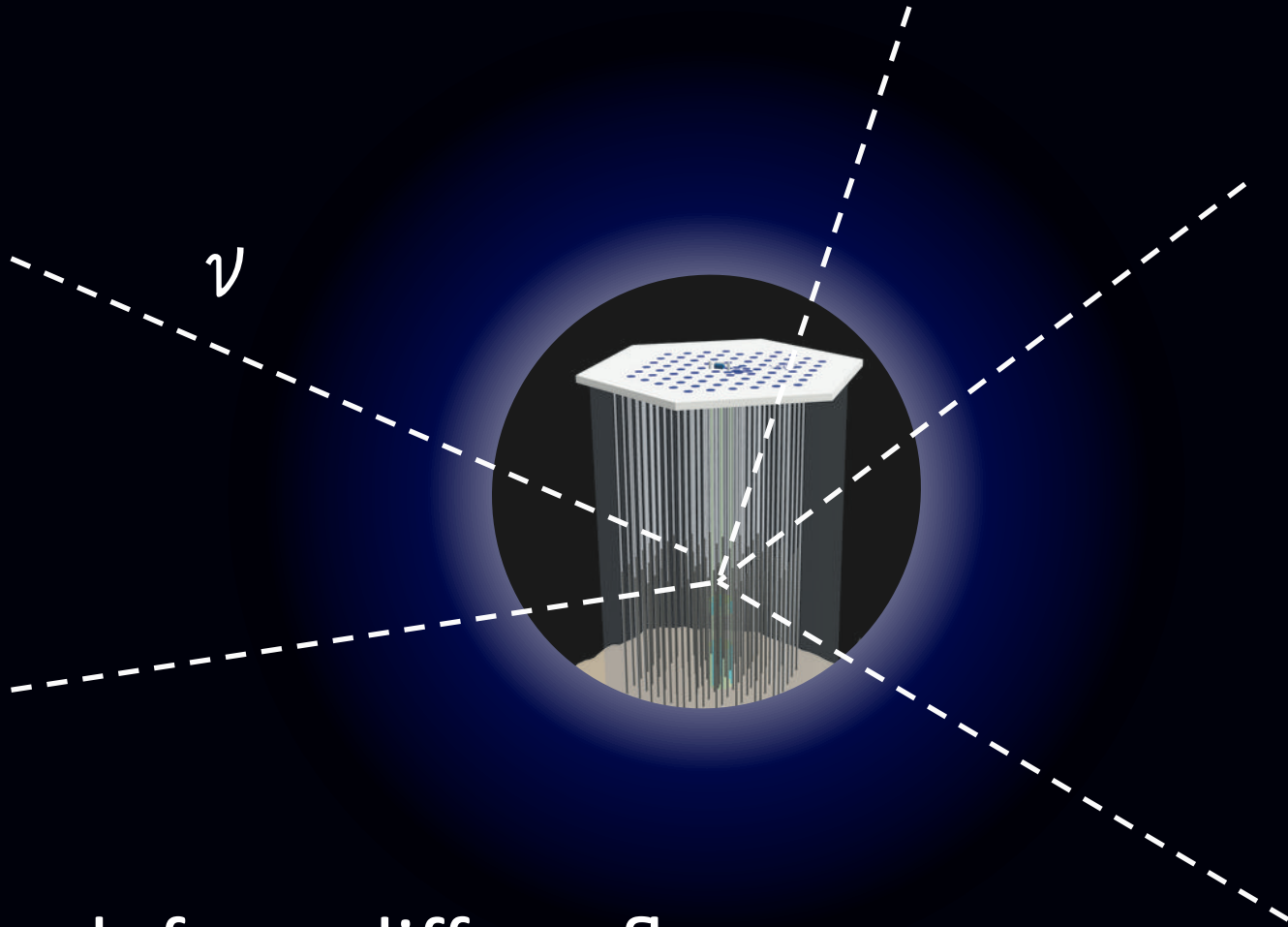
Potential high-energy  $\nu$  emitter

Goal: Identifying hadronic accelerators in the Universe

Neutrino telescope



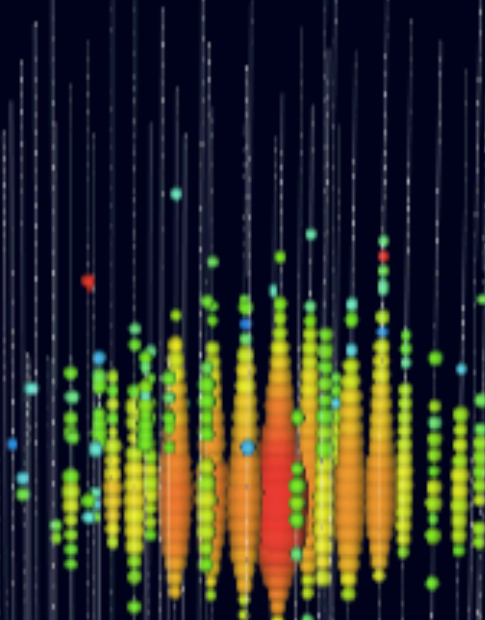
# How to search for astrophysical neutrino sources?



1. Search for a diffuse flux

Detected event

Astrophysical  
neutrino



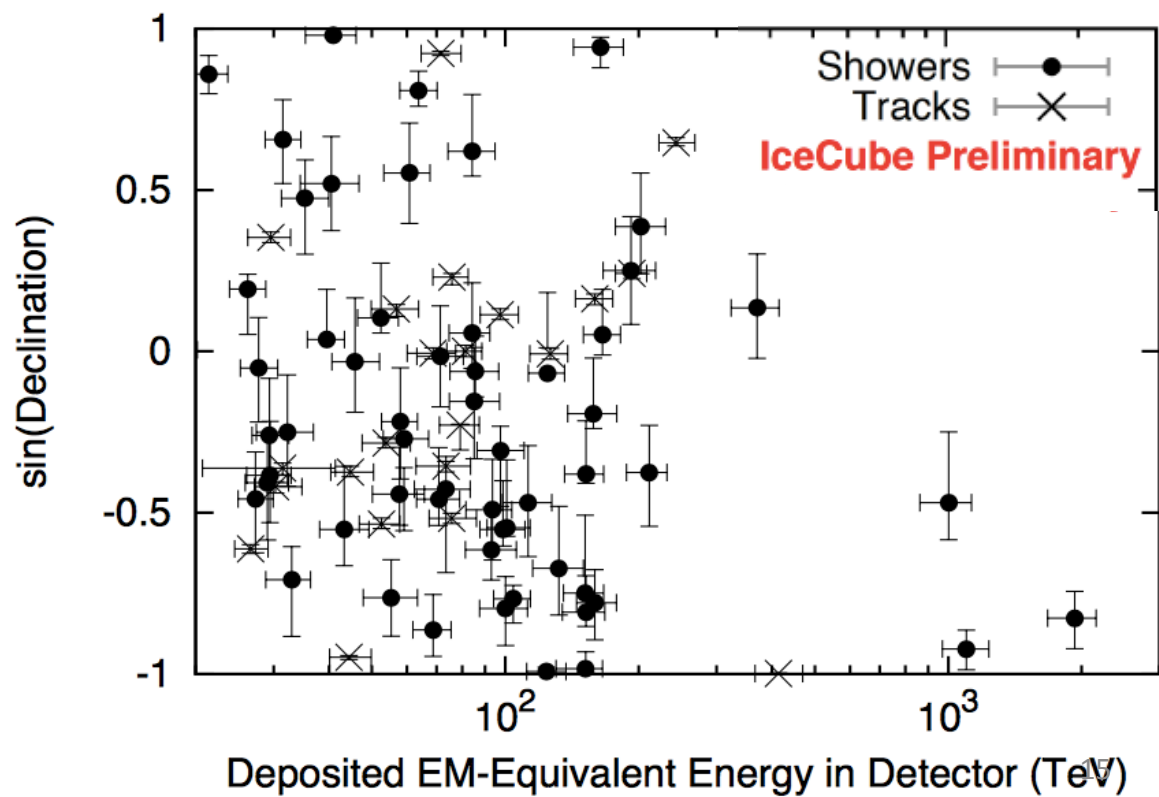
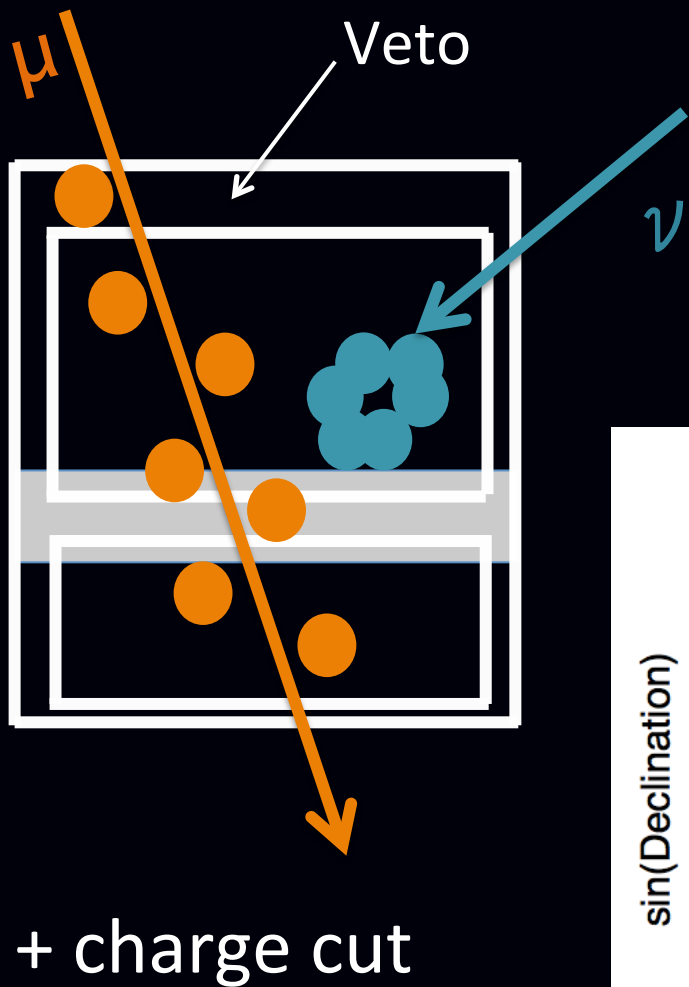
PeV neutrino



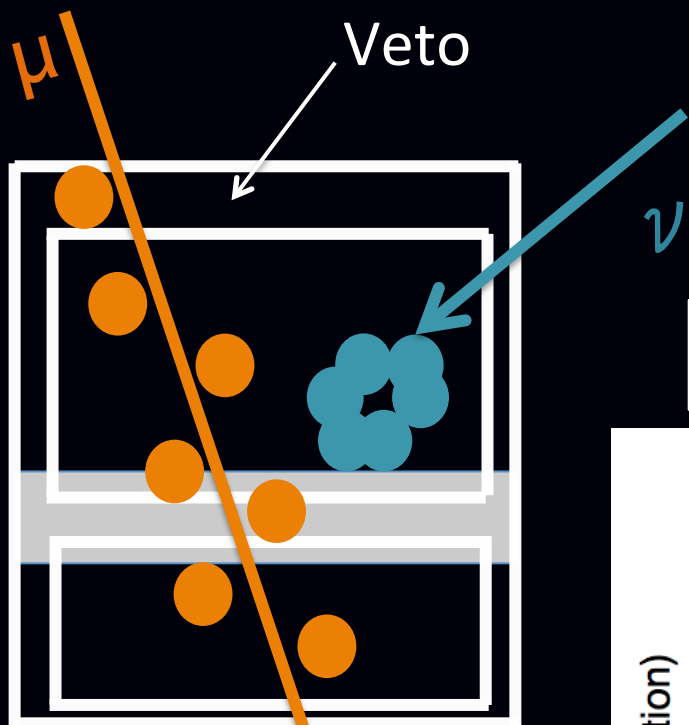
1. Search for a diffuse flux



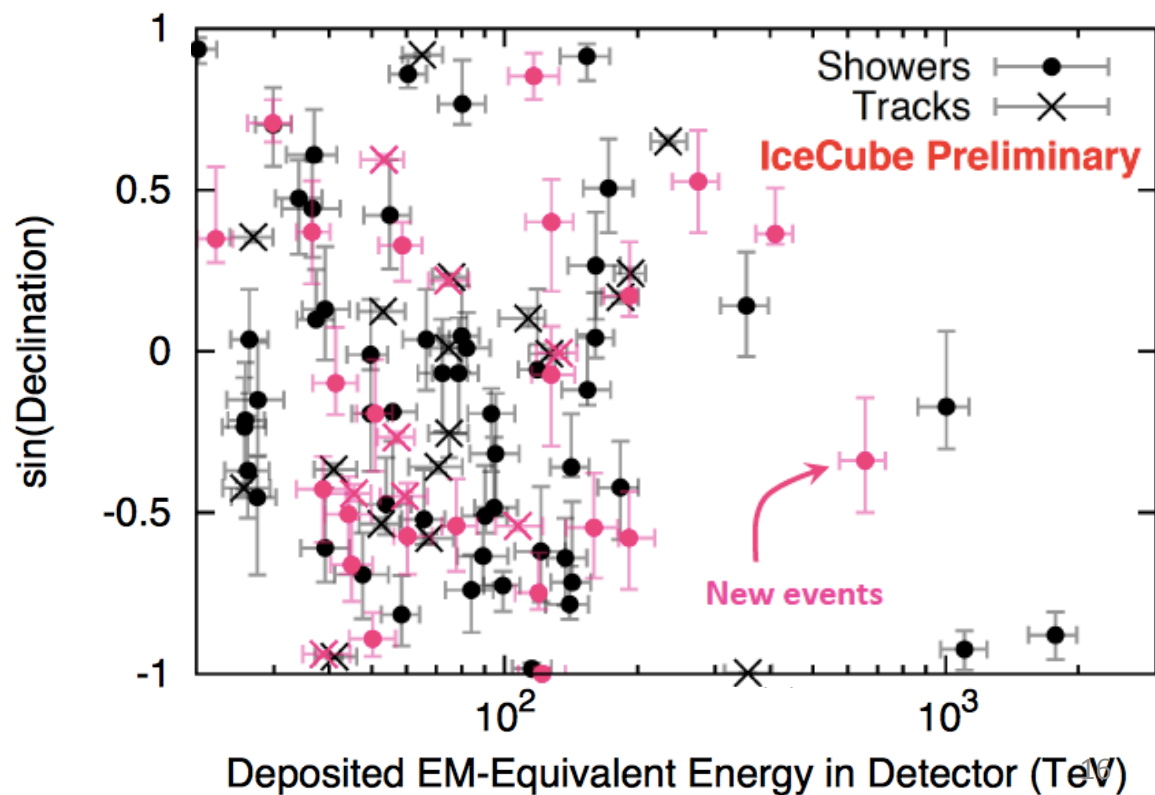
# Diffuse neutrino flux



# Diffuse neutrino flux 7.5 y

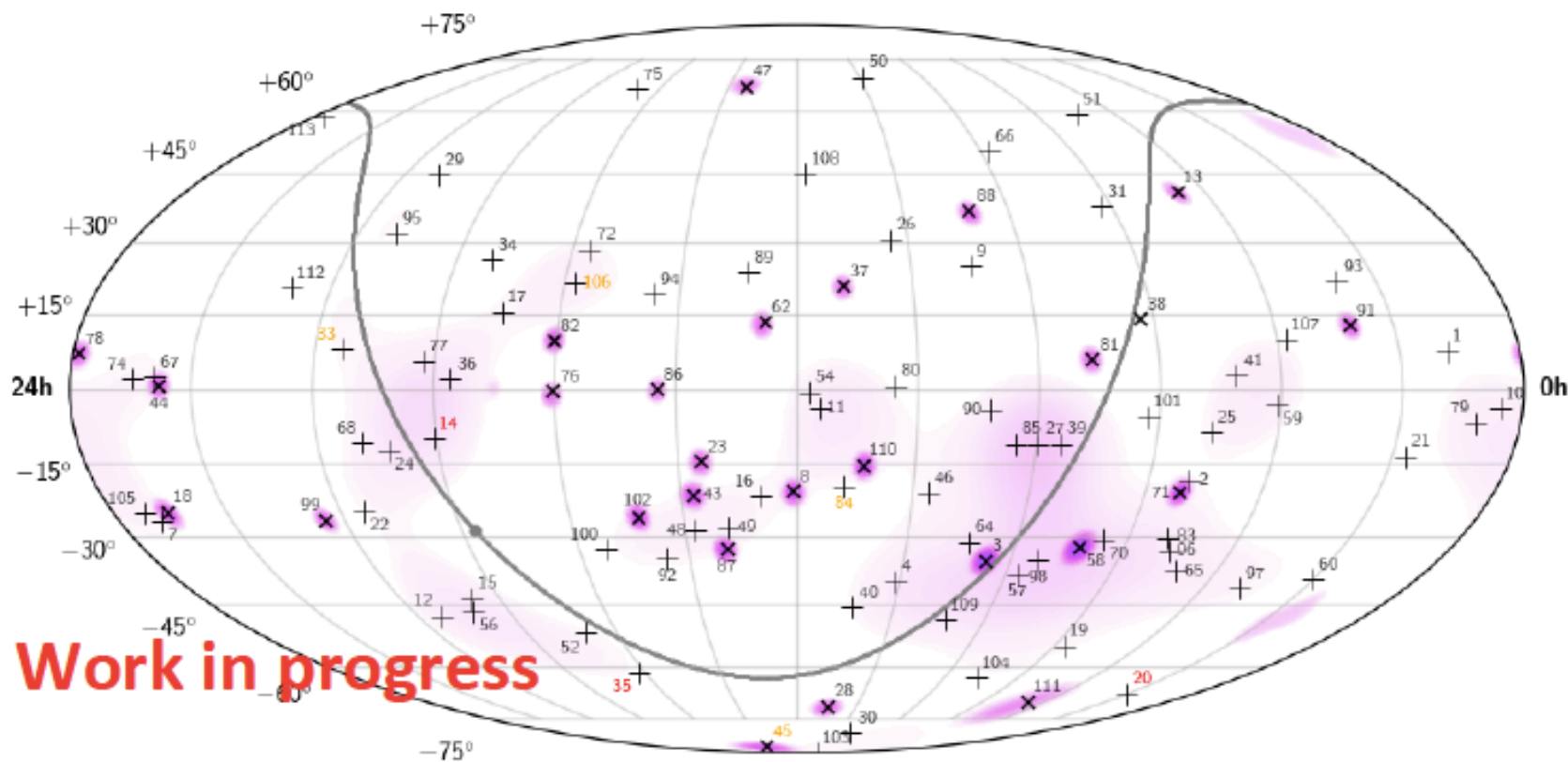


103 events, with 60 events  $> 60$  TeV



- Updated calibration and ice model
- Changes to RA, Dec, energy



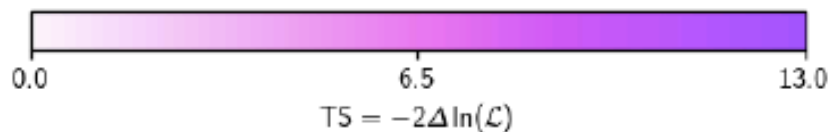


Work in progress

Coincident events: 32, 55

Dropped events: 5, 6, 42, 53, 61, 63, 69, 73

Equatorial



$E < 300 \text{ TeV}$

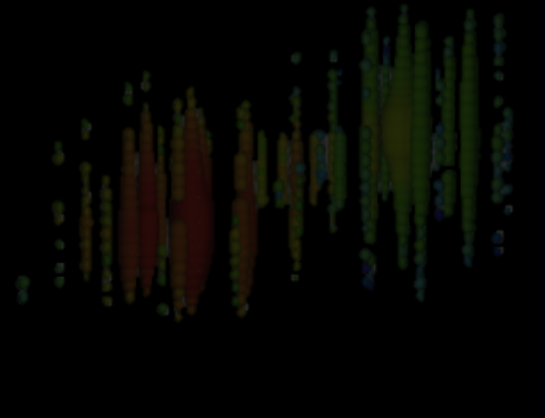
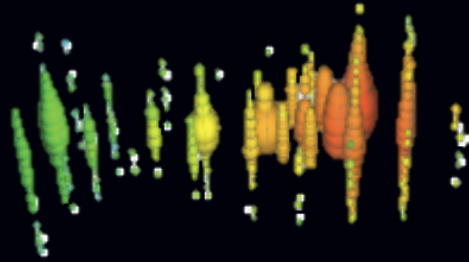
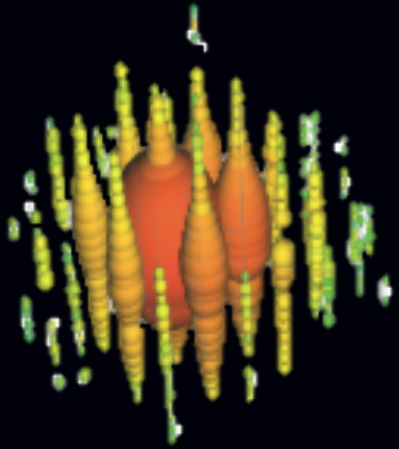
$300 \text{ TeV} < E < 1 \text{ PeV}$

$1 \text{ PeV} < E$

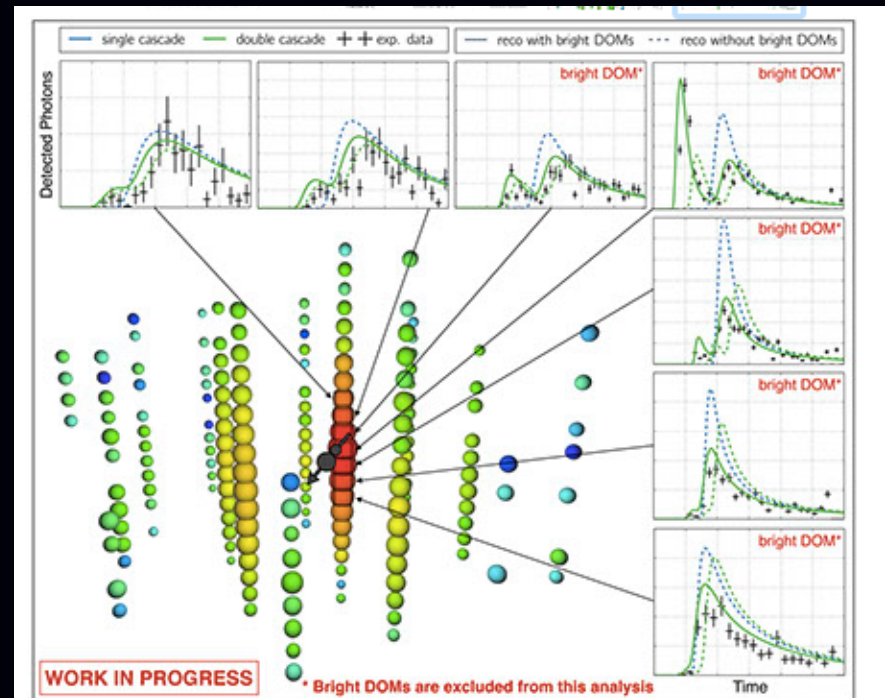
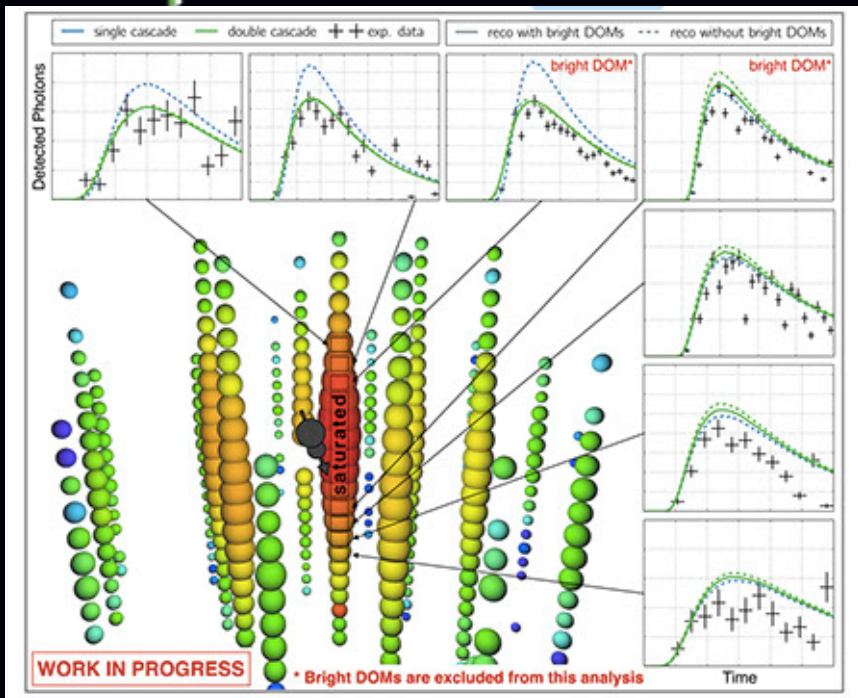
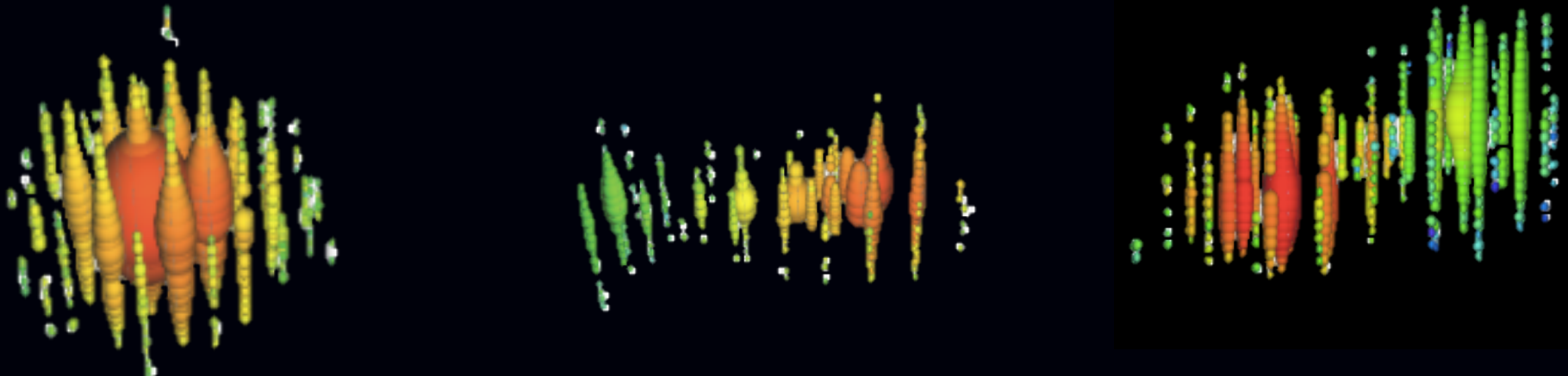
- No evidence for point sources

- No correlation with the galactic plane

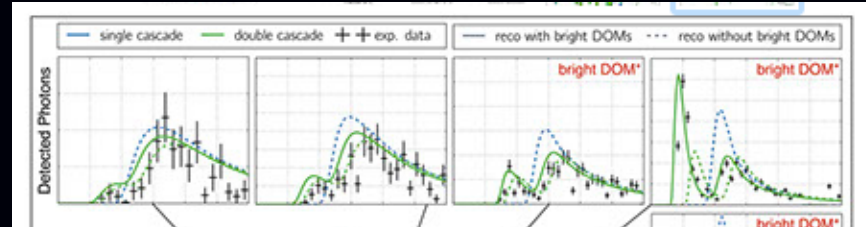
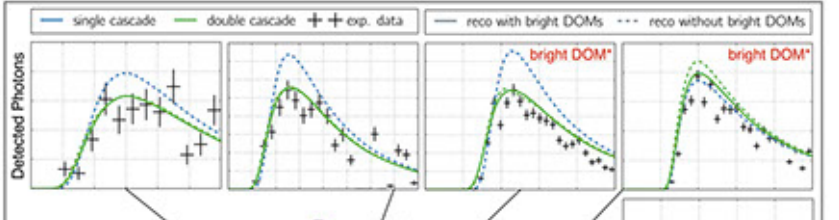
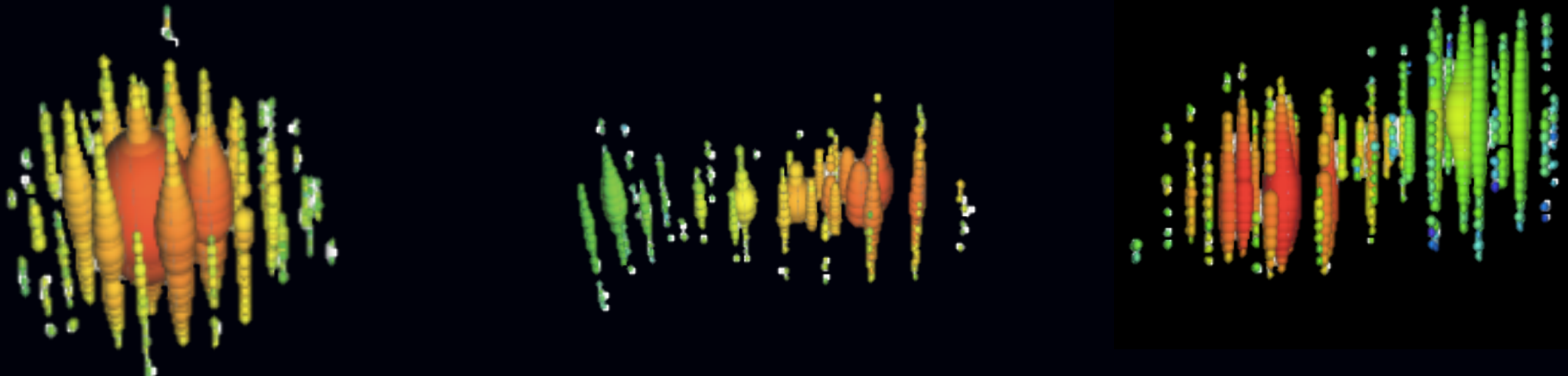
# Topology of the events



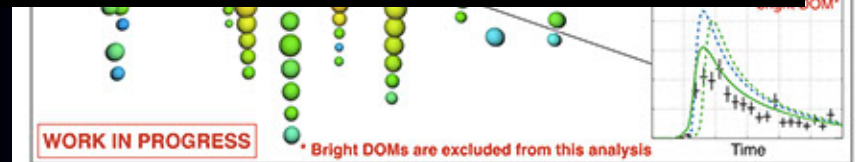
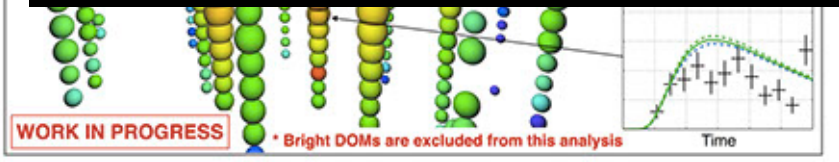
# Topology of the events



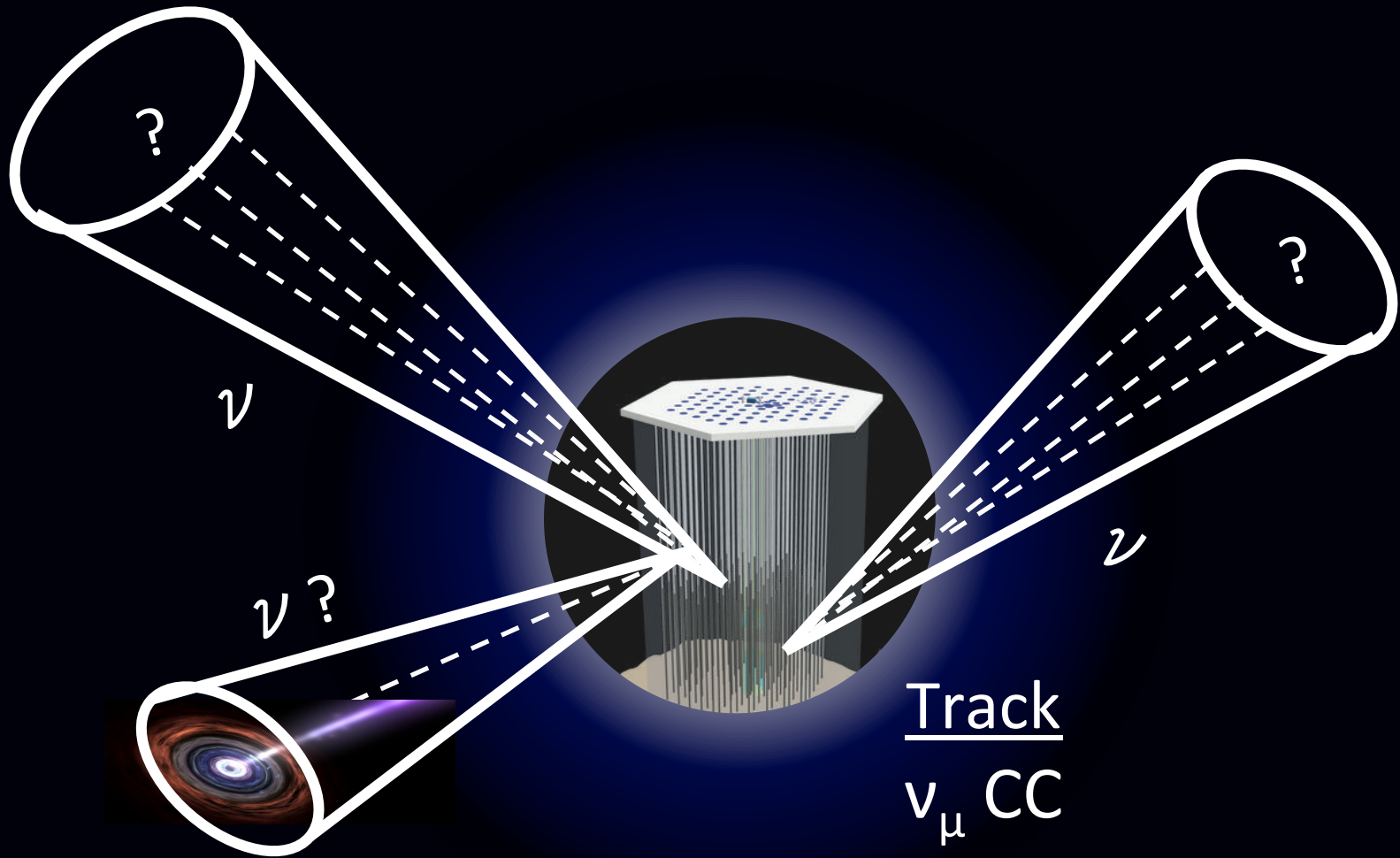
# Topology of the events



$\nu_\tau$  or mis-identified background (astro  $\nu$ / atm)?

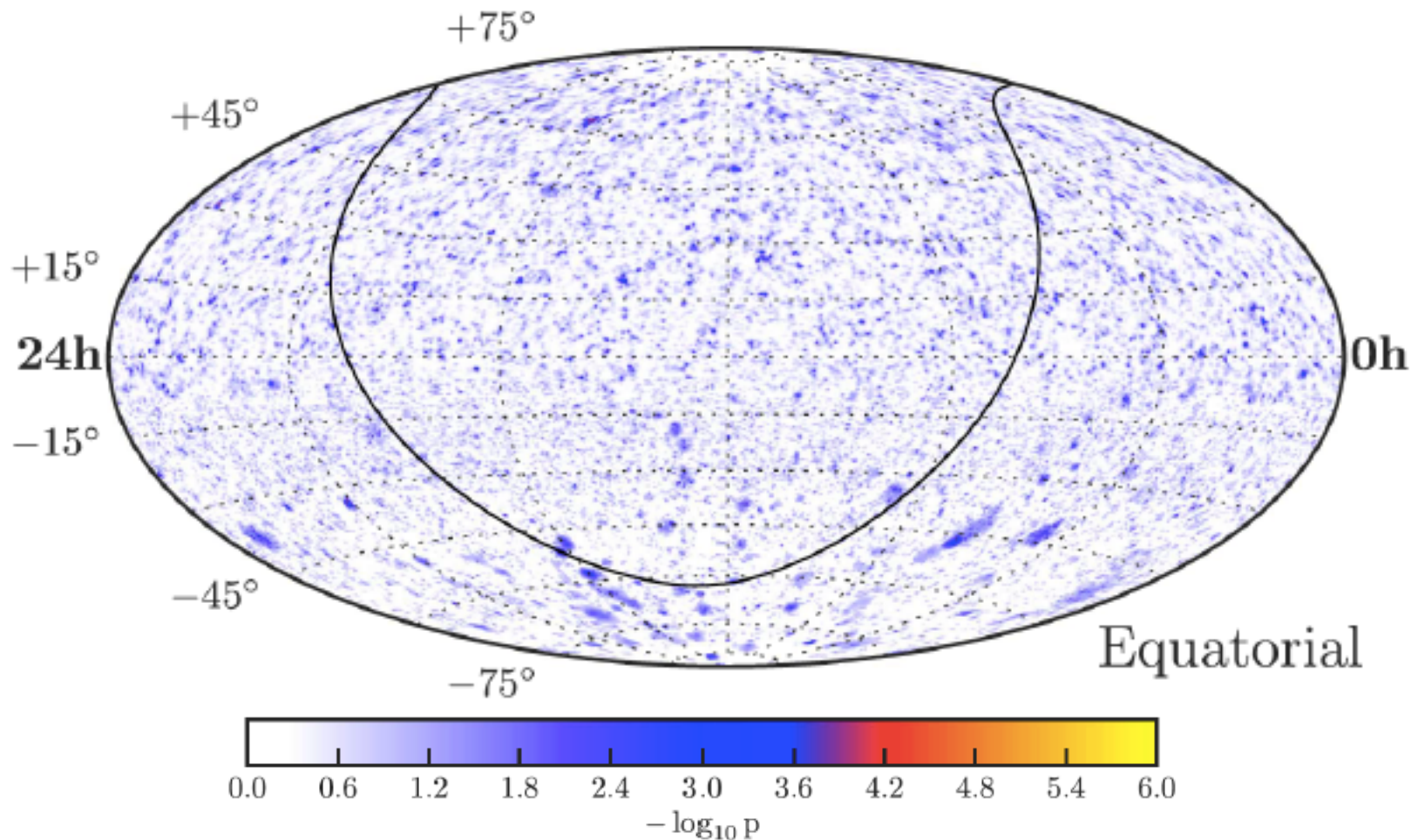


# How to search for astrophysical neutrino sources?

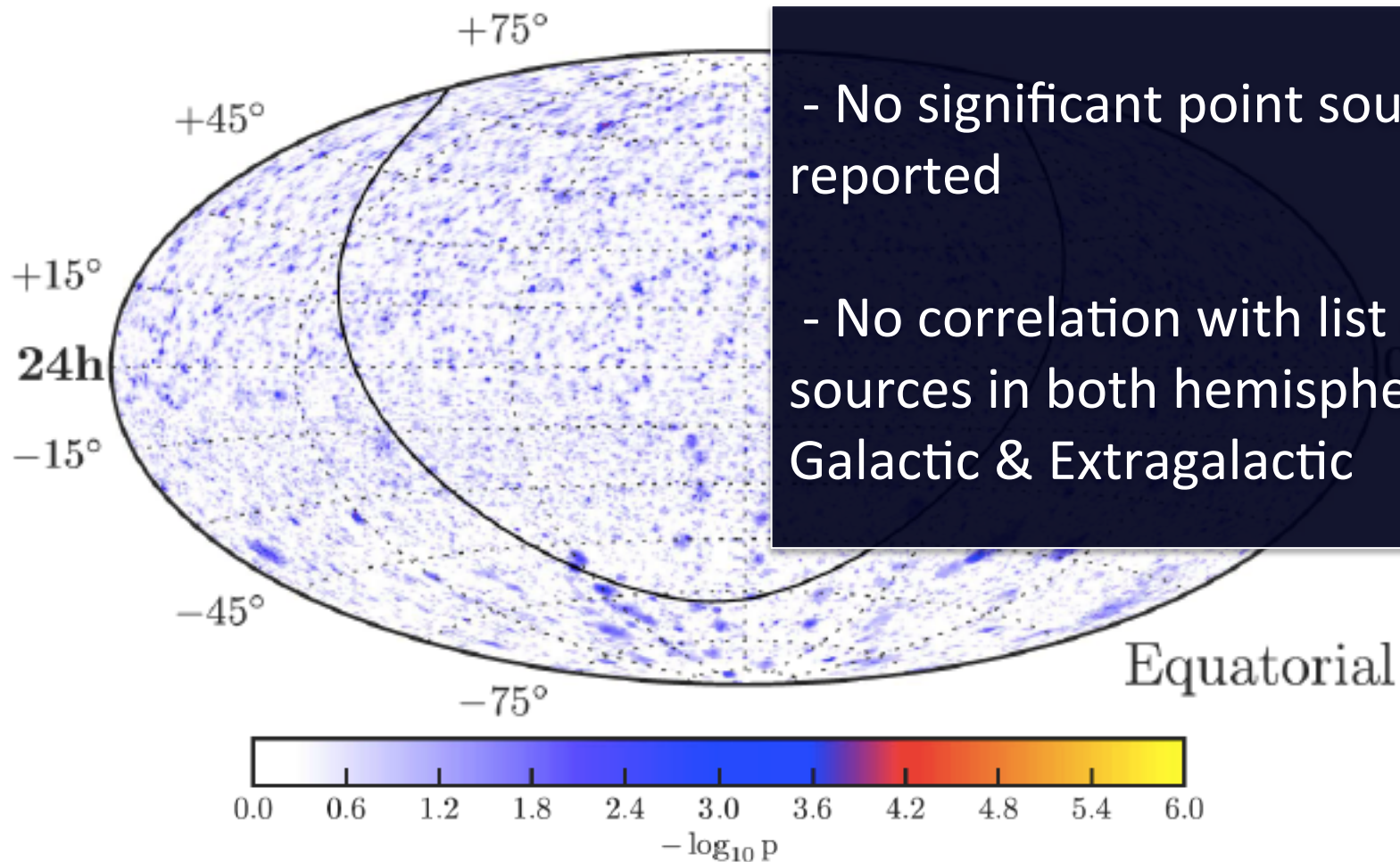


2. Search for an emission from point sources 21

# How to search for astrophysical neutrino sources?



# How to search for astrophysical neutrino sources?



# How to search for astrophysical neutrino sources?

astrophysical

$t = t_0$



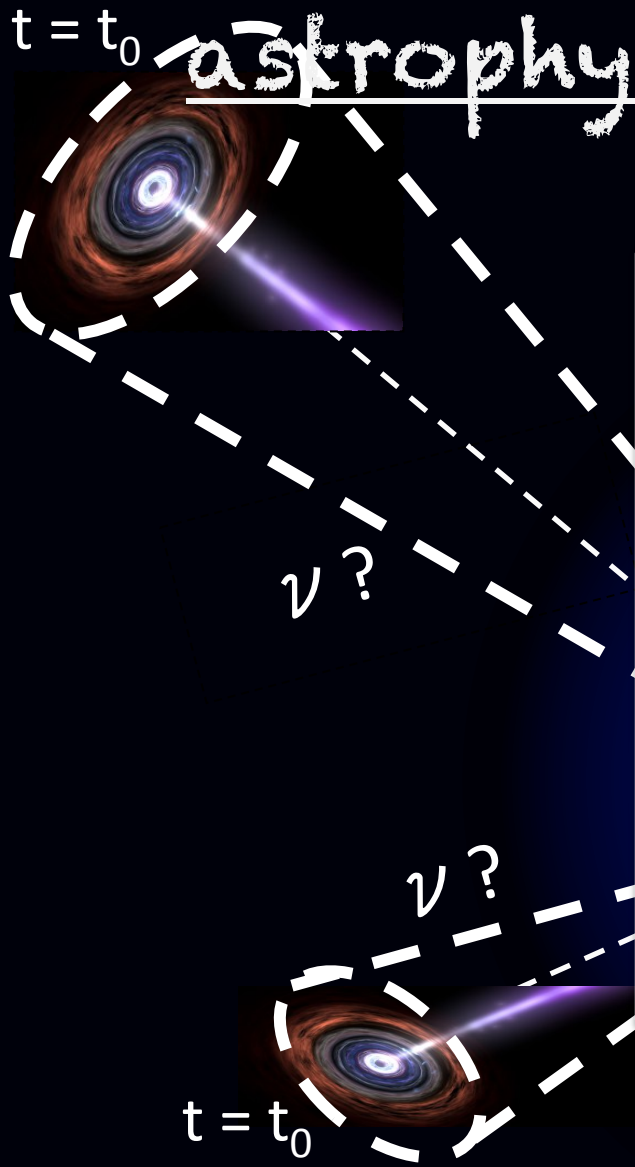
Track:  $\nu_\mu$  CC  
Cascade:  $\nu_e$  CC,  $\nu$  NC

3. Search for an emission from transient sources



# How to search for

## astrophysical neutrino sources?



- Gamma-ray Bursts, Fast radio Burst, Novae,...

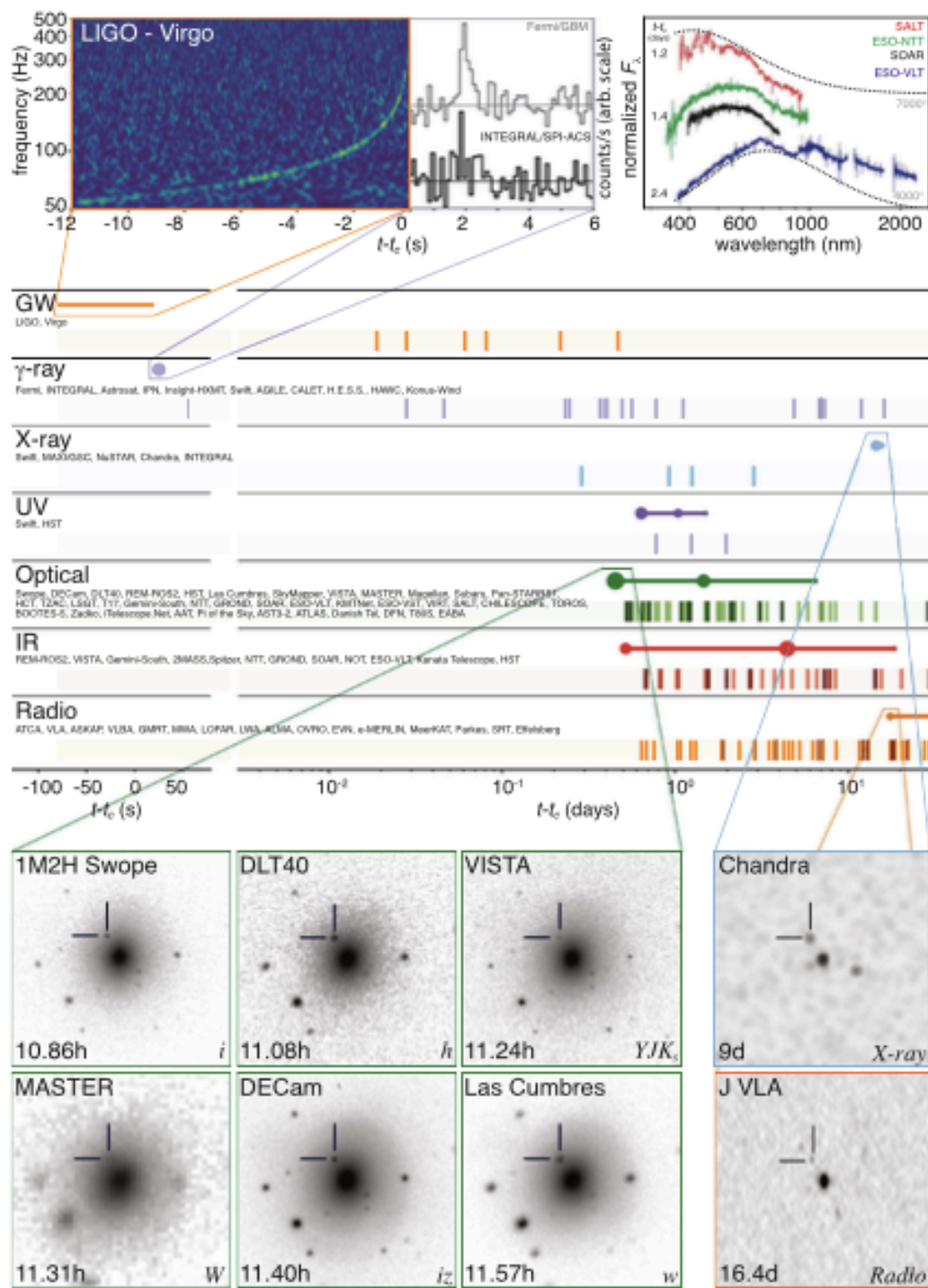
- Gravitational wave events

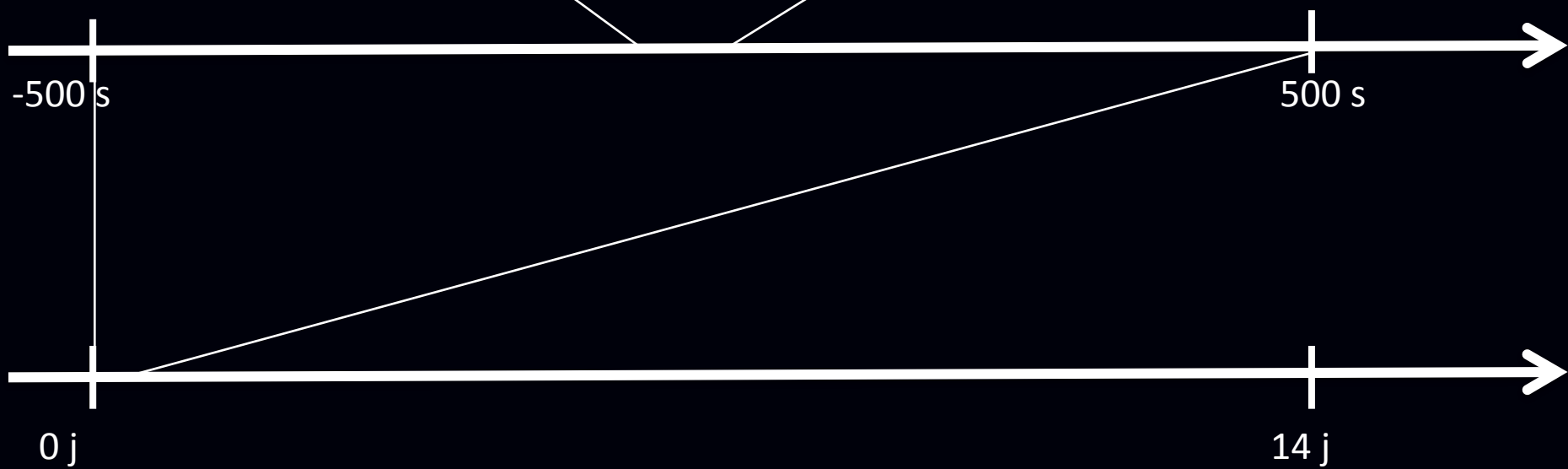
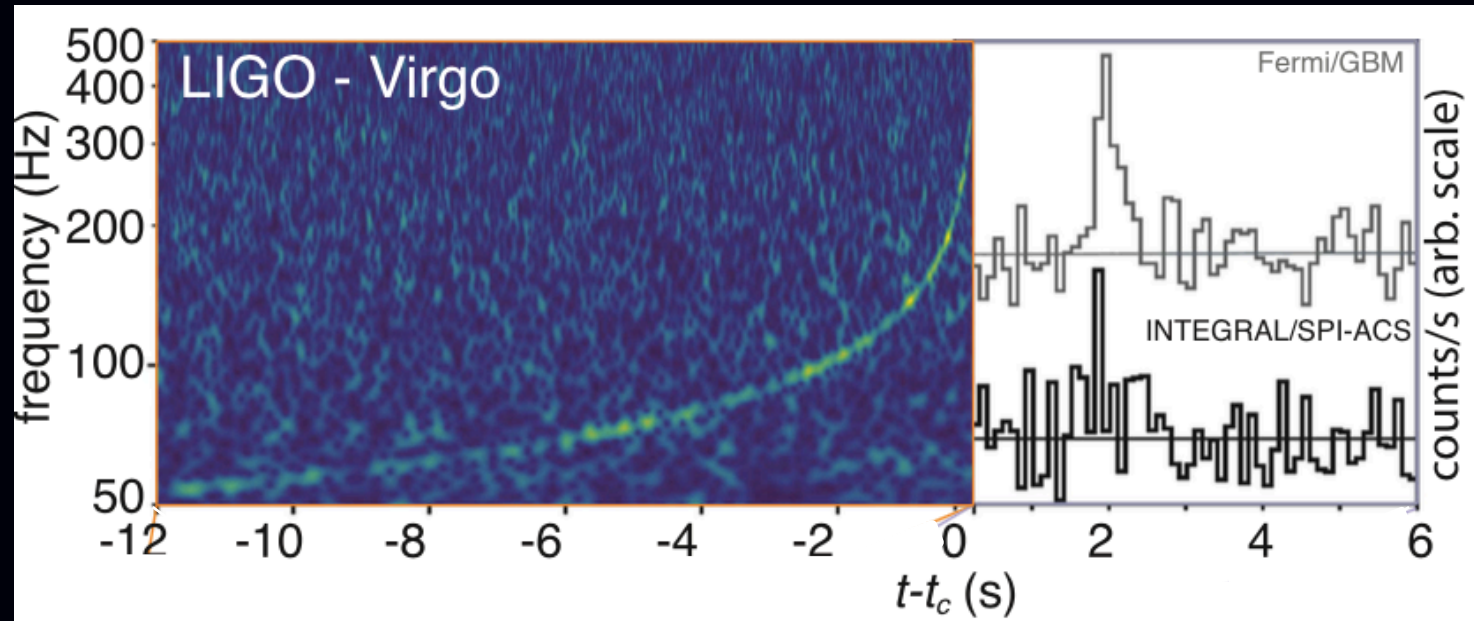
Track:  $\nu_\mu$  CC

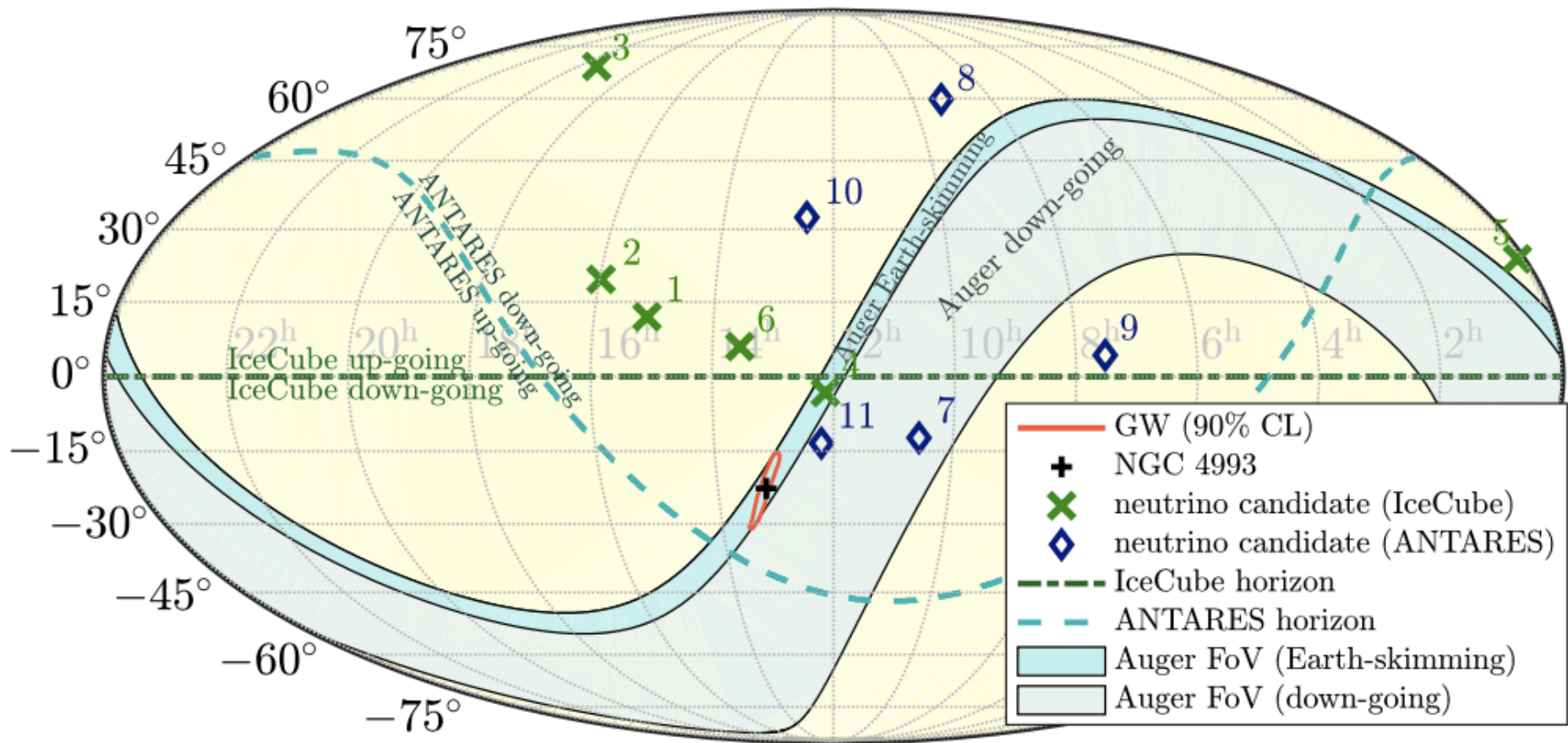
Cascade:  $\nu_e$  CC,  $\nu$  NC

3. Search for an emission from transient sources

17/08/17



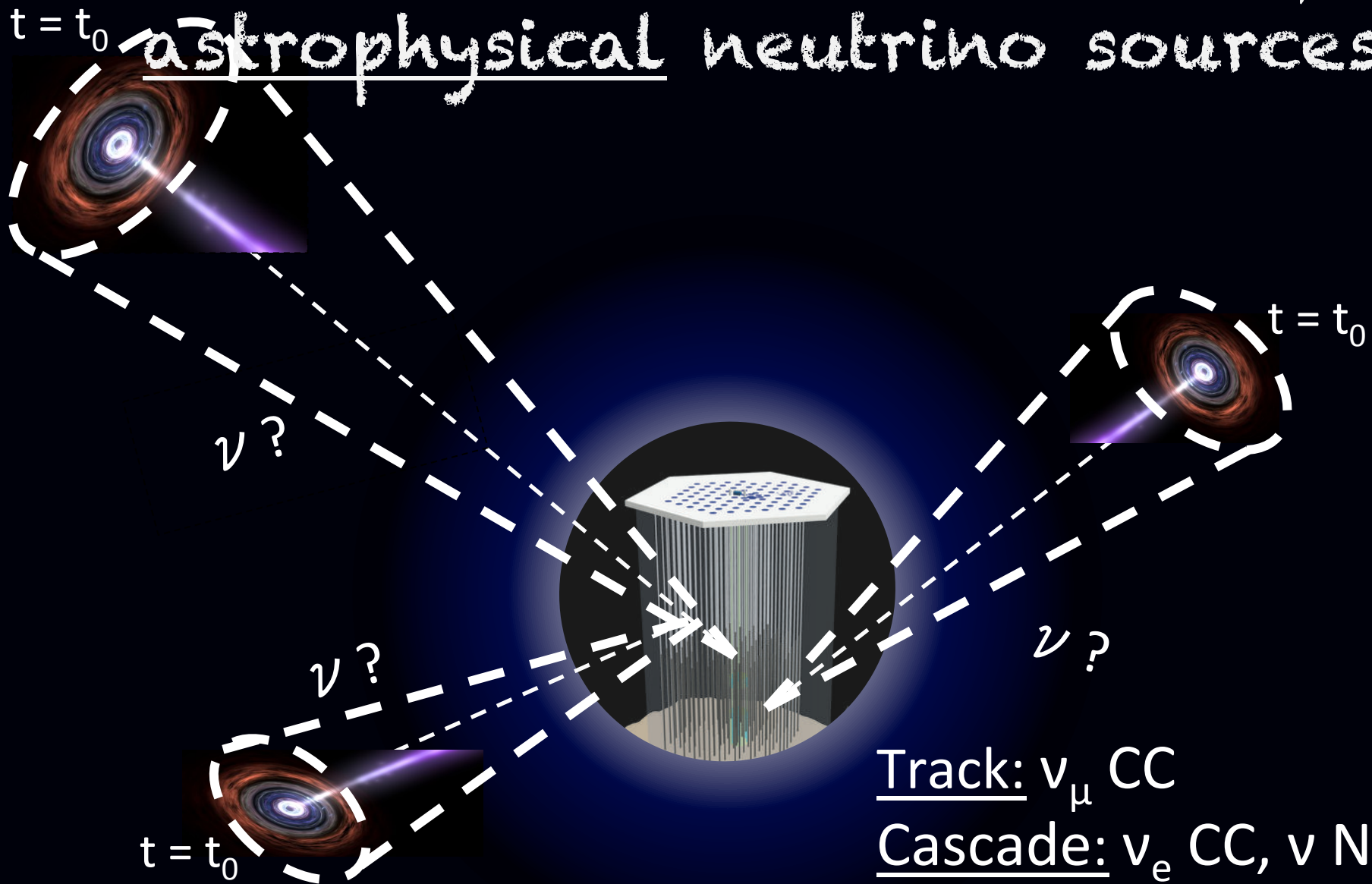




[-500s , +500s]

# How to search for

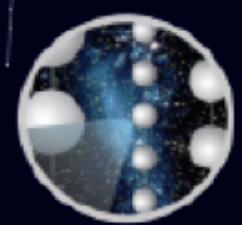
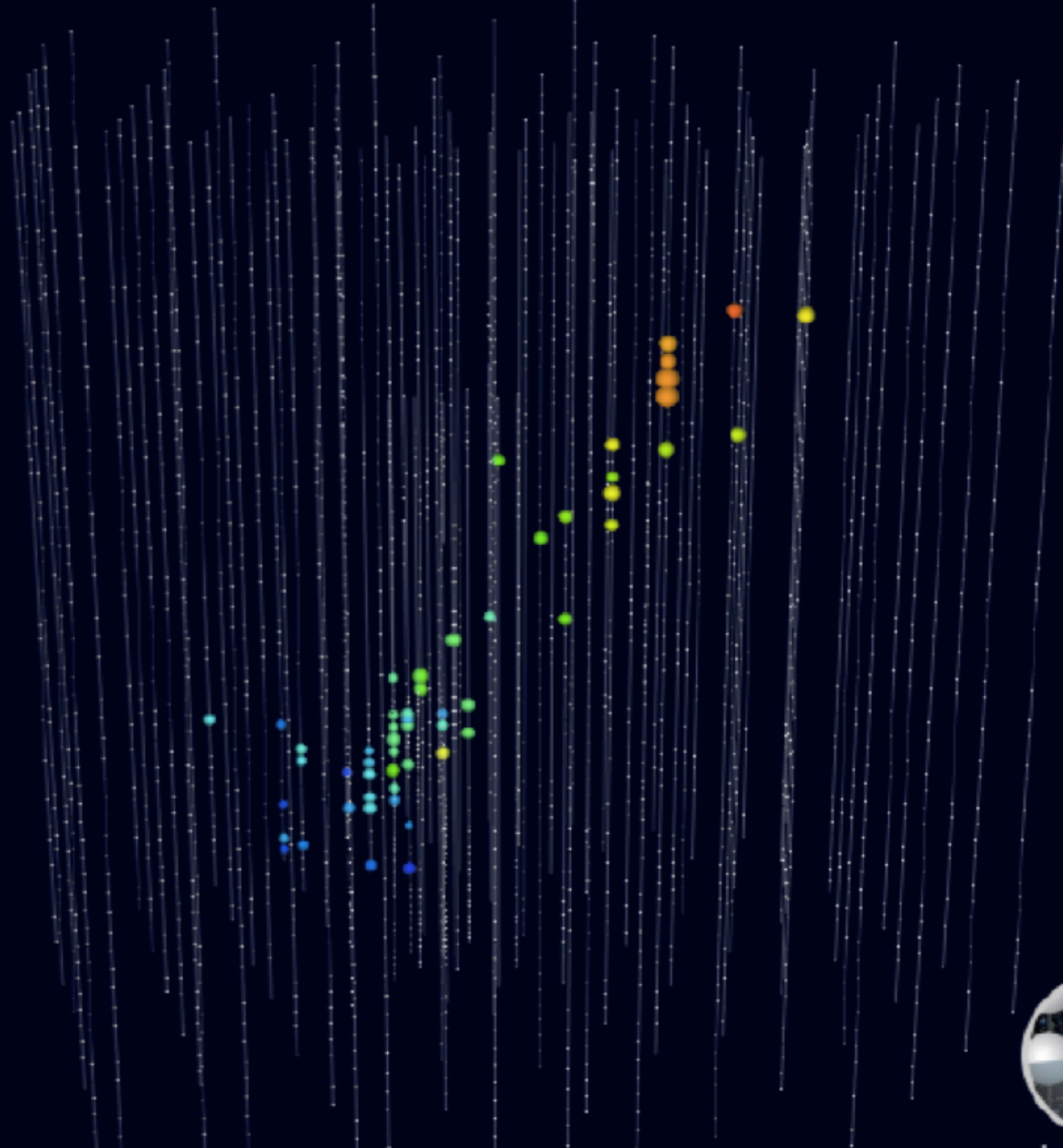
astrophysical neutrino sources?



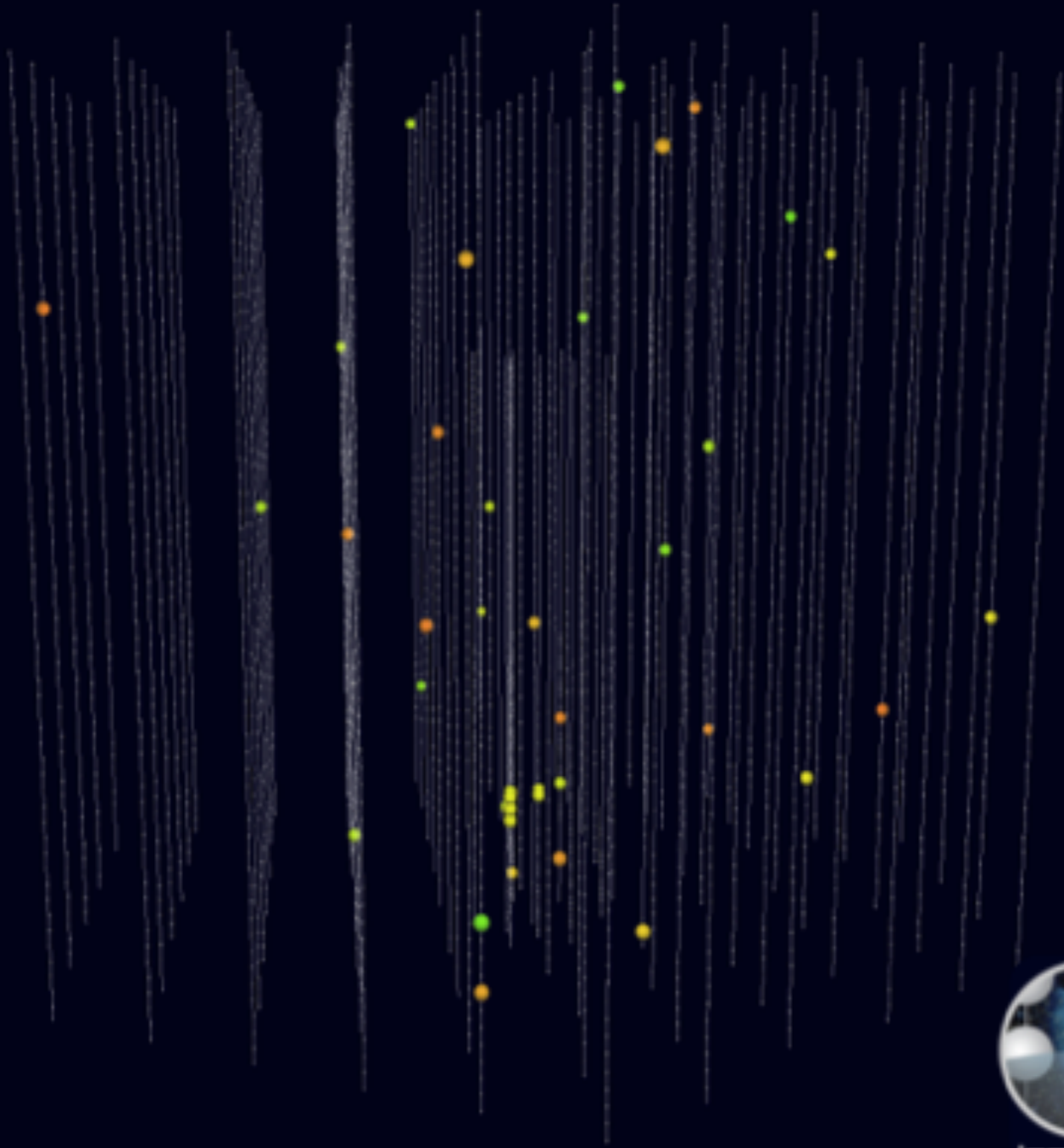
Track:  $\nu_{\mu}$  CC

Cascade:  $\nu_e$  CC,  $\nu$  NC

3. Search for an emission from transient sources



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# Simulated event

GeV neutrino





# How to detect a GeV neutrino signal?

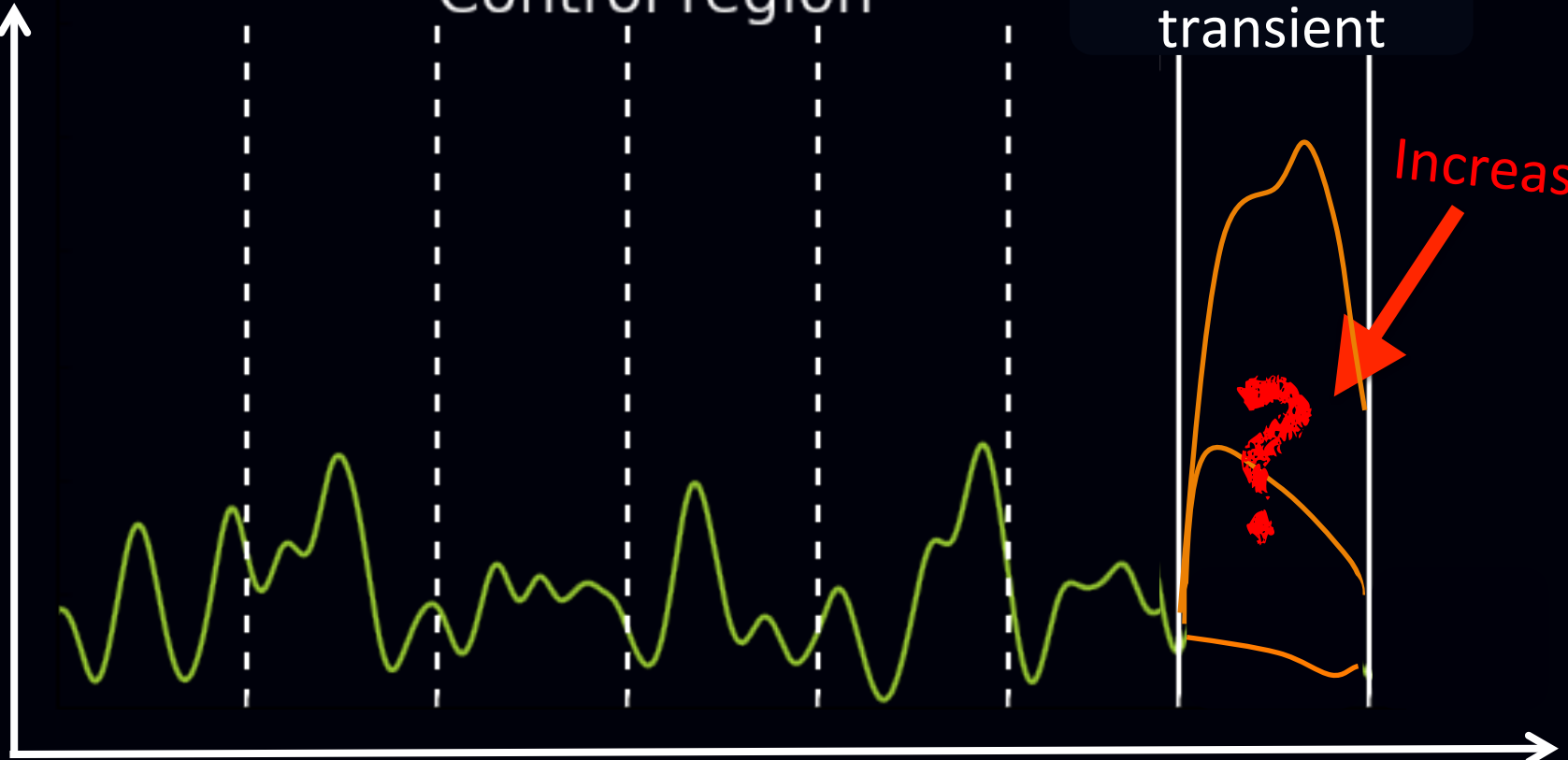
# of events

Control region

Astrophysical transient

Increase?

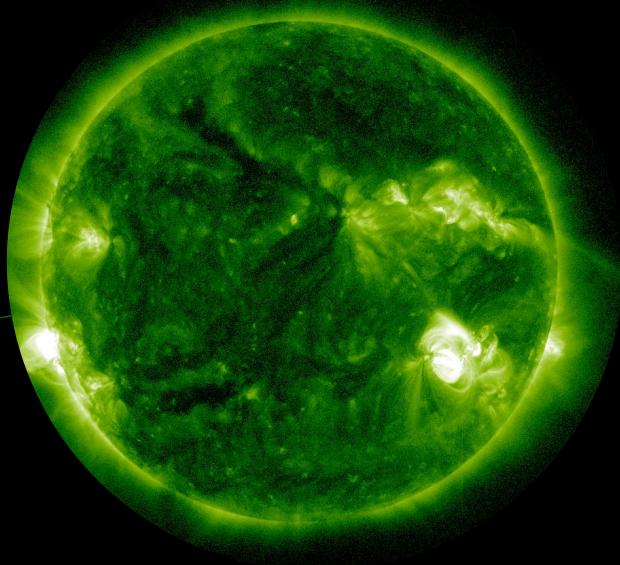
?



Time

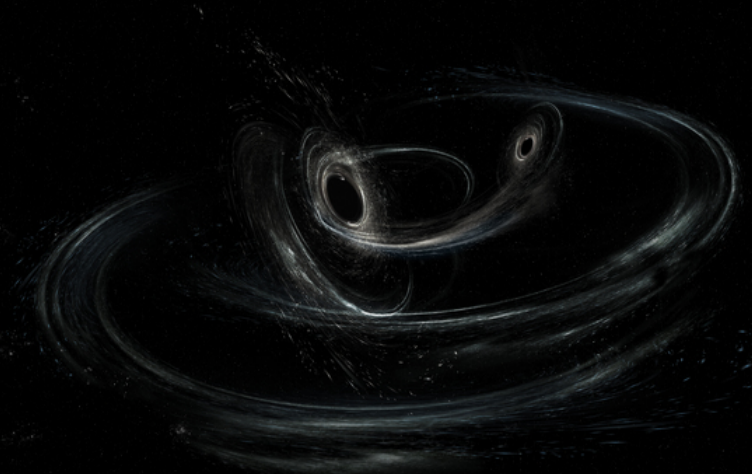
# How to detect a GeV neutrino signal?

Neutrino production  
up to a few GeV



Solar flares

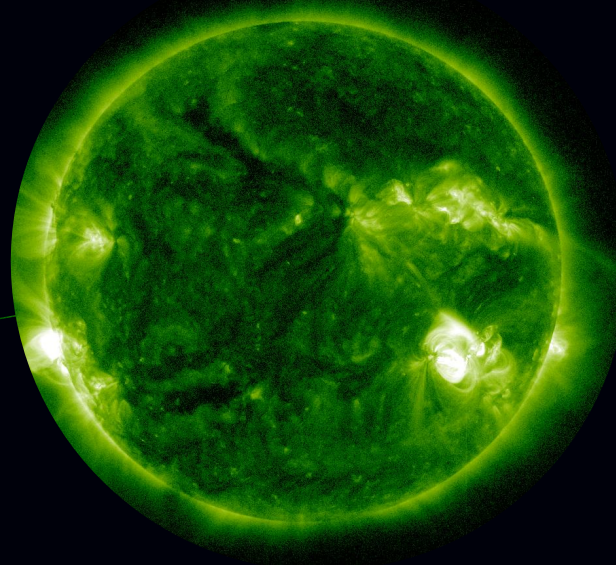
Study from  $\sim 0.5$  GeV  
up to PeV



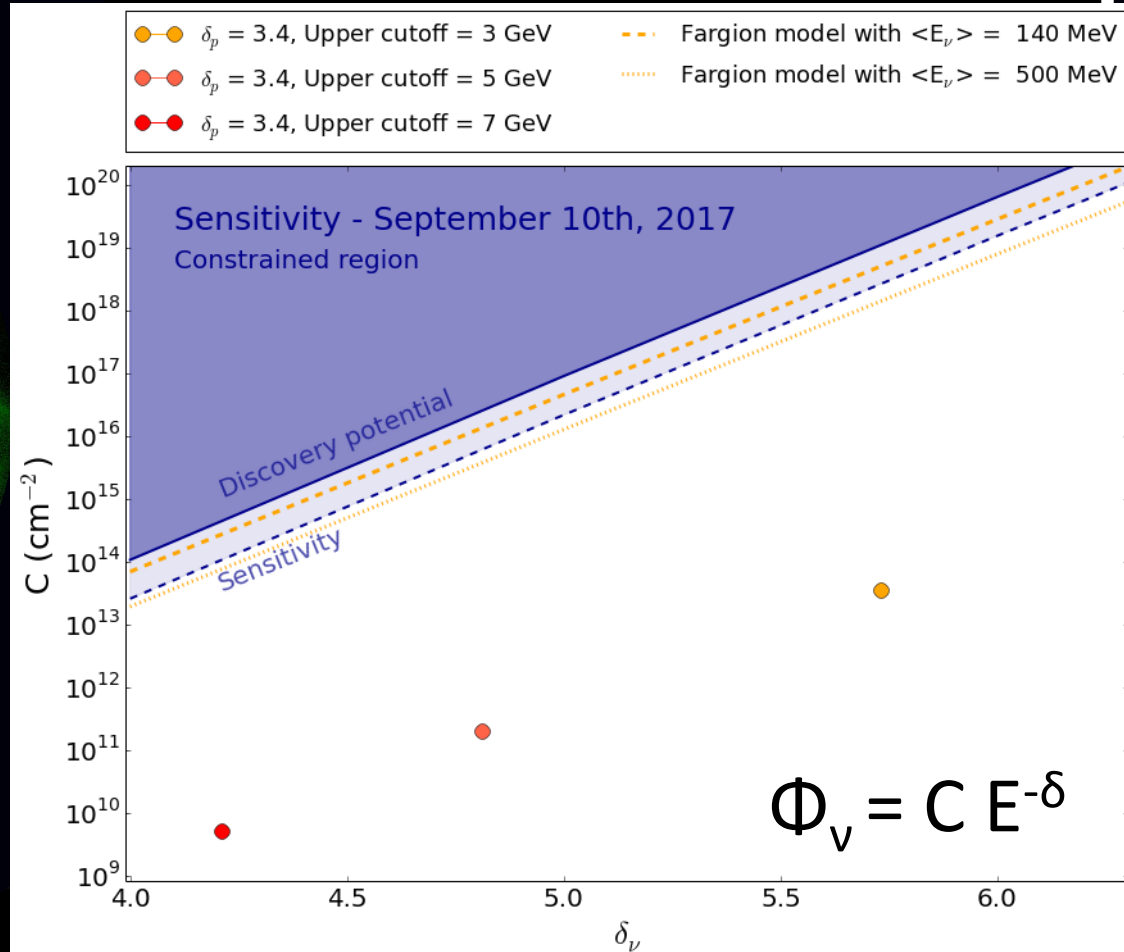
GW events

# How to detect a GeV neutrino signal?

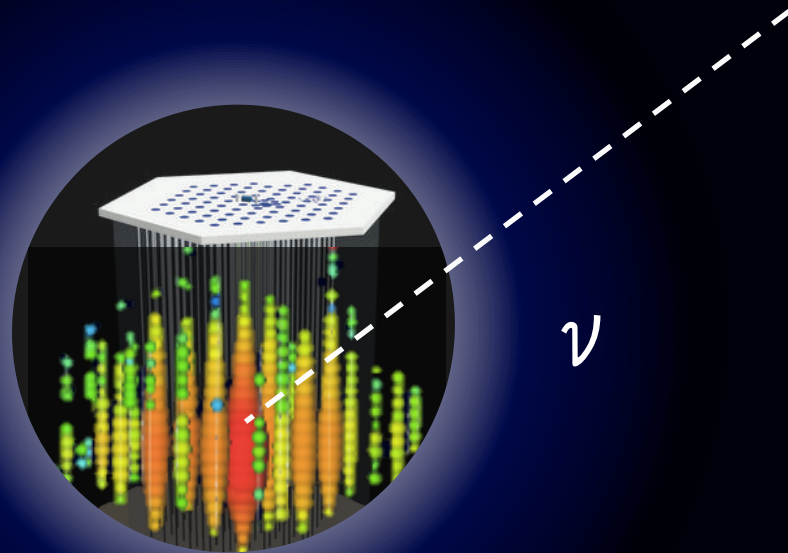
Stay tuned!



Solar flares



# How to search for astrophysical neutrino sources?

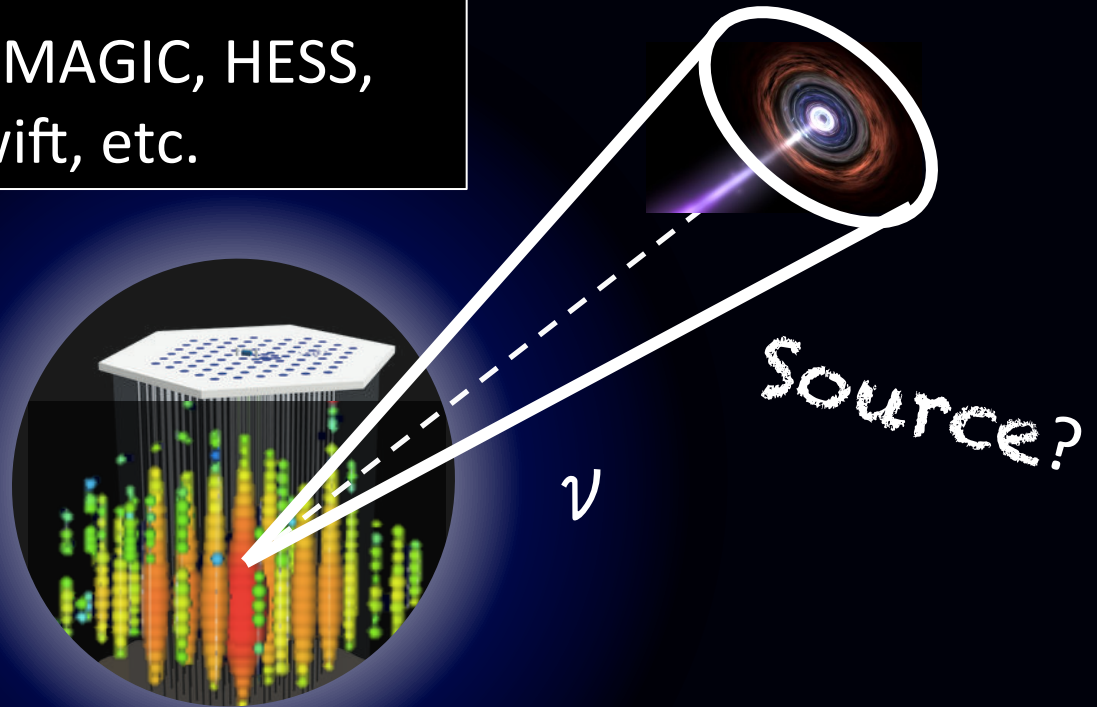


4. Trigger other observatories

# How to search for astrophysical neutrino sources?

Real time!

Follow-up from: VERITAS, MAGIC, HESS, Fermi LAT, Fermi GBM, Swift, etc.



Since 2016:  $\approx 6-8/\text{yr}$

4. Trigger other observatories

# IceCube-170922A & TXS 0506+056

Work on-going

**TITLE: GCN CIRCULAR**  
**NUMBER: 21916**  
**SUBJECT: IceCube-170922A - IceCube observation of a high-energy neutrino candidate event**

DATE: 17  
FROM: E

Claudio Ko  
report on I

On 22 Sep,  
probability  
Extremely  
normal on

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

ATel #10791; Ya  
Ka

Credet

Subjects: Gamma

Referred to by ATel #10844, 10845, 108

[Tweet](#) [Rec](#)

We searched for neutrino event (10787) with all-sky ray Space Telescope and also included

**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

[Tweet](#) [Recommend 448](#)

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

**September 22, 2017: a neutrino alert issued by IceCube  
Fermi and MAGIC identify a spatially coincident flaring blazar  
(TXS 0506+056)**

# Take-home messages

- We detect astrophysical neutrinos
- Sources unindentified so far
- Many new results coming
- We keep pushing the detection limit



Thanks!