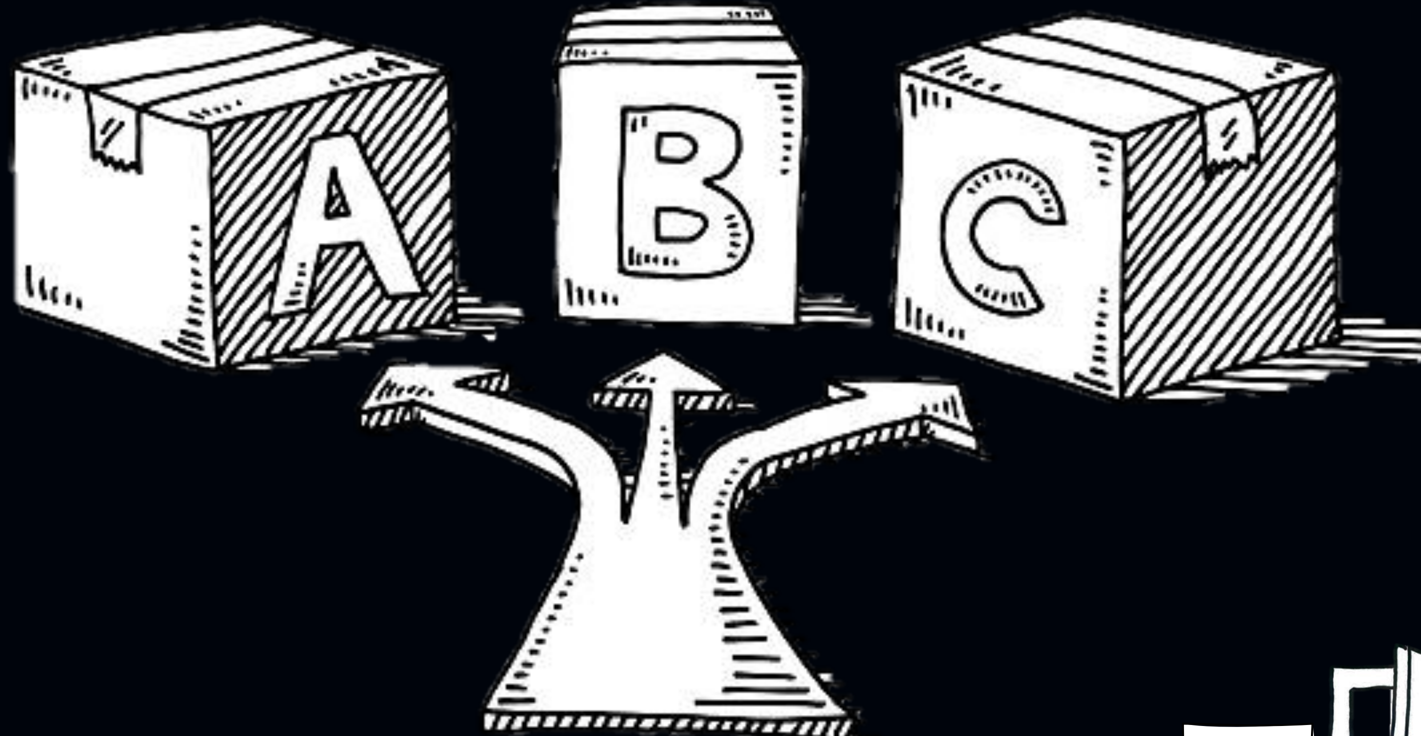
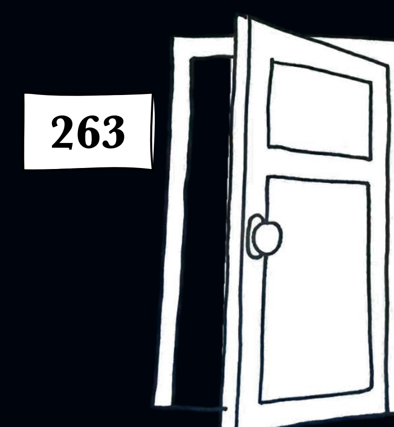
Discovering Neutrino Astronomy

Gwenhaël De Wasseige

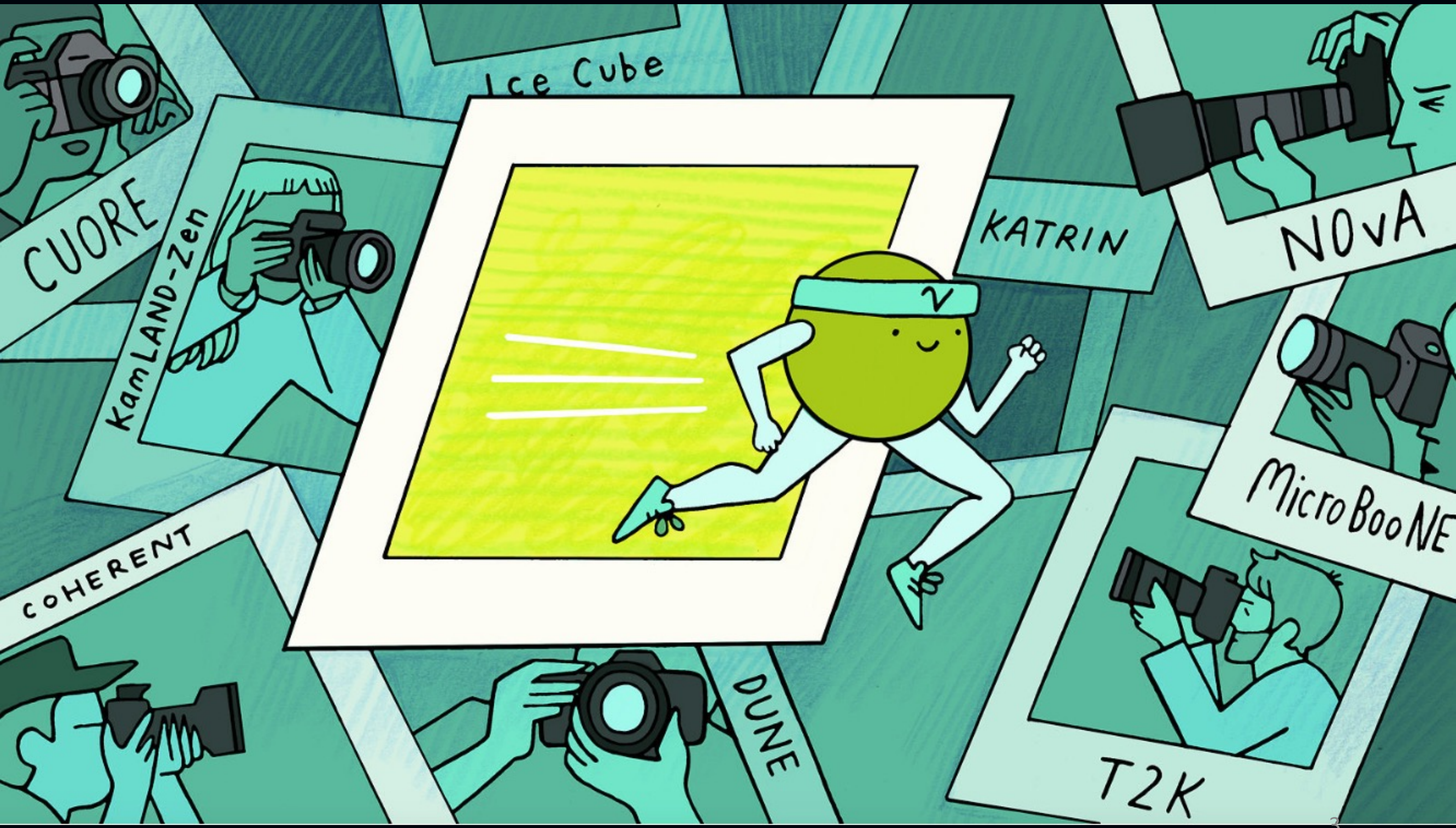
Disclaimer

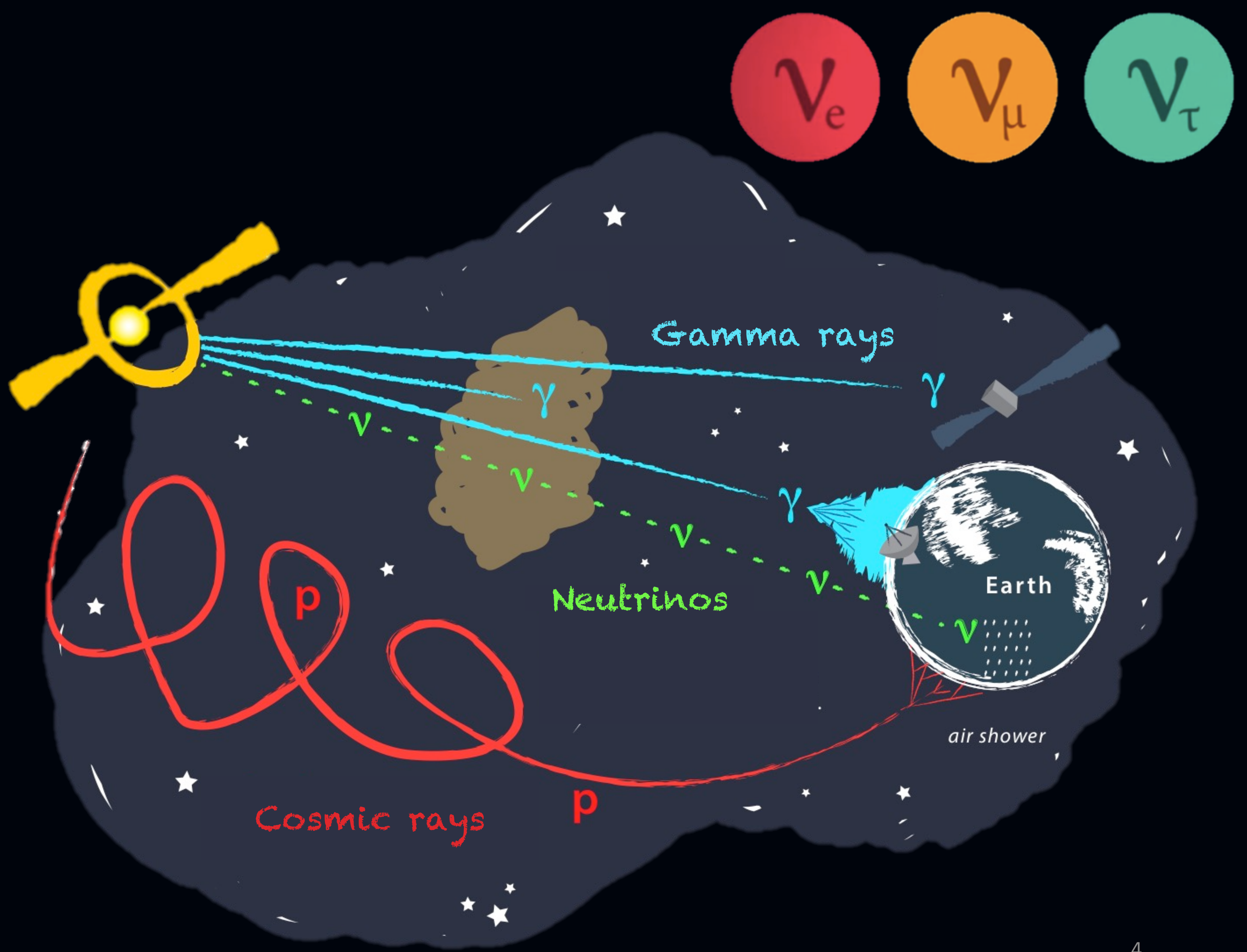


If you did not hear what you were interested in:




ν_e
ν_μ
ν_τ


Ice Cube
CUORE
KamLAND-Zen
KATRIN
NOvA
MicroBooNE
COHERENT
DUNE
T2K

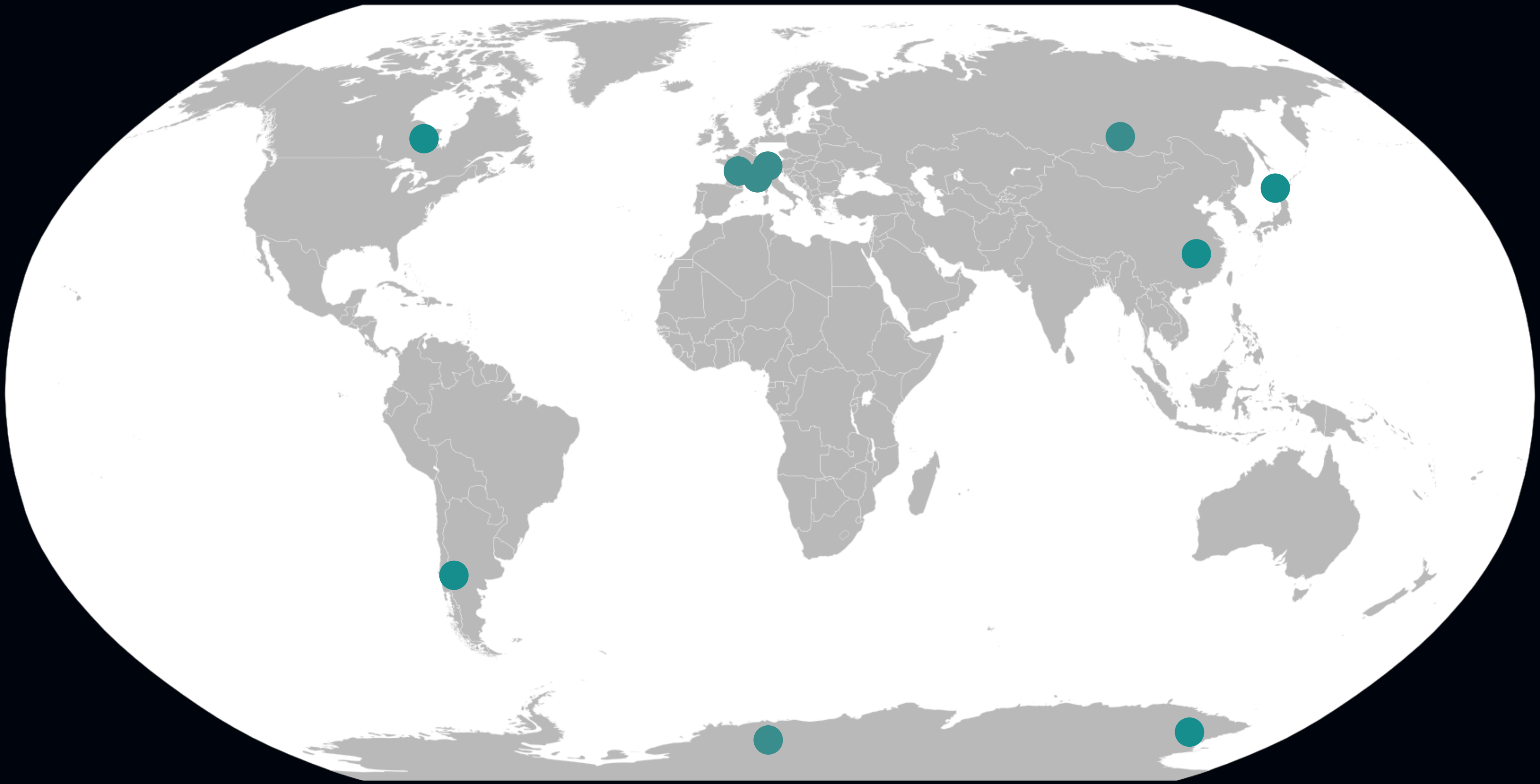

ν_e
ν_μ
ν_τ
Gamma rays
γ
γ
γ
ν
ν
ν
ν
ν
Earth
Neutrinos
p
p
Cosmic rays
air shower

Where are high-energy astrophysical neutrinos coming from?

Can we identify cosmic hadronic accelerators ?

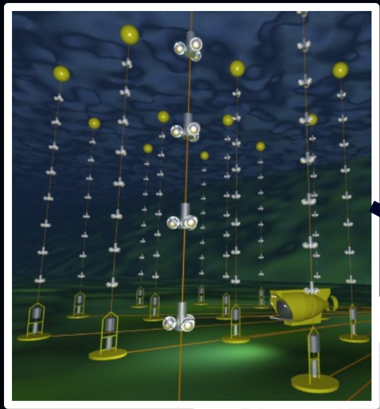
What are the properties of these accelerators?

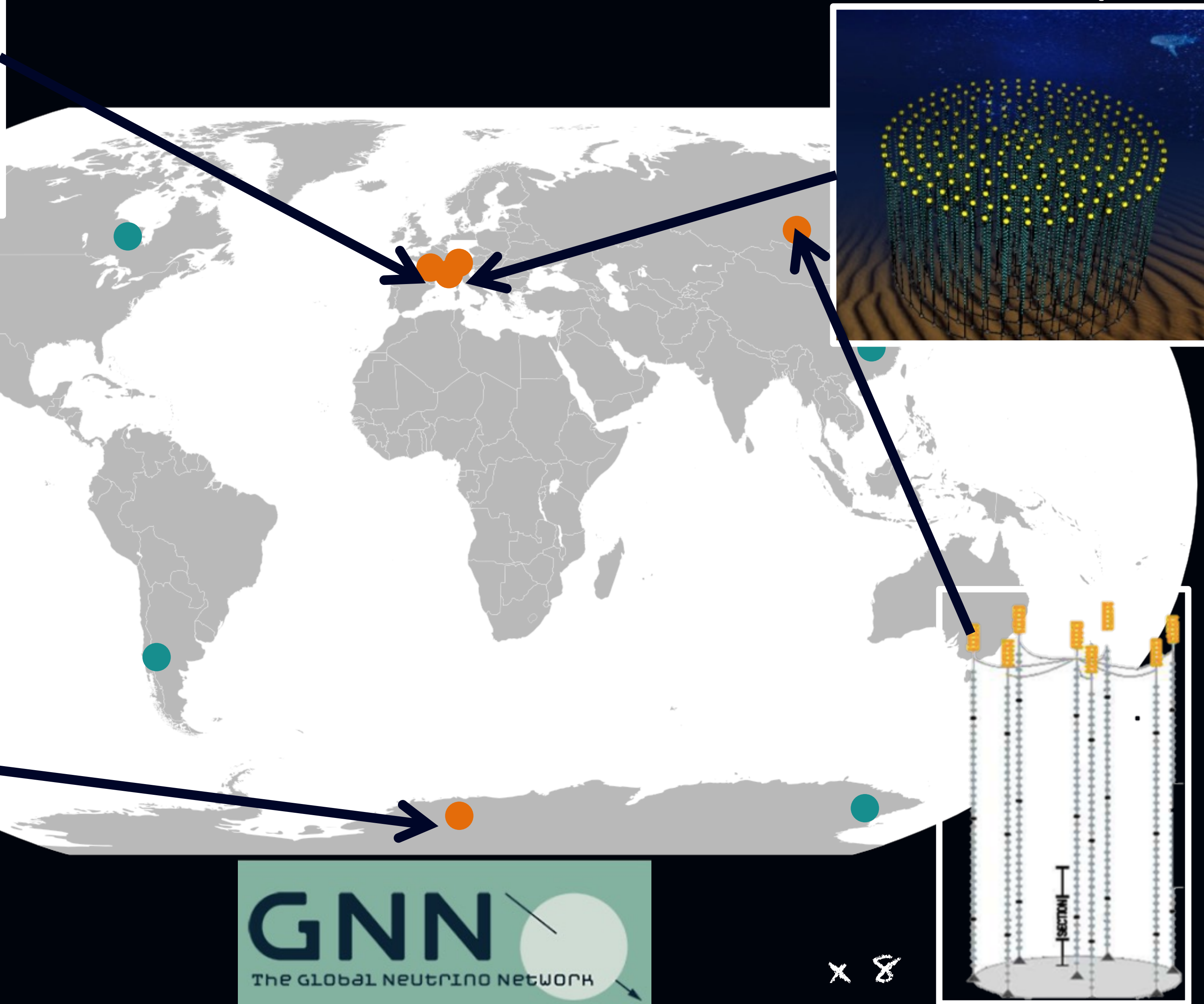
Neutrino telescopes



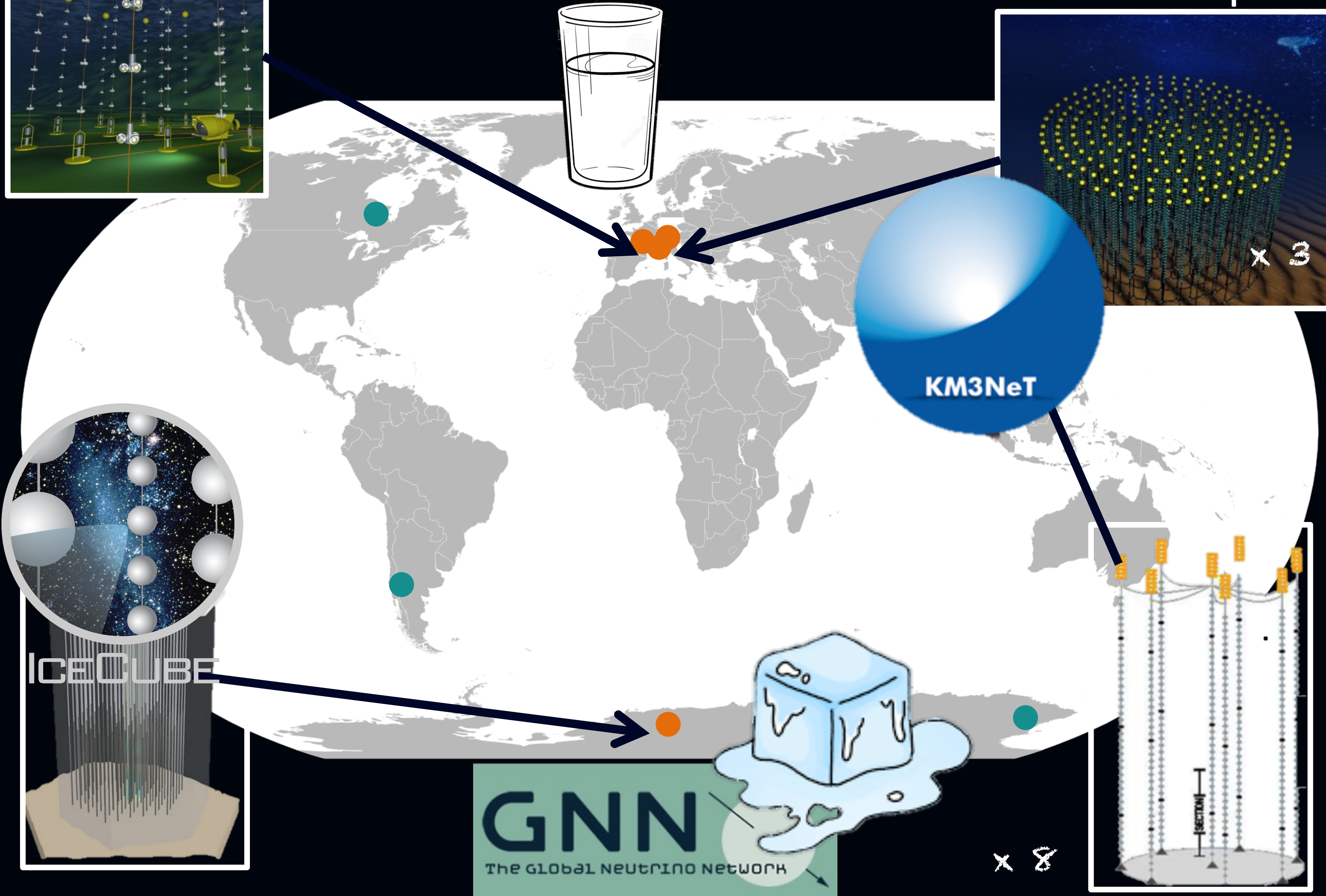
Non-exhaustive list

Neutrino telescopes





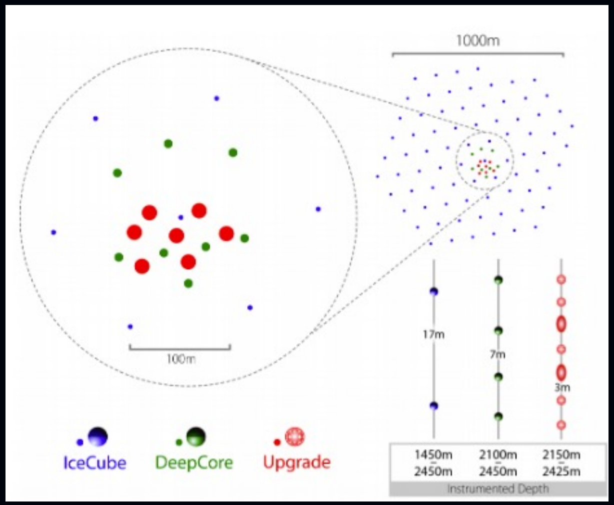
Neutrino telescopes




IceCube
South Pole,
Antarctica

IceCube: exciting times!

IceCube-Upgrade

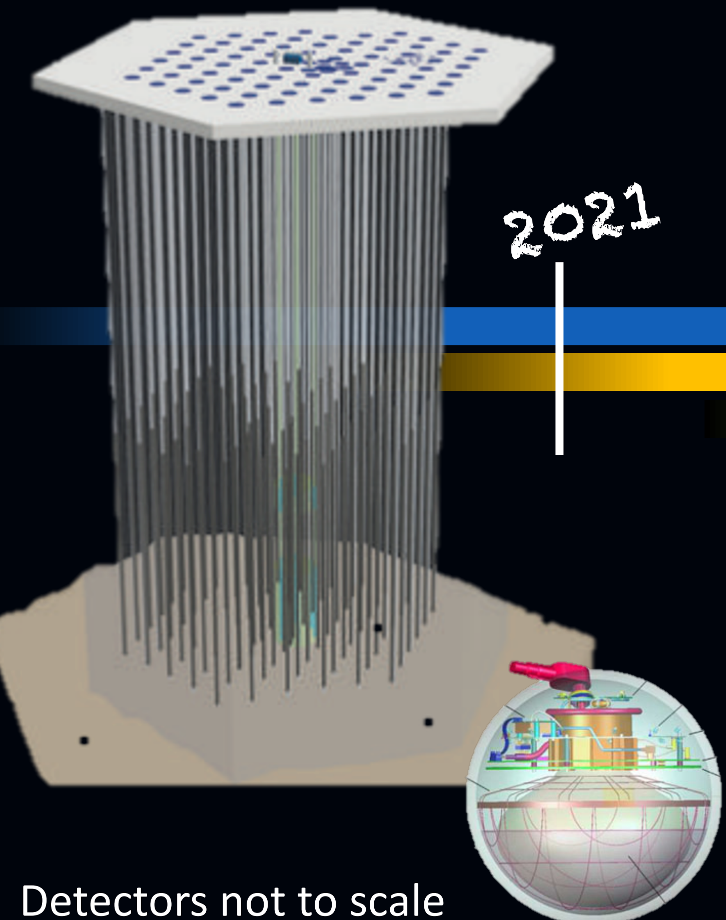


IceCube

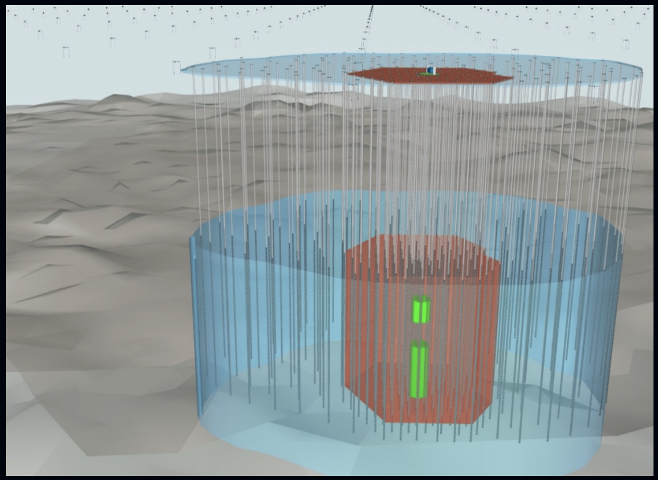
86 strings

7 strings

2021



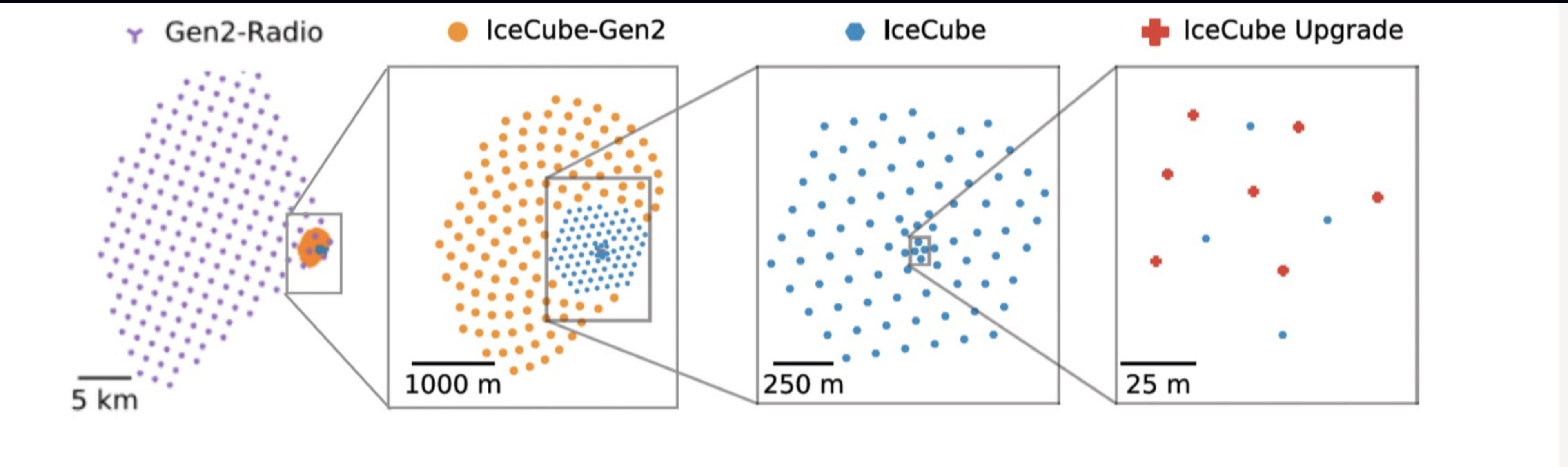
Super detector



IceCube-Gen2

Detectors not to scale

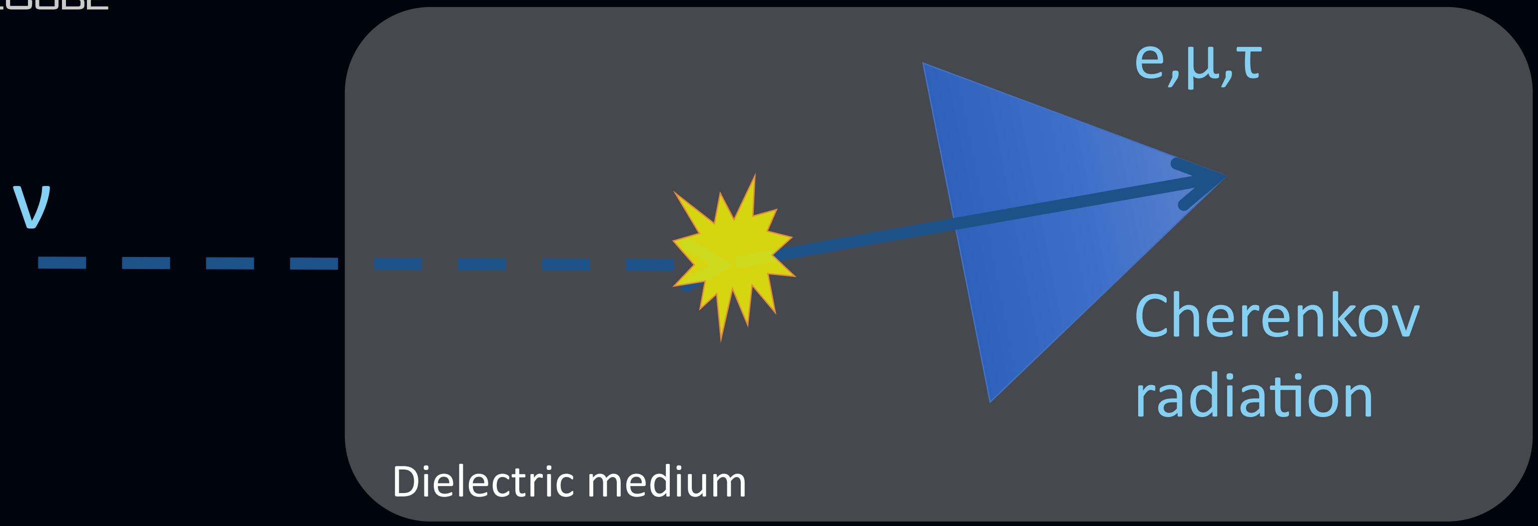
IceCube: exciting times!

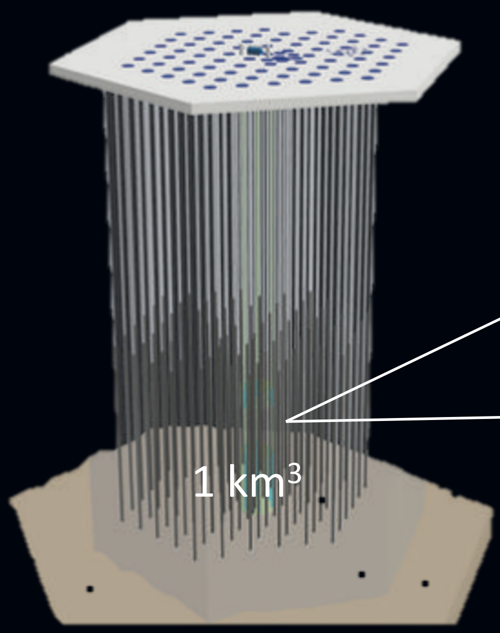


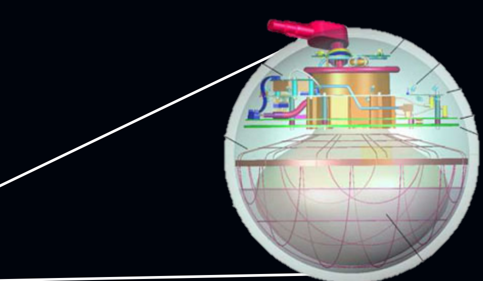
EeV PeV TeV GeV

Energy

How to detect high-energy neutrinos?

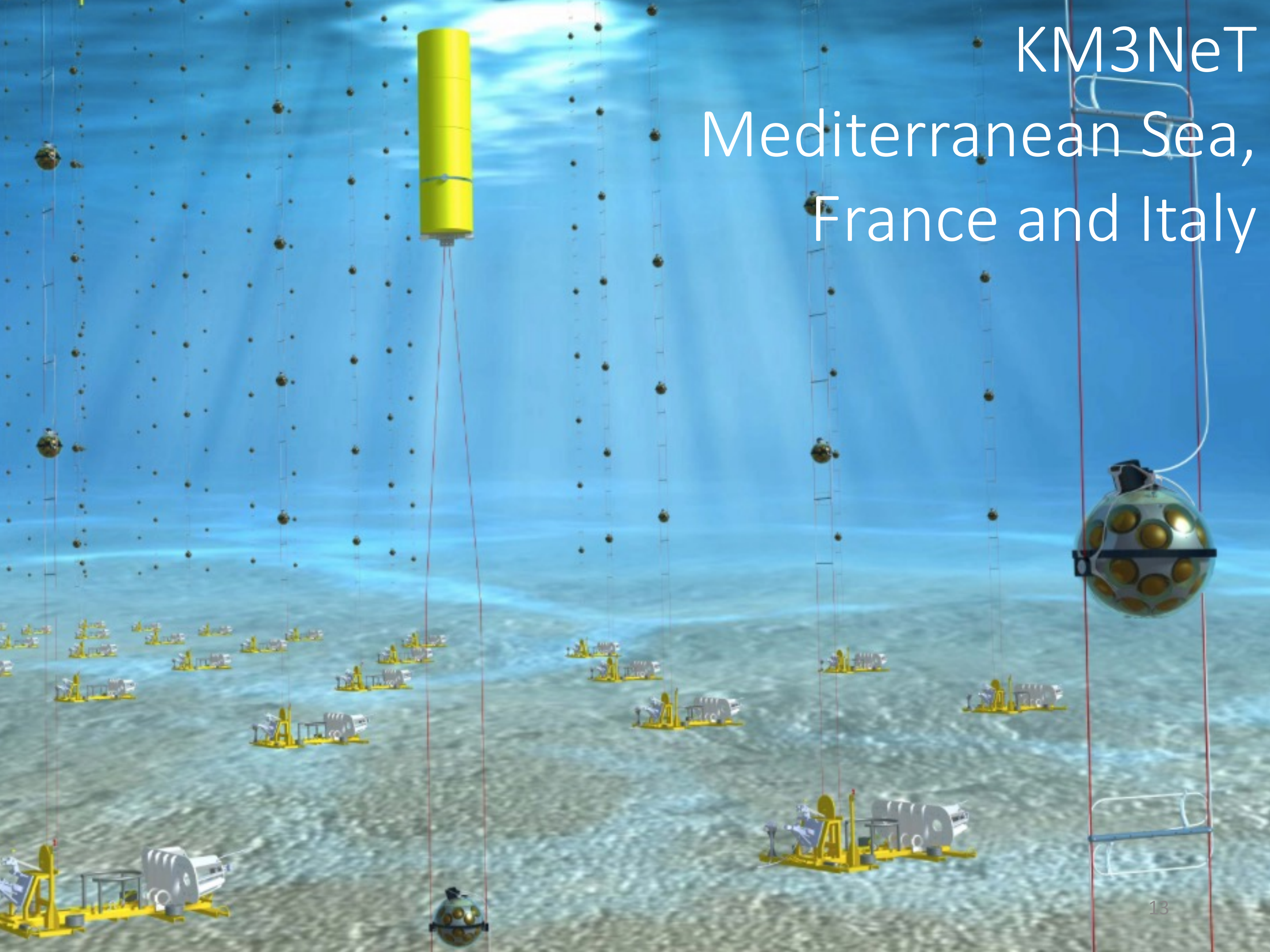






~ 5000 sensors or
Digital Optical Modules (DOMs)

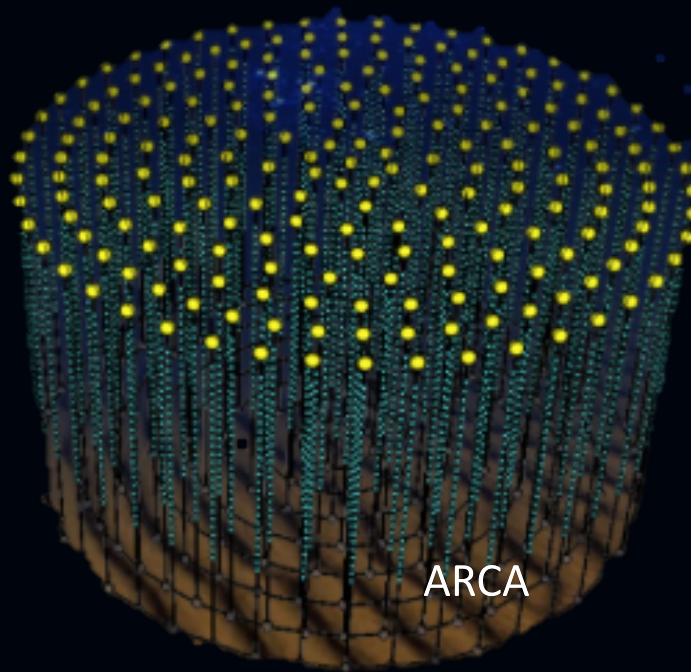
KM3NeT Mediterranean Sea, France and Italy



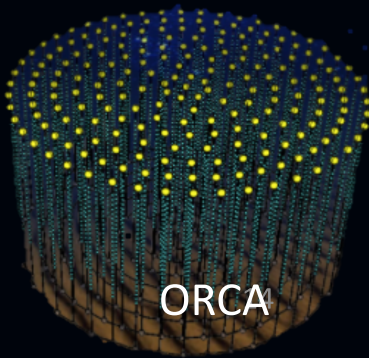
ANTARES and KM3NeT: exciting times!

2021

More than 15 years of data taking!



8 ARCA Detection Unit
6 ORCA Detection Units



Detectors not to scale

ANTARES and KM3NeT: exciting times!

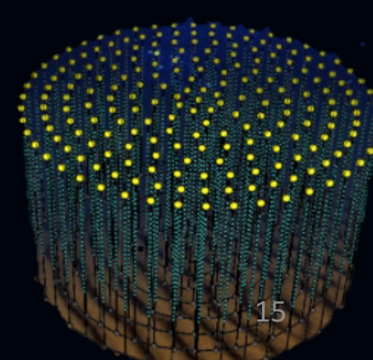
Expected for the next 6 months:

- 7 + 2-3 more ORCA DUs
- ORCA Instrumentation Unit
- 15 more ARCA DUs

2021

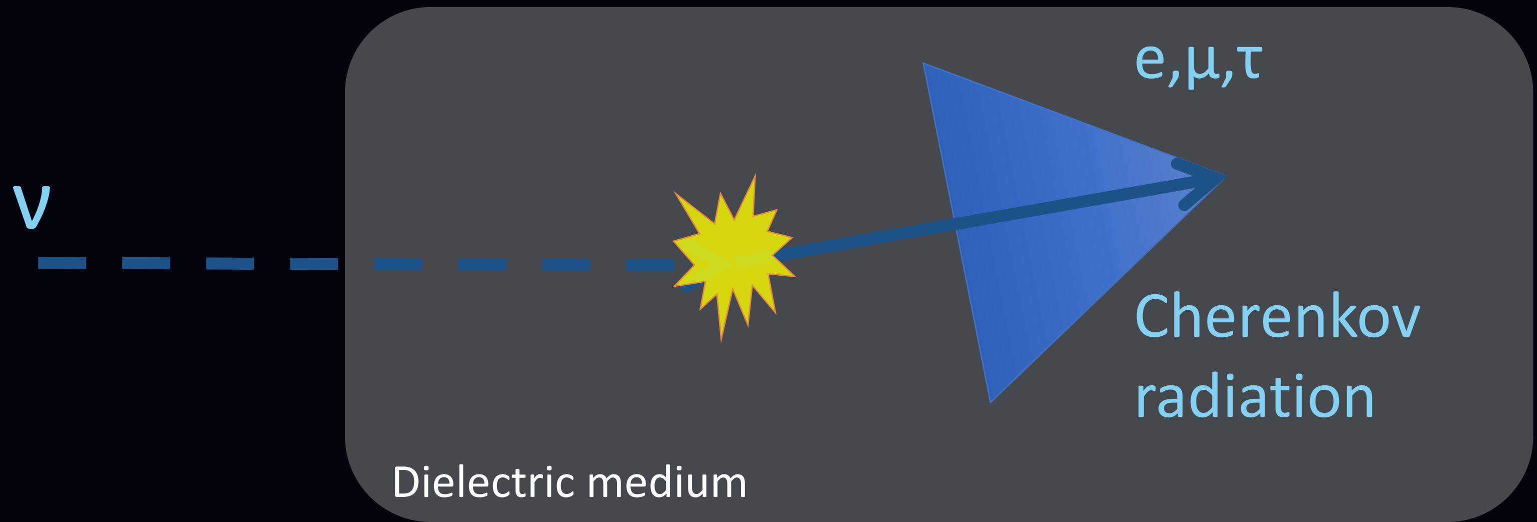
More than 15 years of data taking!

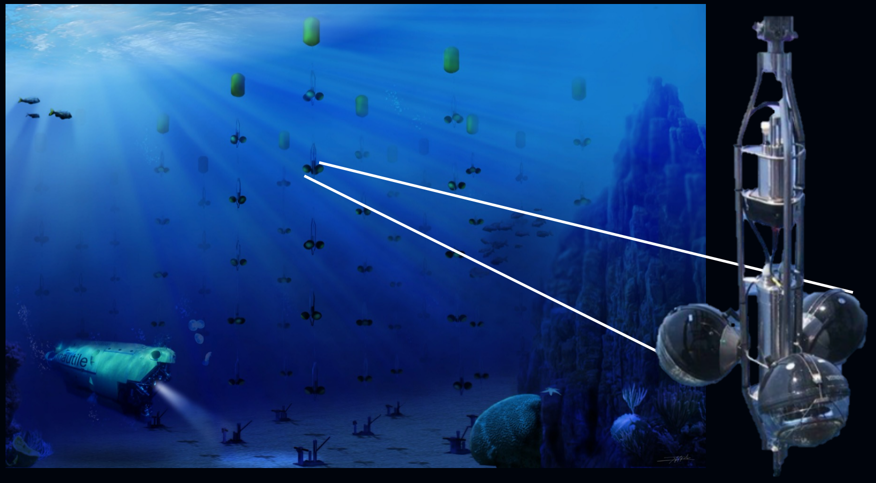
8 ARCA Detection Unit
6 ORCA Detection Units



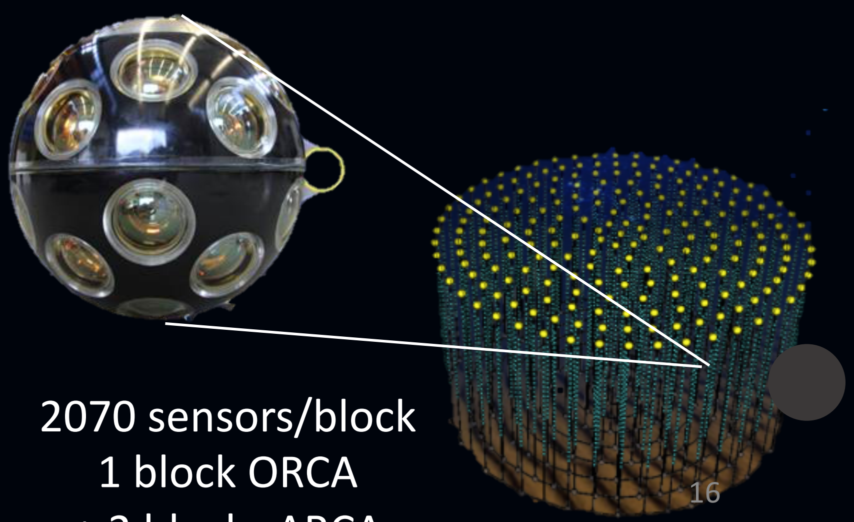
Detectors not to scale

How to detect high-energy neutrinos?



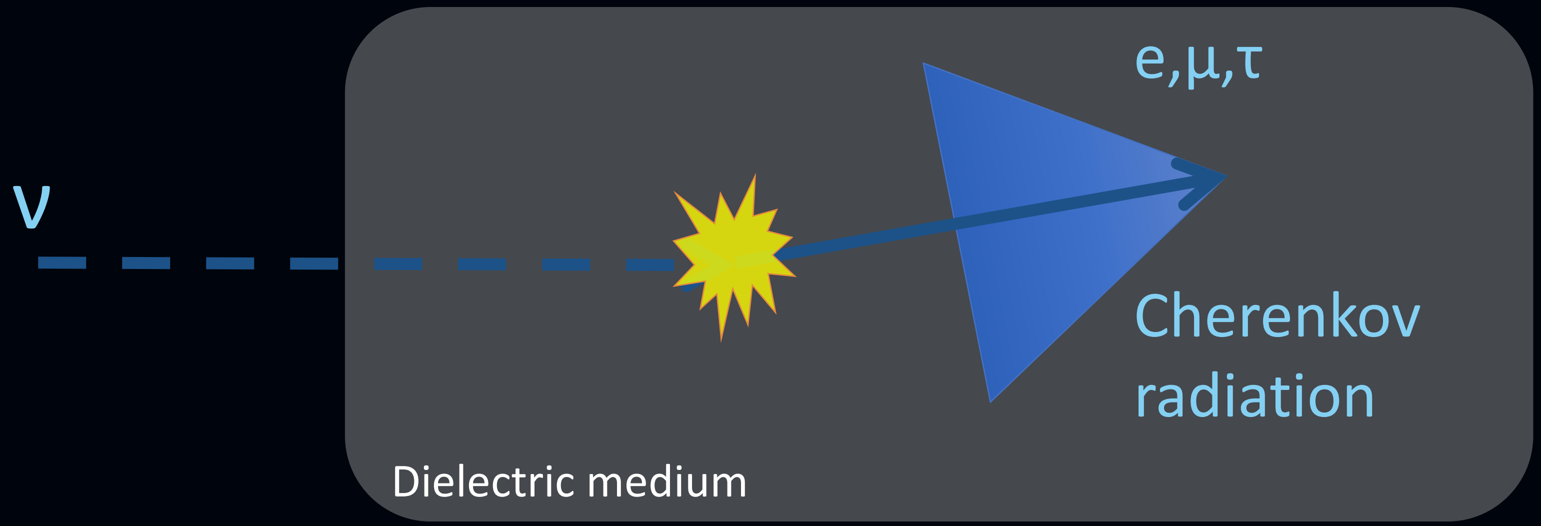


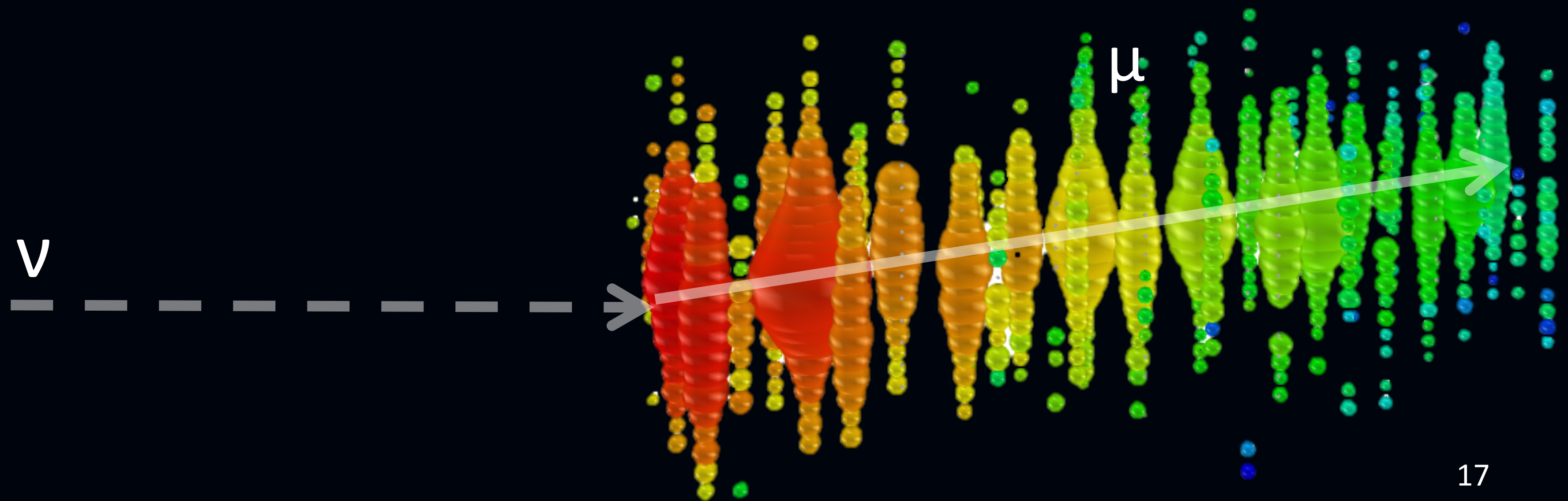
885 sensors



2070 sensors/block
1 block ORCA
+ 2 blocks ARCA

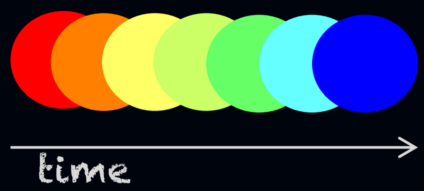
How to detect high-energy neutrinos?



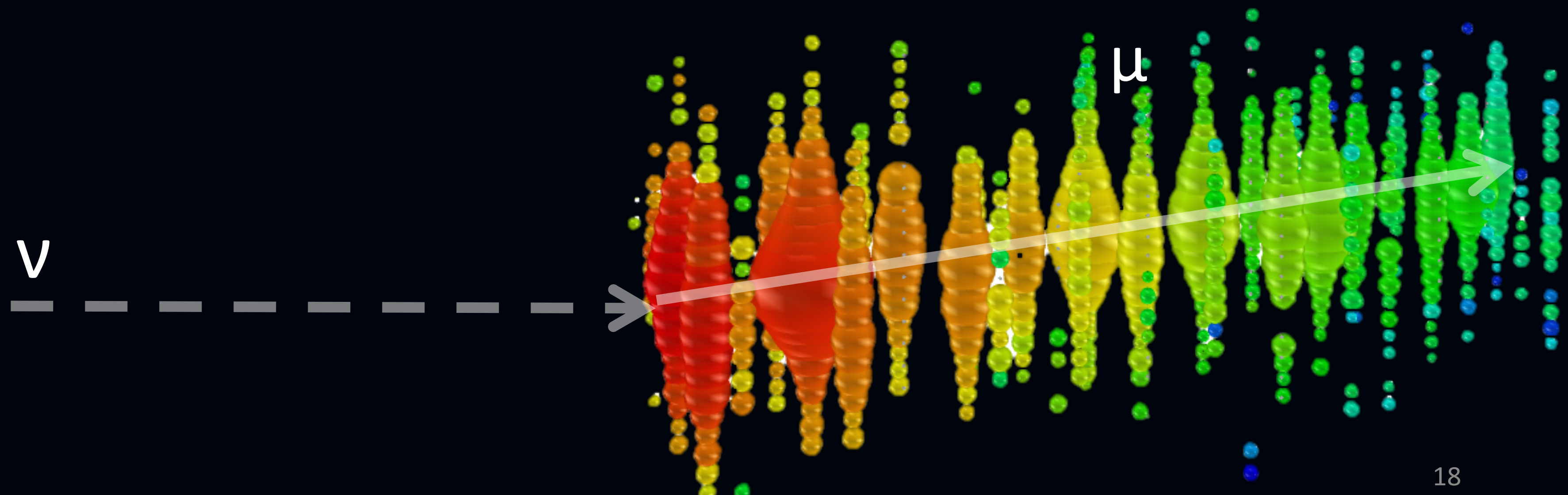


Which information can we get?

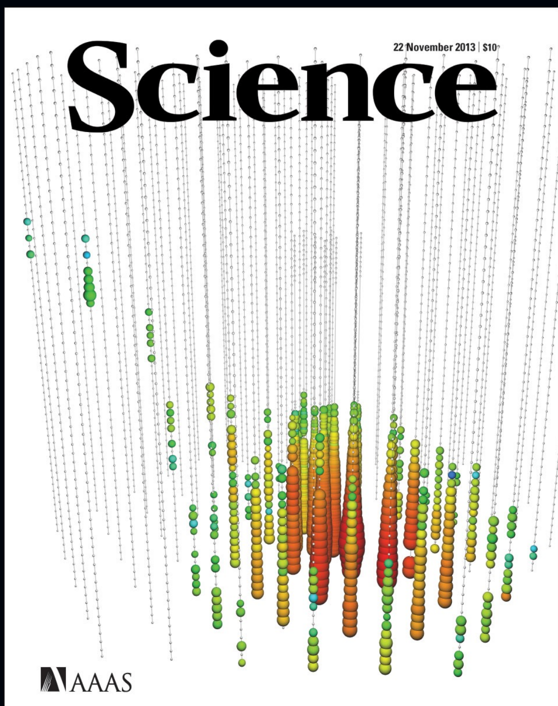
- Amount of light -> Energy
- Timing -> Direction



- Topology (track/cascade) -> Flavour

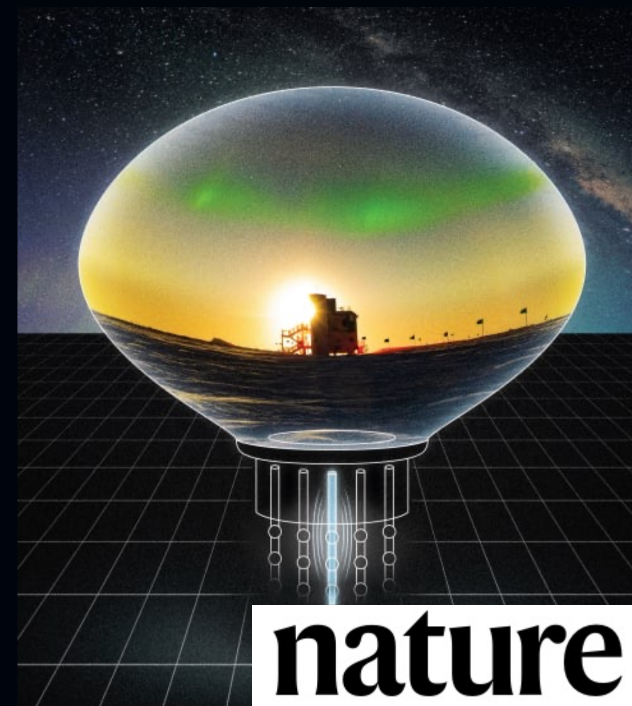


What are the biggest achievements so far?



Diffuse astrophysical neutrino flux

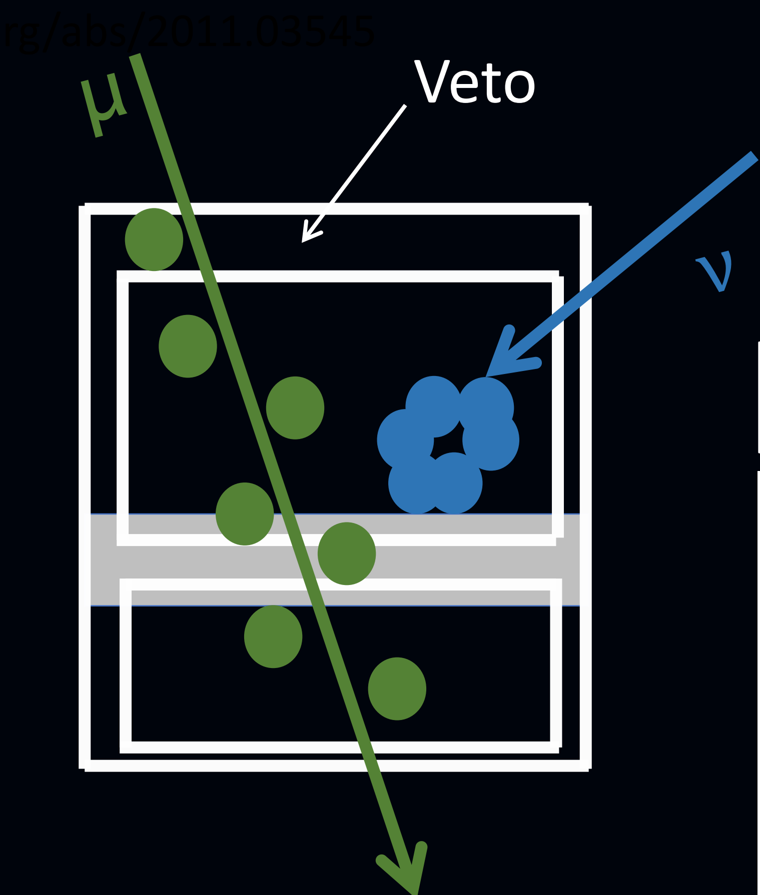
Joint neutrino-EM detection



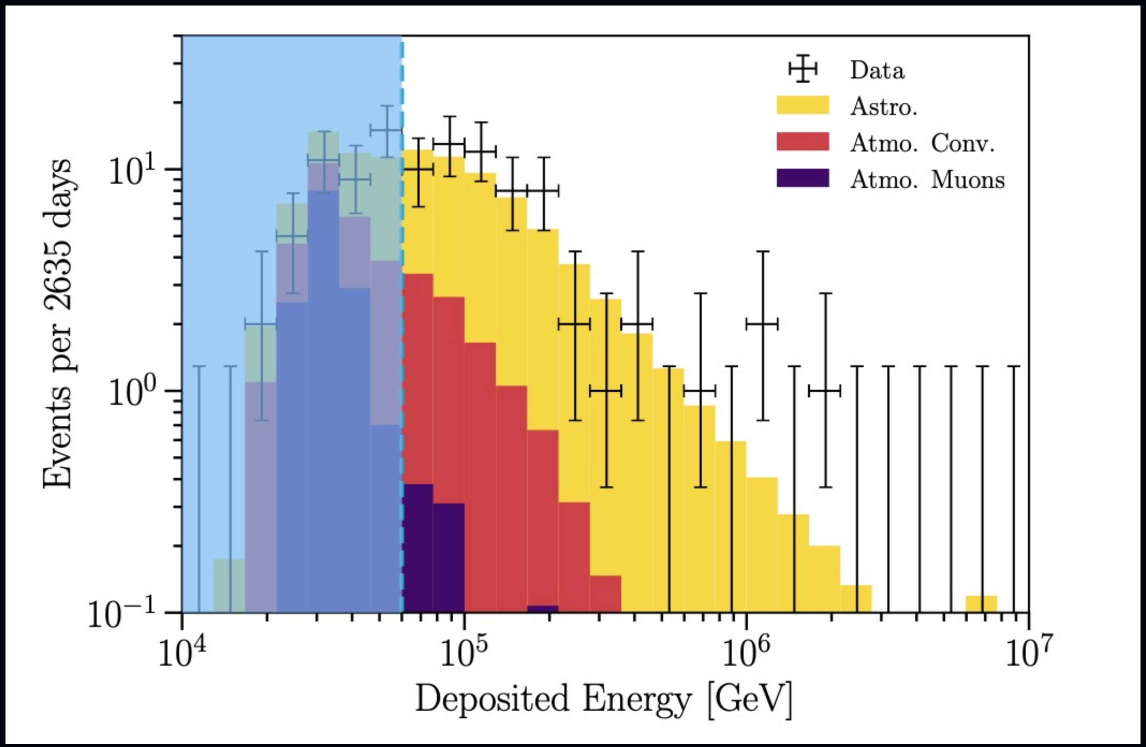
First Glashow resonance event

https://arxiv.org/abs/2011.03545

Diffuse neutrino flux 7.5 year

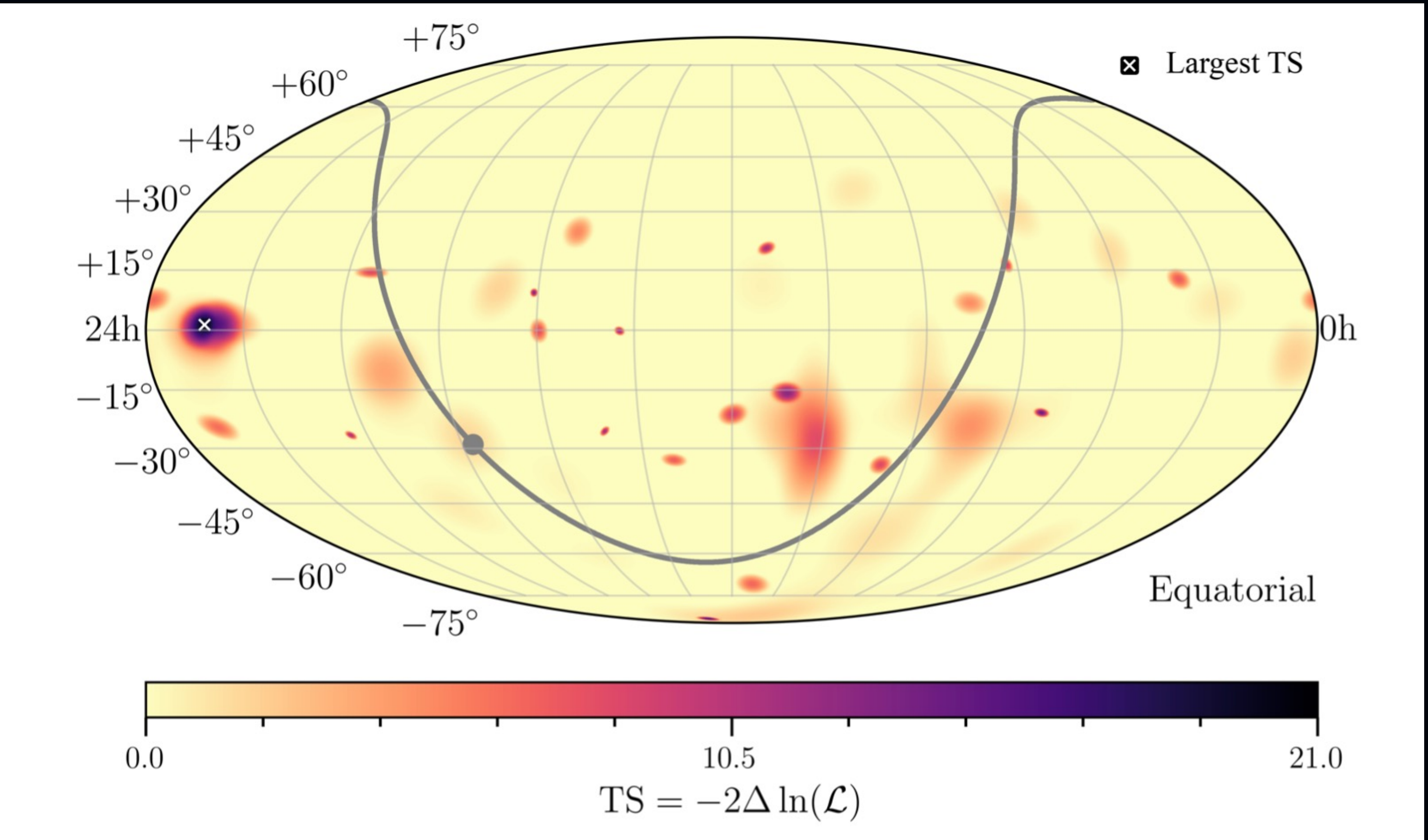


102 events, with 60 events > 60 TeV



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

Diffuse neutrino flux
7.5 year

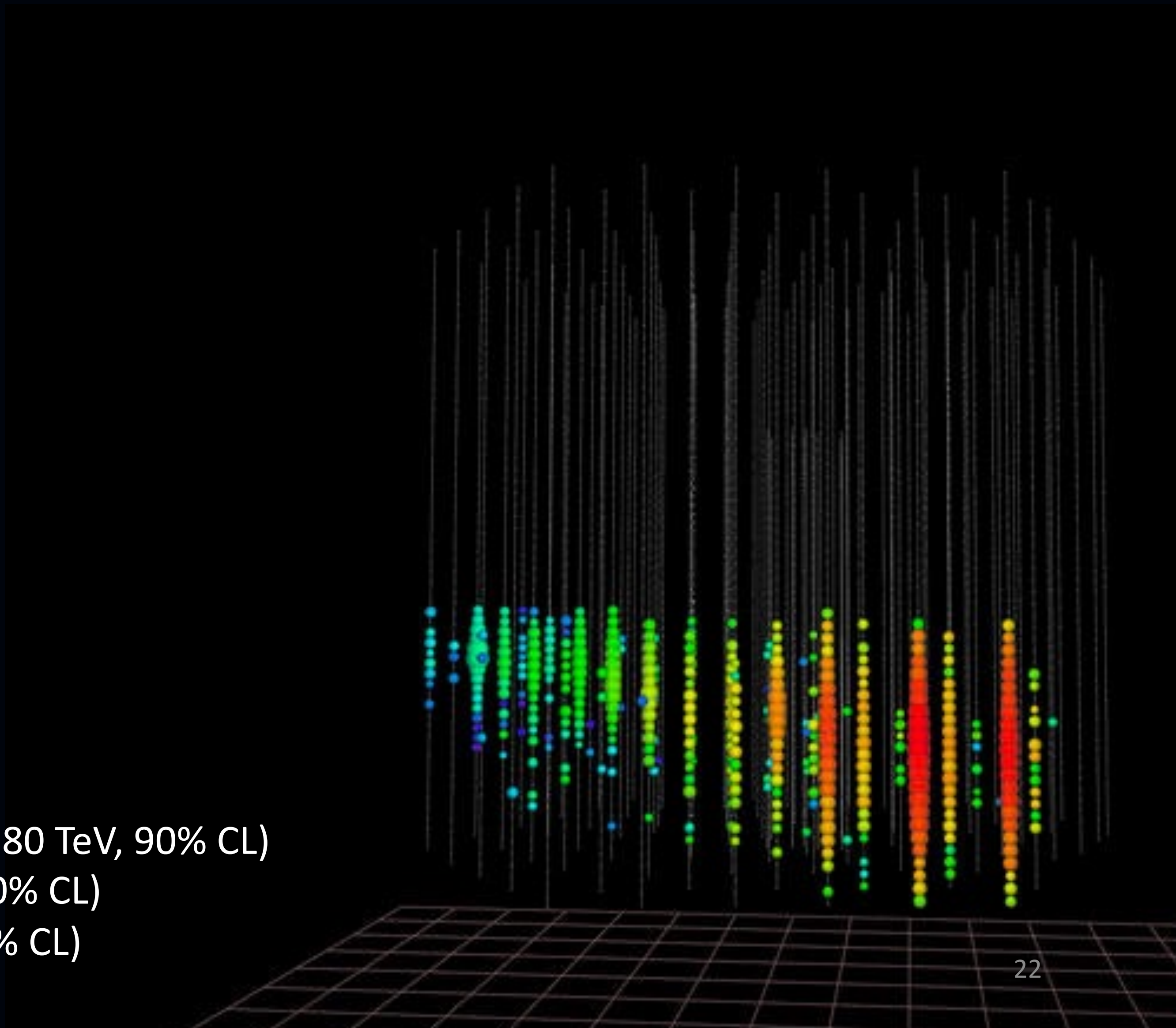


- No evidence for point sources
- No correlation with the galactic plane
- <u>Best fit</u>: Single power law with spectral index $\gamma = 2.89^{+0.20}_{-0.19}$
  all-flavor flux normalization $\Phi = 6.45^{+1.46}_{-0.46}$
- Data does not prefer a broken power law model

https://arxiv.org/pdf/1807.08816

https://arxiv.org/abs/1807.08794

22 September 2017
IceCube-170922A

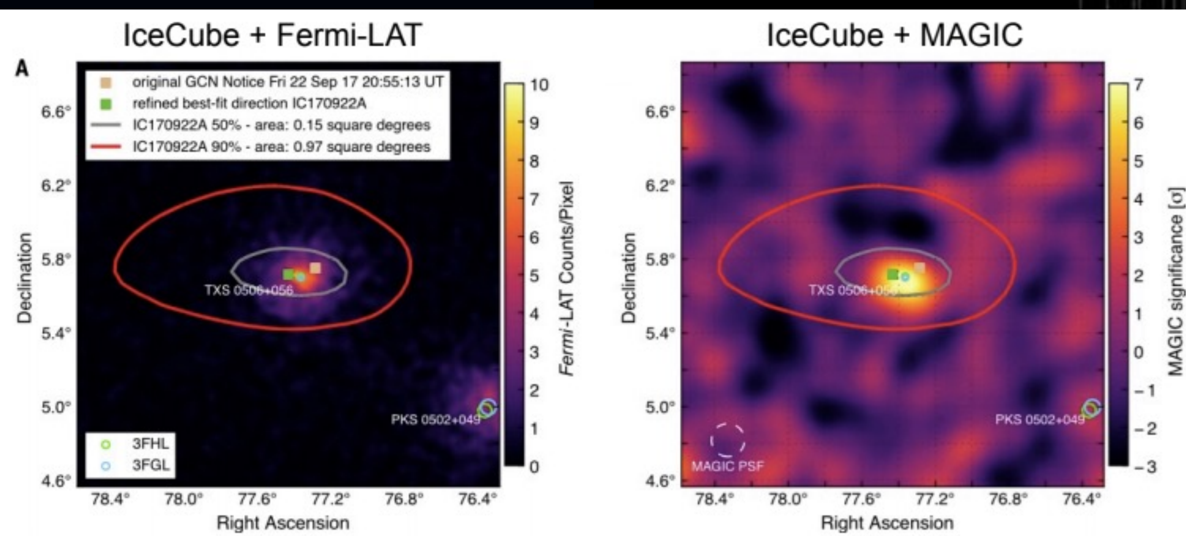


Neutrino Energy: 290 TeV (>180 TeV, 90% CL)
RA: 77.43° (-0.65°/+0.95° 90% CL)
Dec: 5.72° (-0.30°/+0.50° 90% CL)

22 September 2017
IceCube-170922A

- Fermi observations of a known blazar TXS 0506+056, in a state of enhanced gamma-ray emission

- MAGIC detection of > 400 GeV gamma rays from the blazar

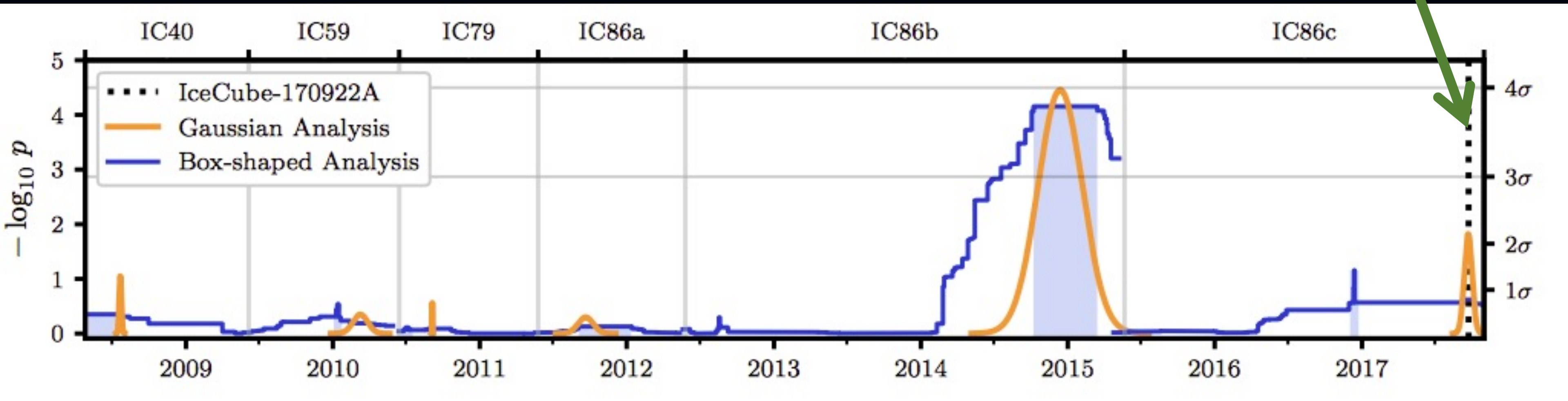


Significance for the overlap: 3σ

Neutrino Energy: 290 TeV (>180 TeV, 90% CL)
RA: 77.43° (-0.65°/+0.95° 90% CL)
Dec: 5.72° (-0.30°/+0.50° 90% CL)

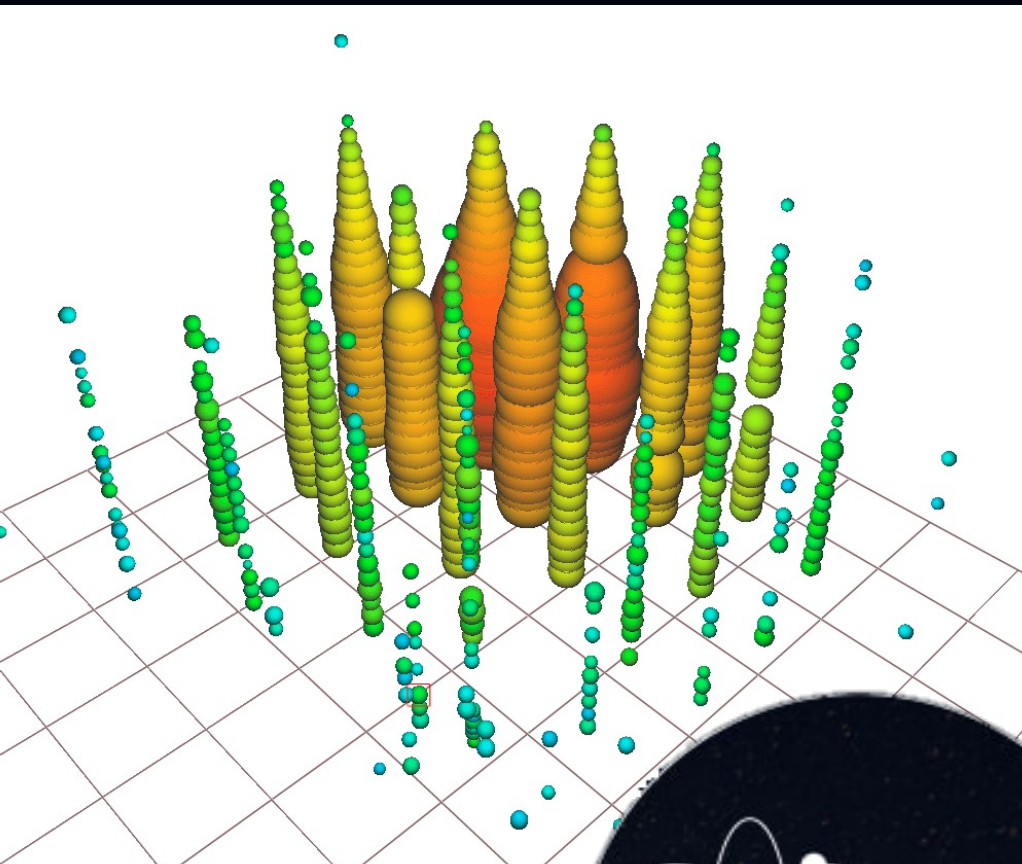
Archival data search

IceCube170922A

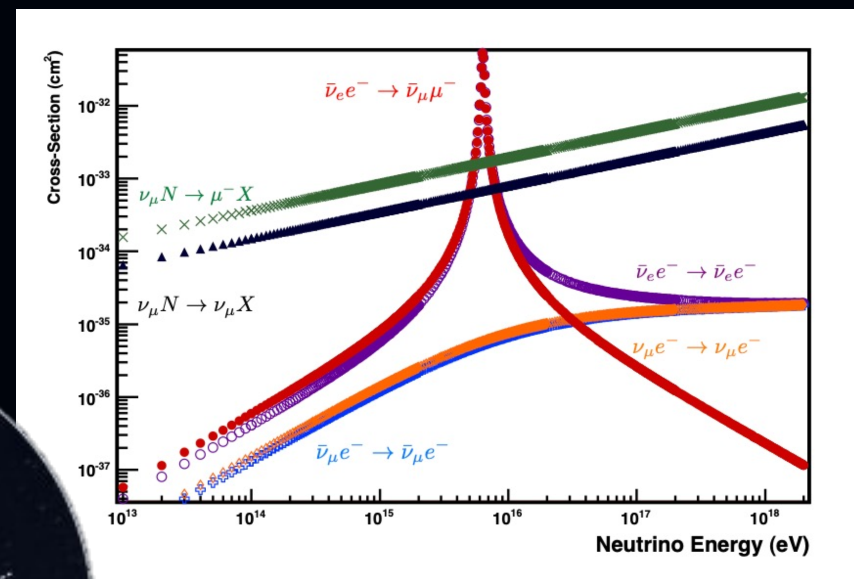


- Time-dependent point source search at location of TXS blazar
- 13 ± 5 neutrino excess in 2014-2015 over 110 days
- Significance defined using identical searches using randomized event directions: 3.5σ

First observation of a Glashow resonance event

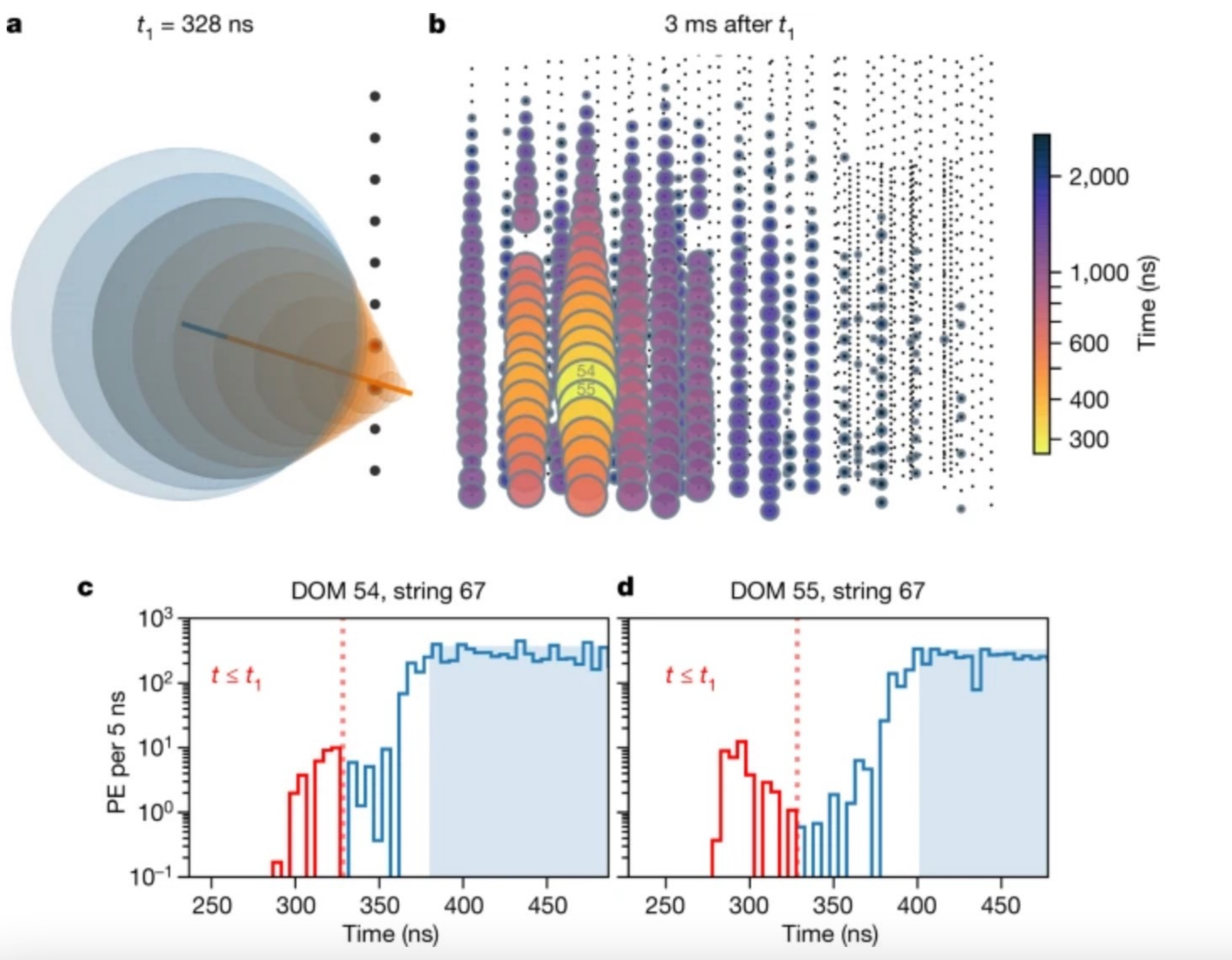


Detection of a shower with an energy of 6.05 ± 0.72 PeV



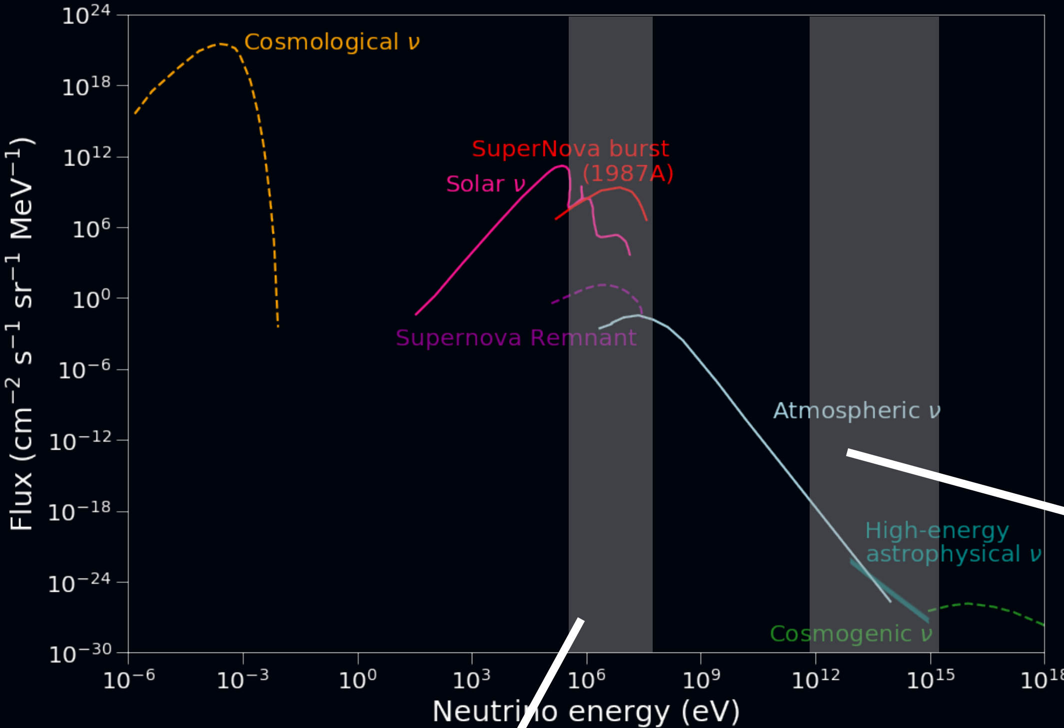
https://www.nature.com/articles/s41586-021-03256-1

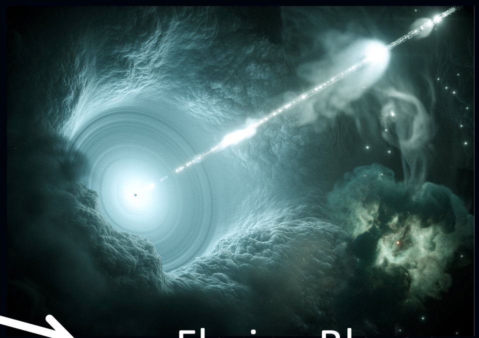
First observation of a Glashow resonance event



https://www.nature.com/articles/s41586-021-03256-1

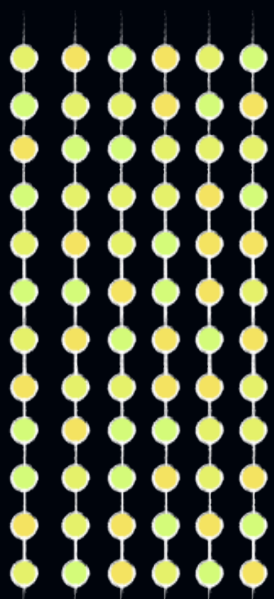
What am I doing?

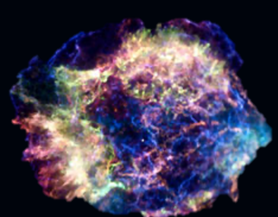




Flaring Blazar

Tidal Disruption Event

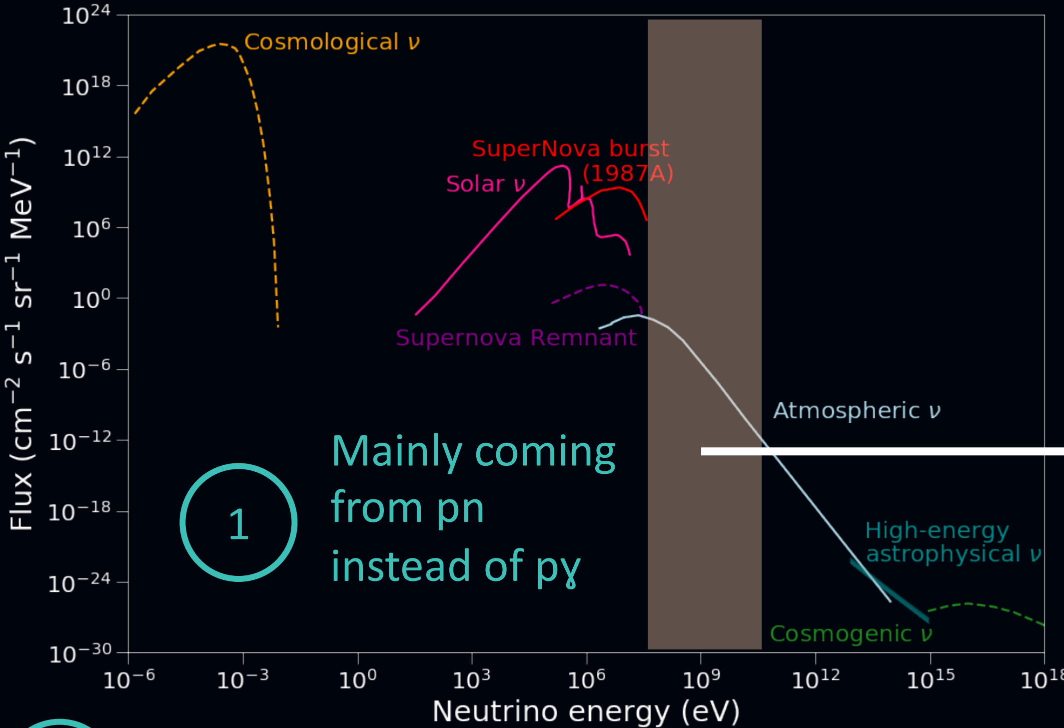




Core Collapse Supernova

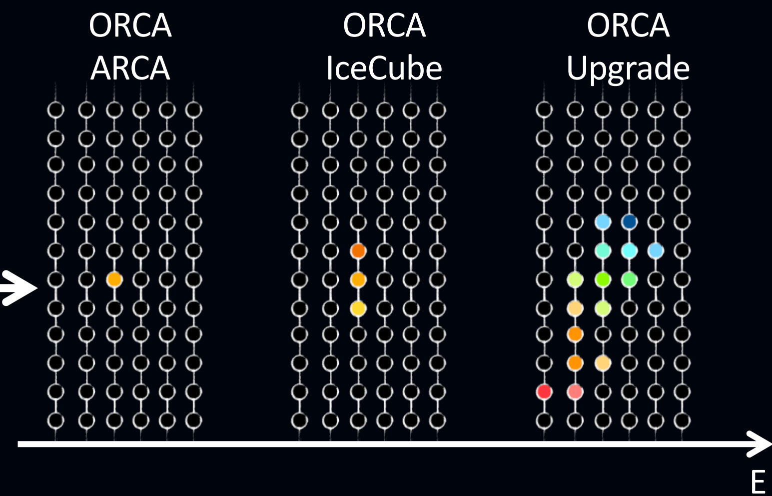
Identification of other sources
Loading

What am I doing?

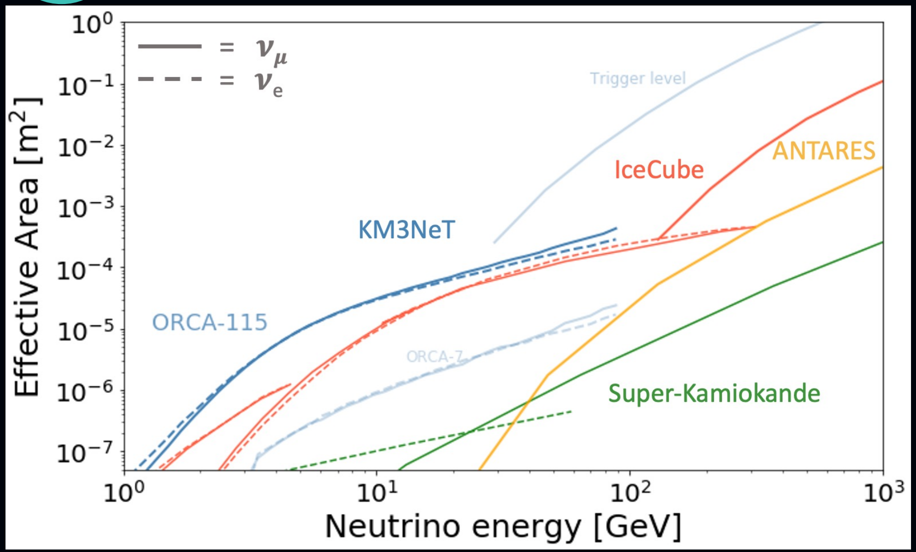


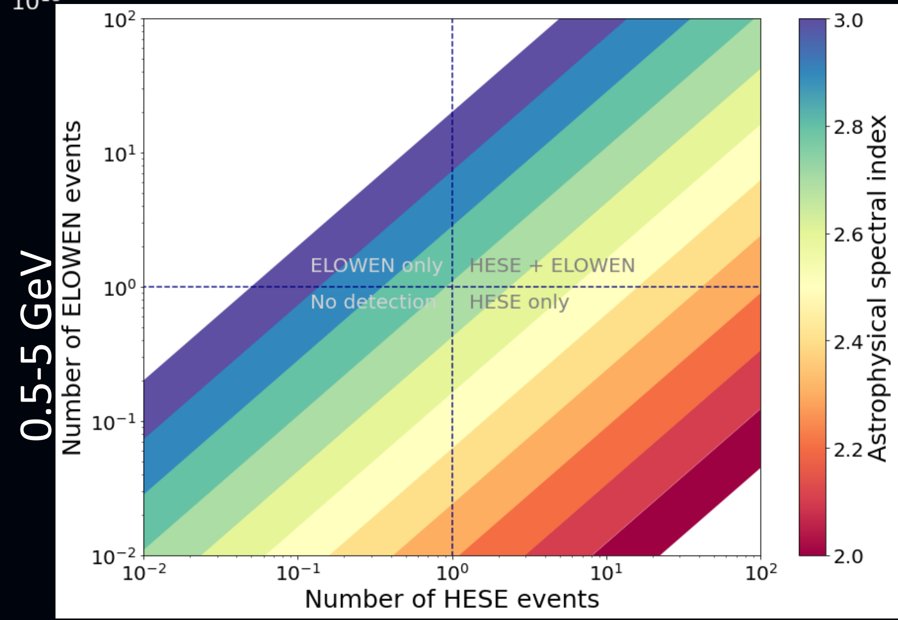
1

Mainly coming from pn instead of pγ



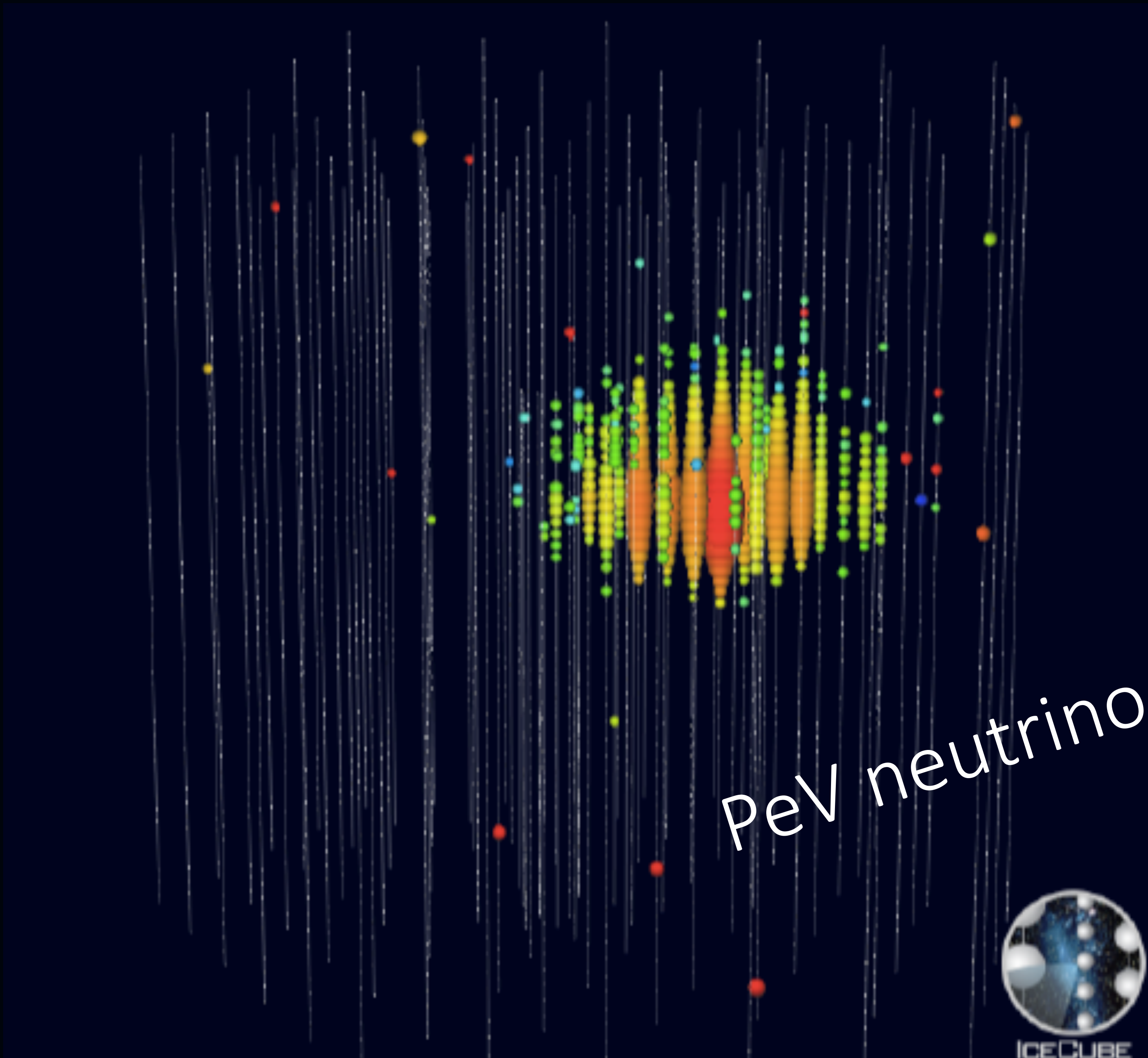
2 Why going to lower energies?

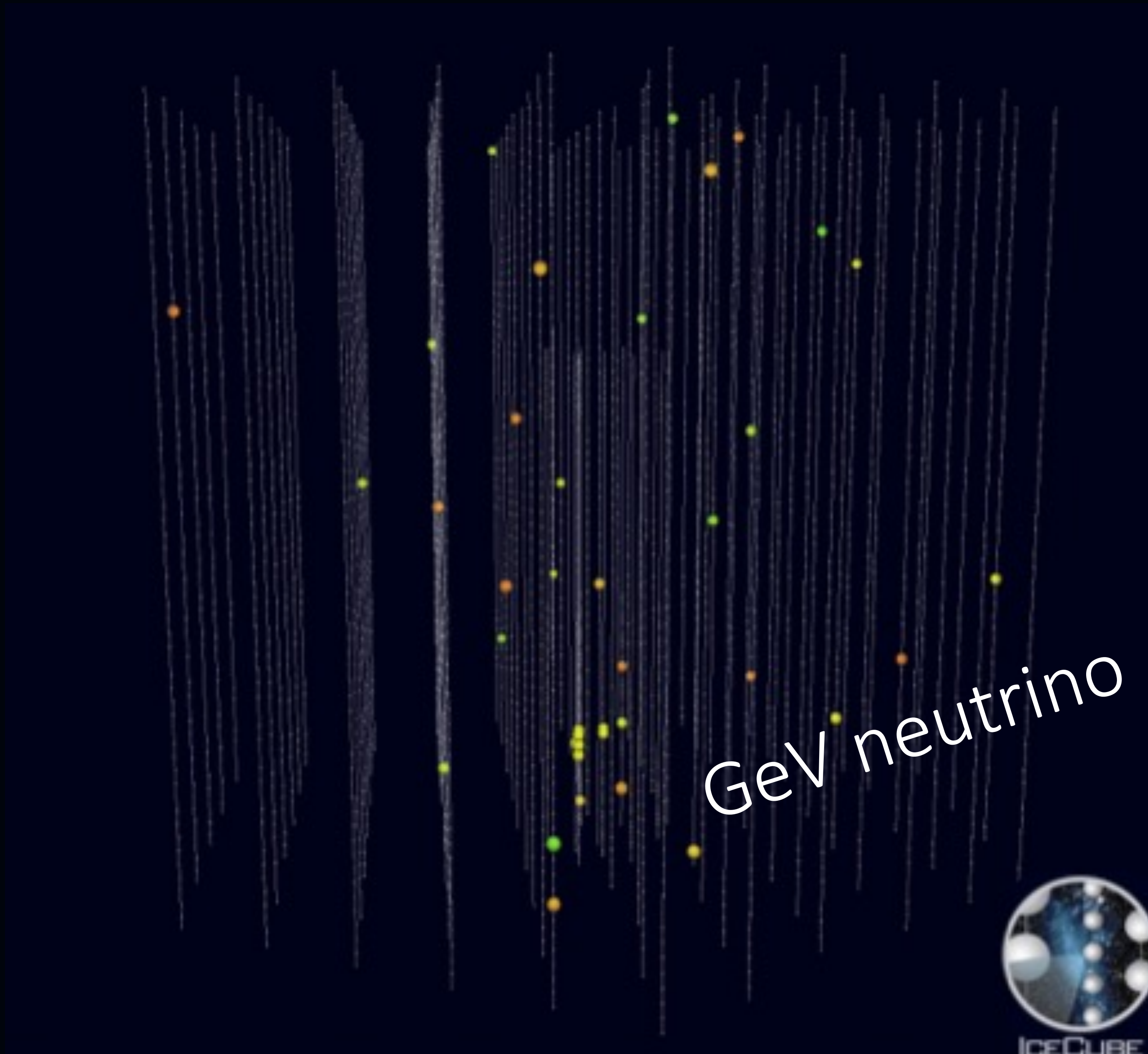


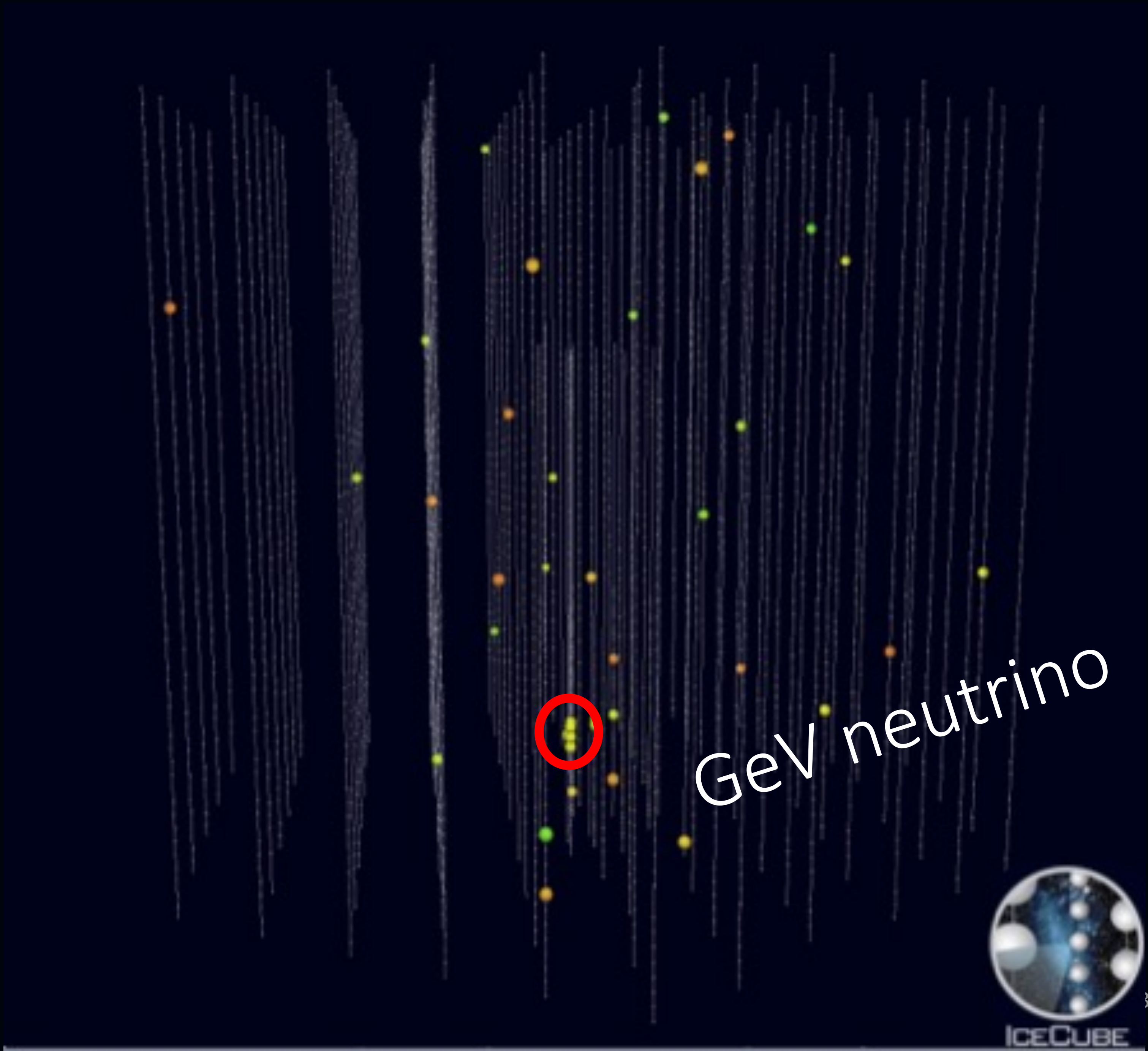


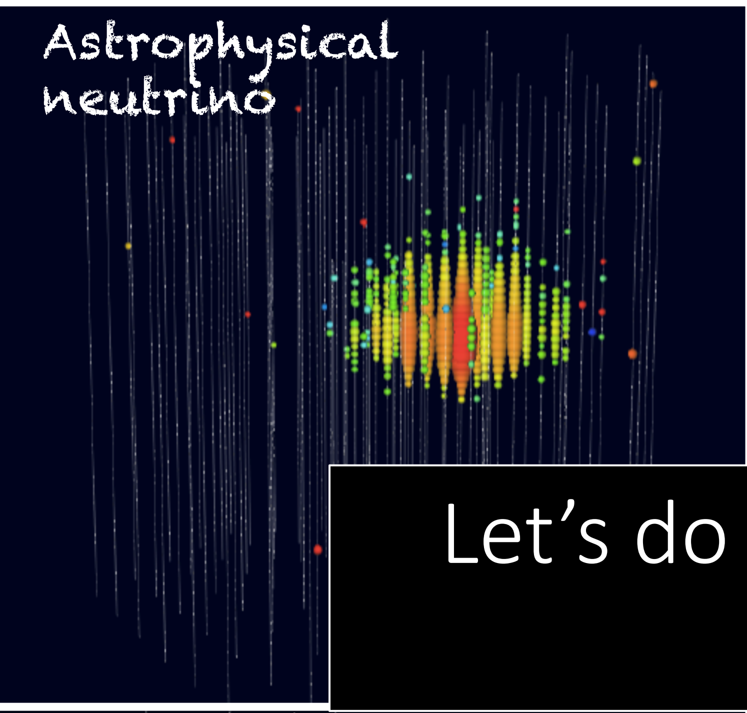
3

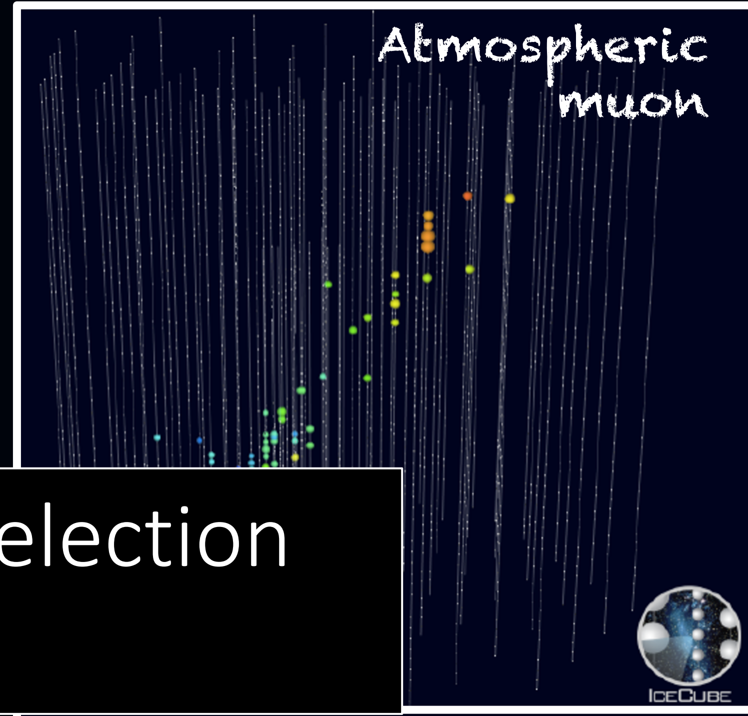
TeV-PeV scale


PeV neutrino
ICECUBE

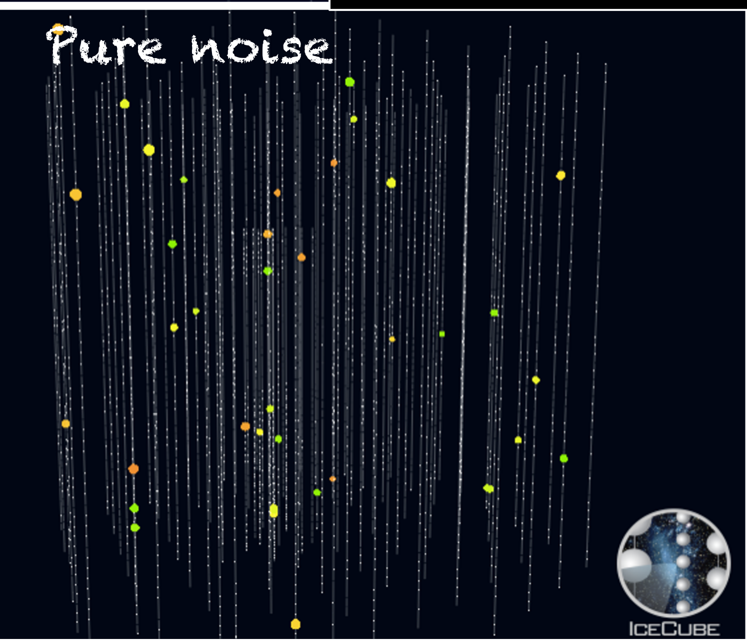

GeV neutrino
ICECUBE

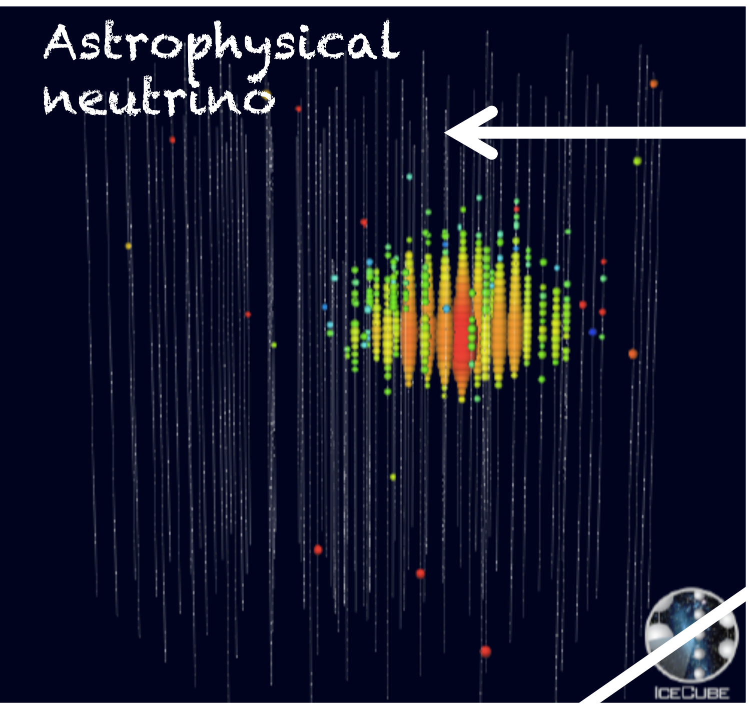

GeV neutrino
ICECUBE



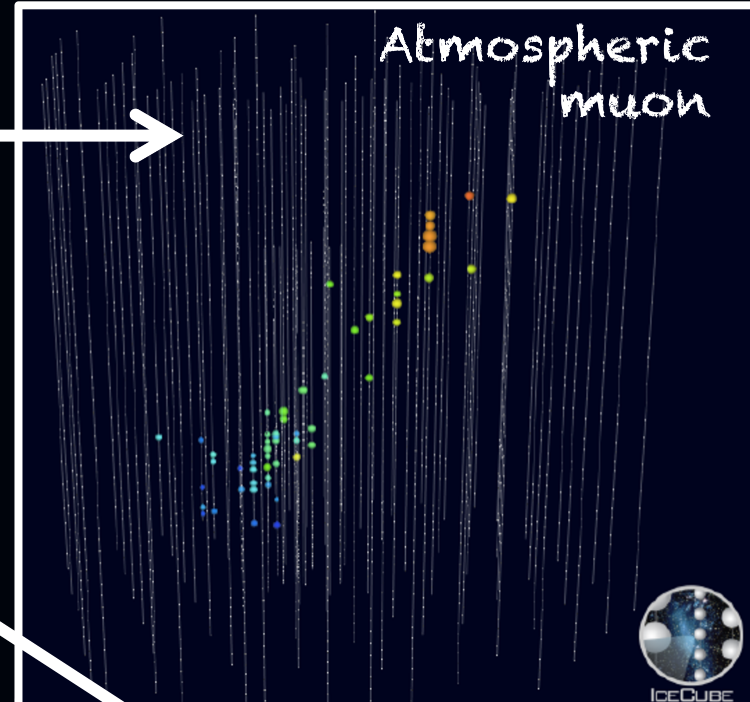


Let’s do the event selection together!

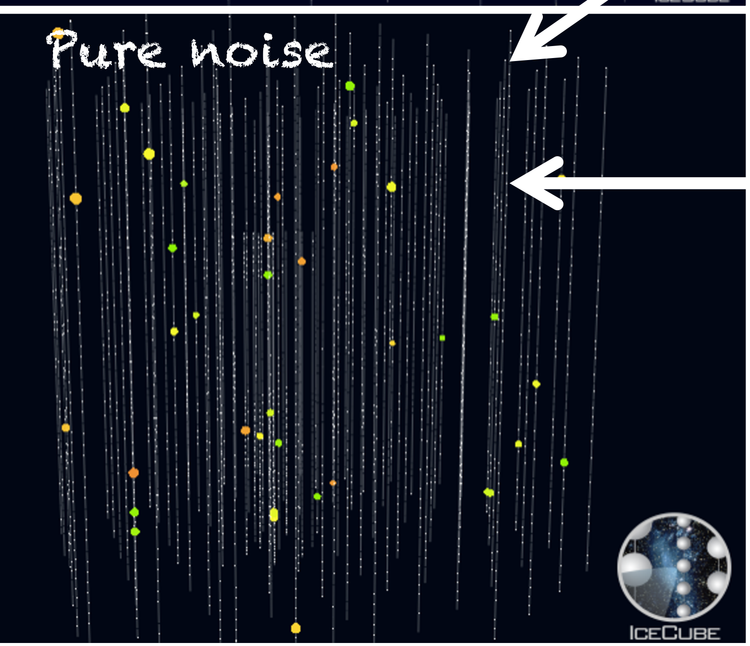




High luminosity

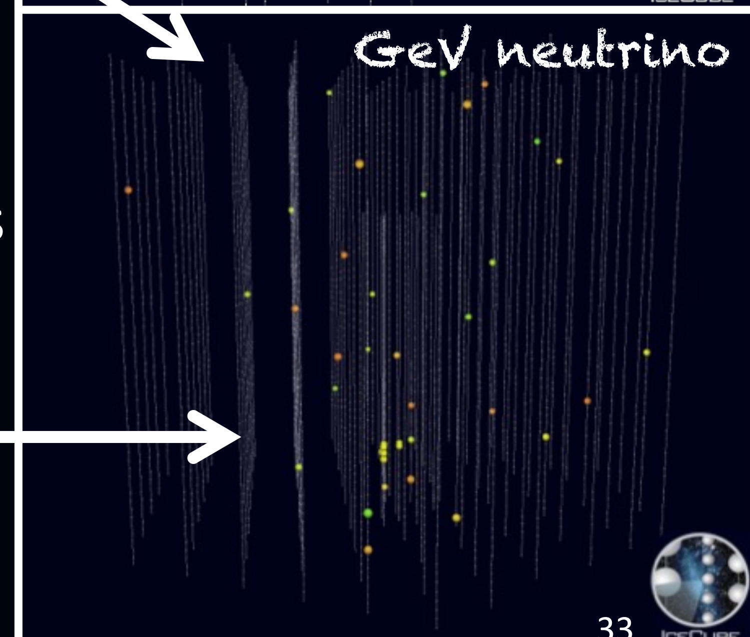


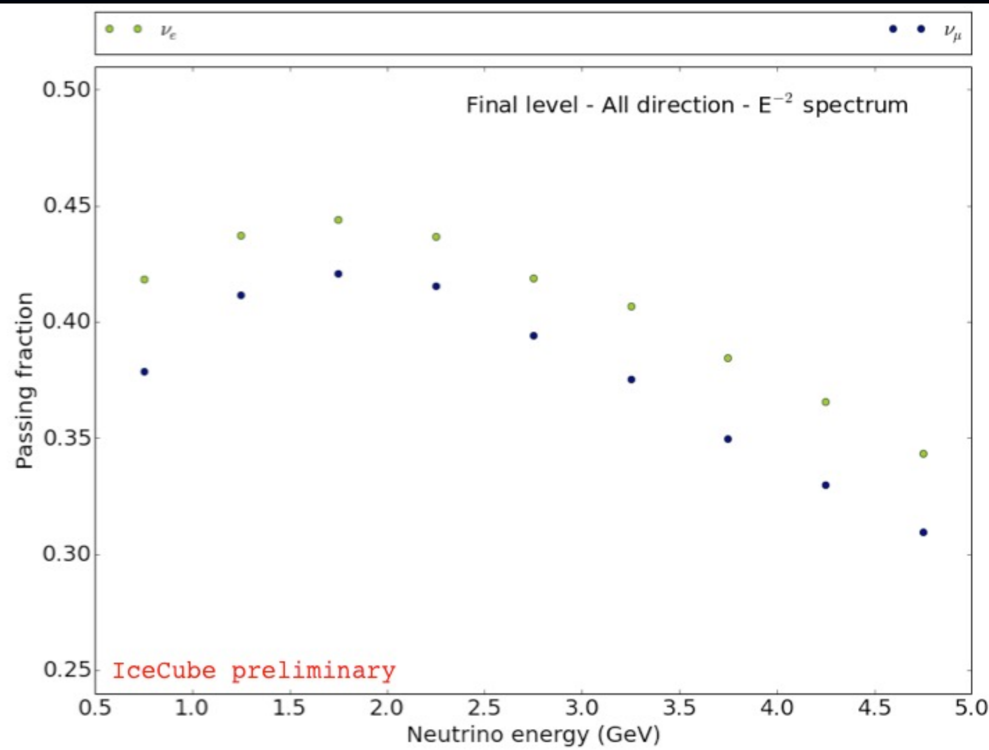
Low luminosity

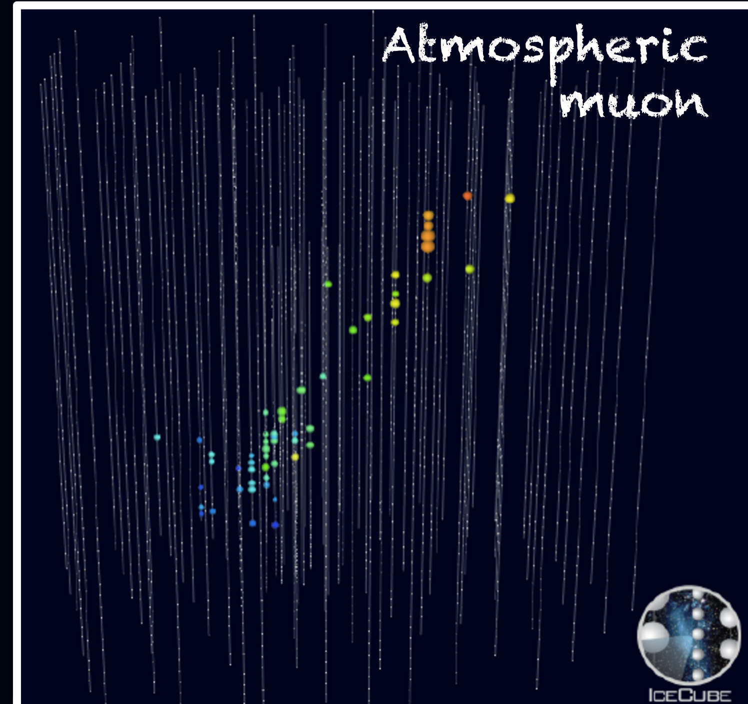


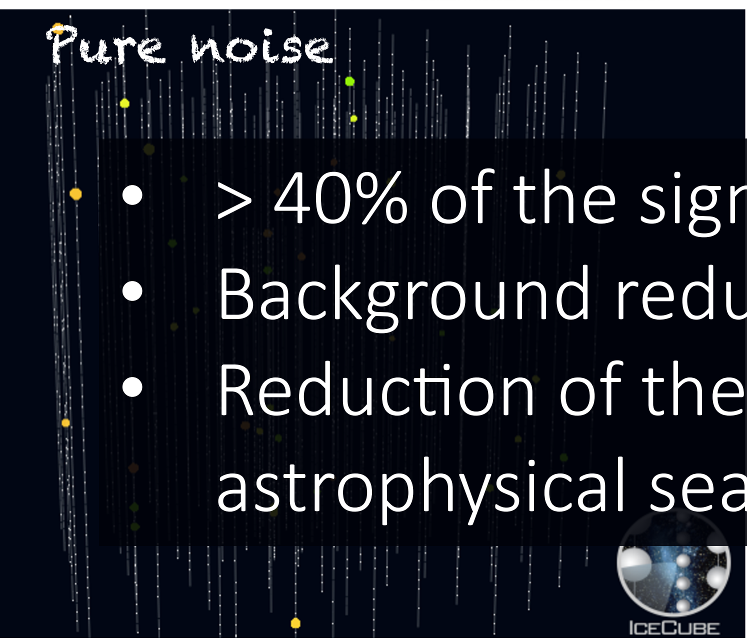
Non-causally connected hits

Causally connected hits

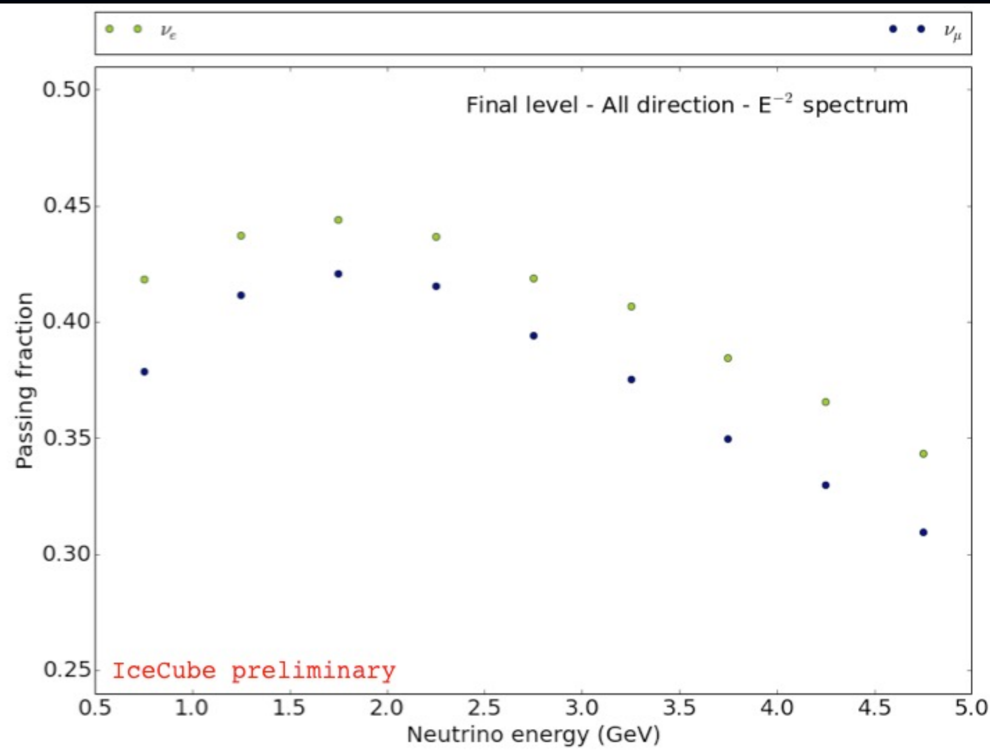


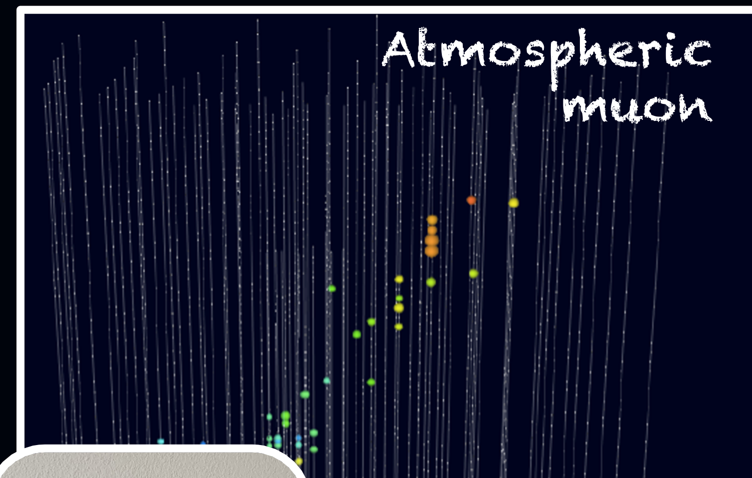


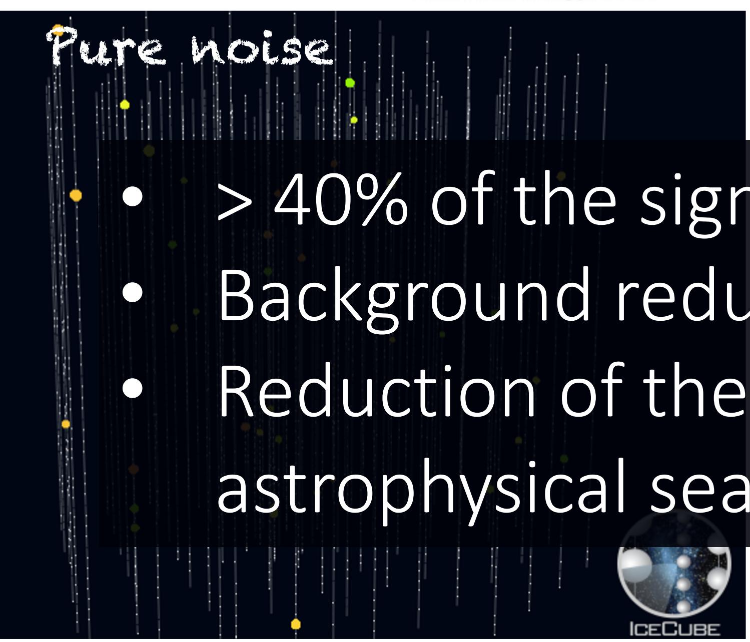




- > 40% of the signal kept
- Background reduction by 5 orders of magnitude
- Reduction of the energy threshold for astrophysical searches by 2 orders of magnitude







- > 40% of the signal kept
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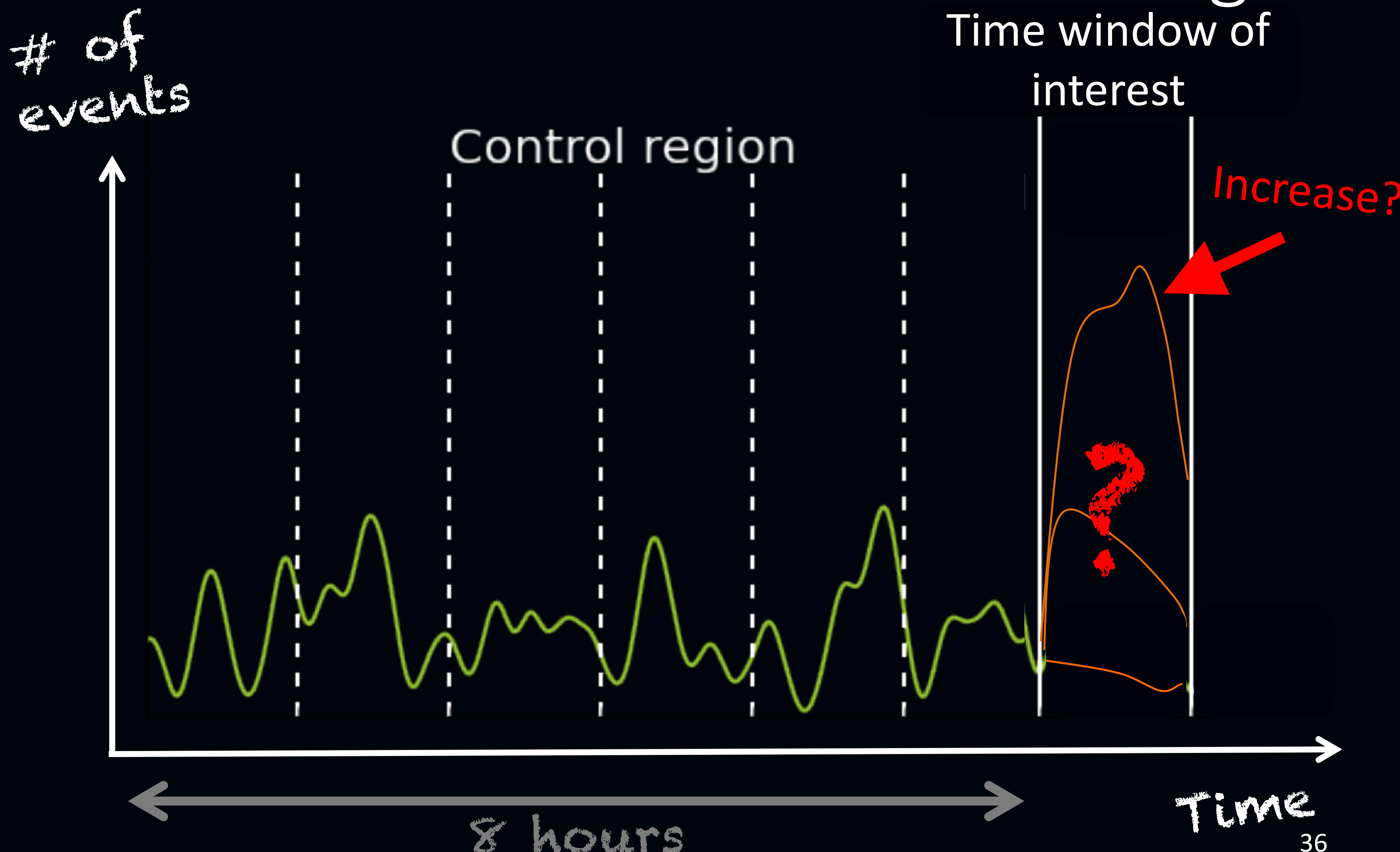
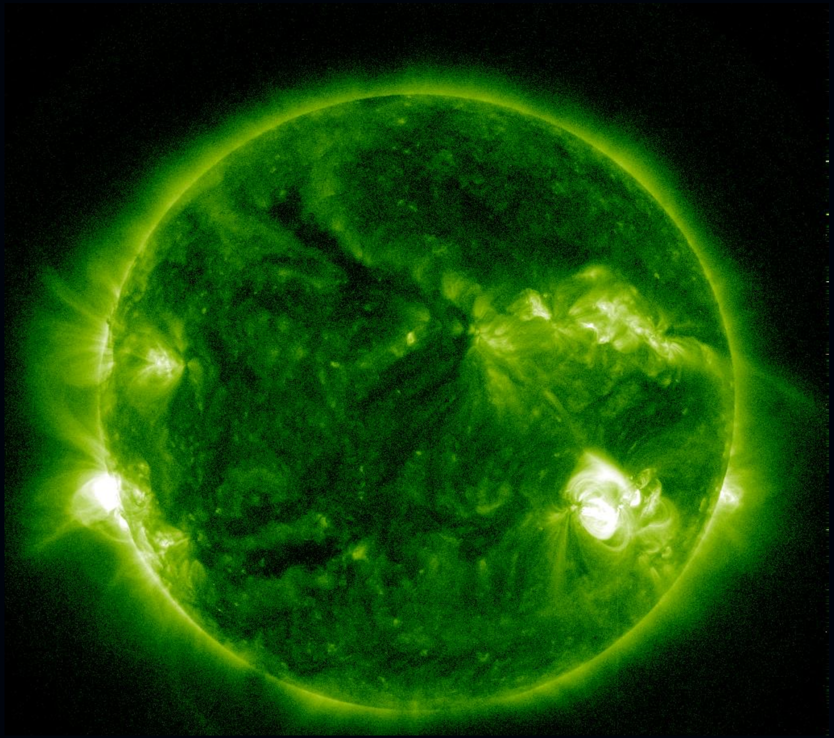
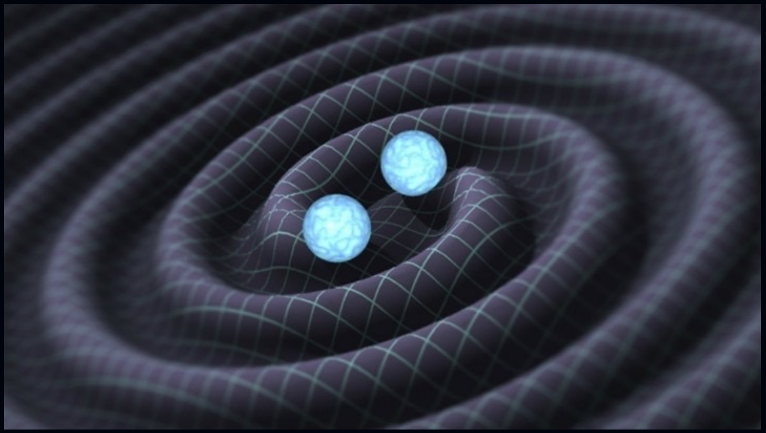
How to detect a GeV neutrino signal?



What am I doing?

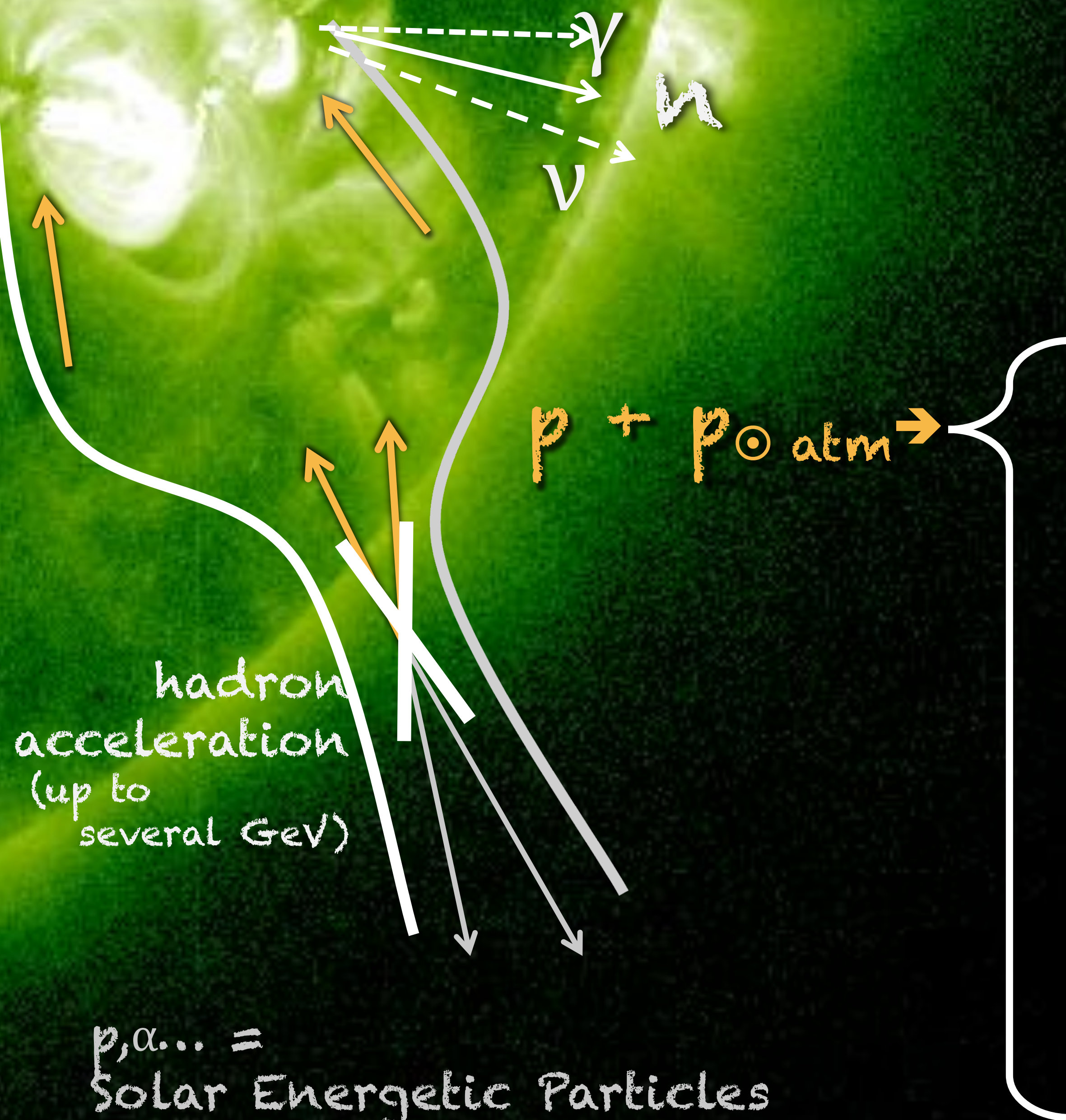


Solar flares



Compact binary mergers

Solar flares



$\pi^+ \rightarrow \mu^+ + \nu_\mu$

$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$

$\pi^0 \rightarrow 2\gamma$

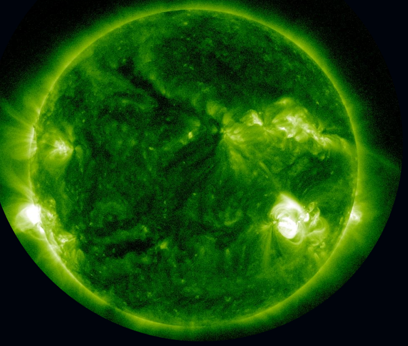
$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$

$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$

https://arxiv.org/abs/2101.00610

Solar flares

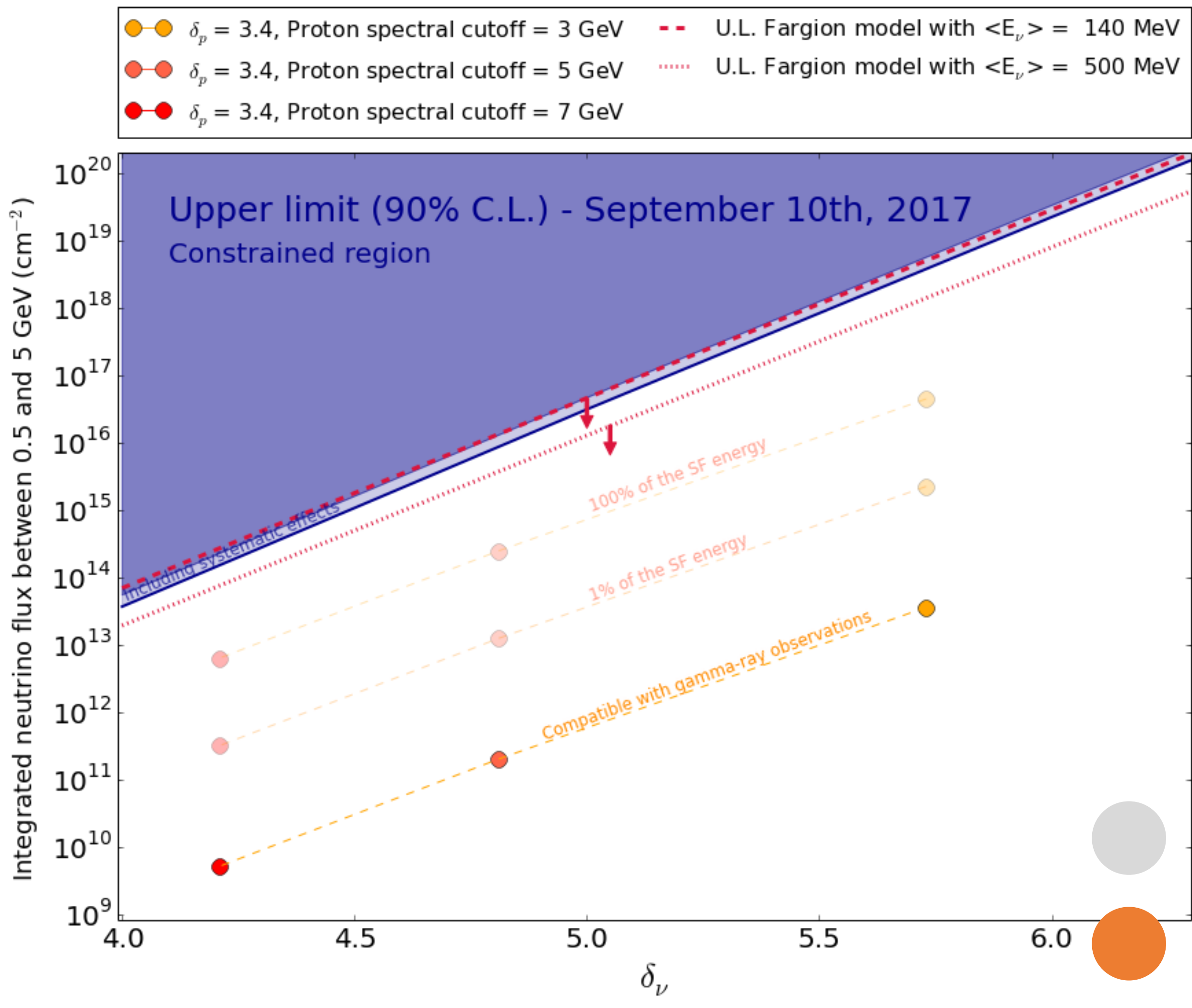
Search for a neutrino signal from the brightest flares seen in gamma rays



$$\Phi_\nu = C\, E^{-\delta_\nu}$$

C

δ_ν



https://arxiv.org/abs/2101.00610

Compact binary mergers

For BNS, NSBH and Mass Gap events

Search for a prompt signal

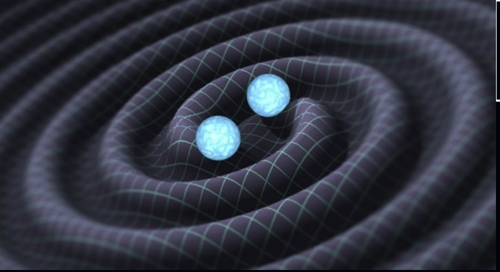
$[t_0, t_0+3]$ s

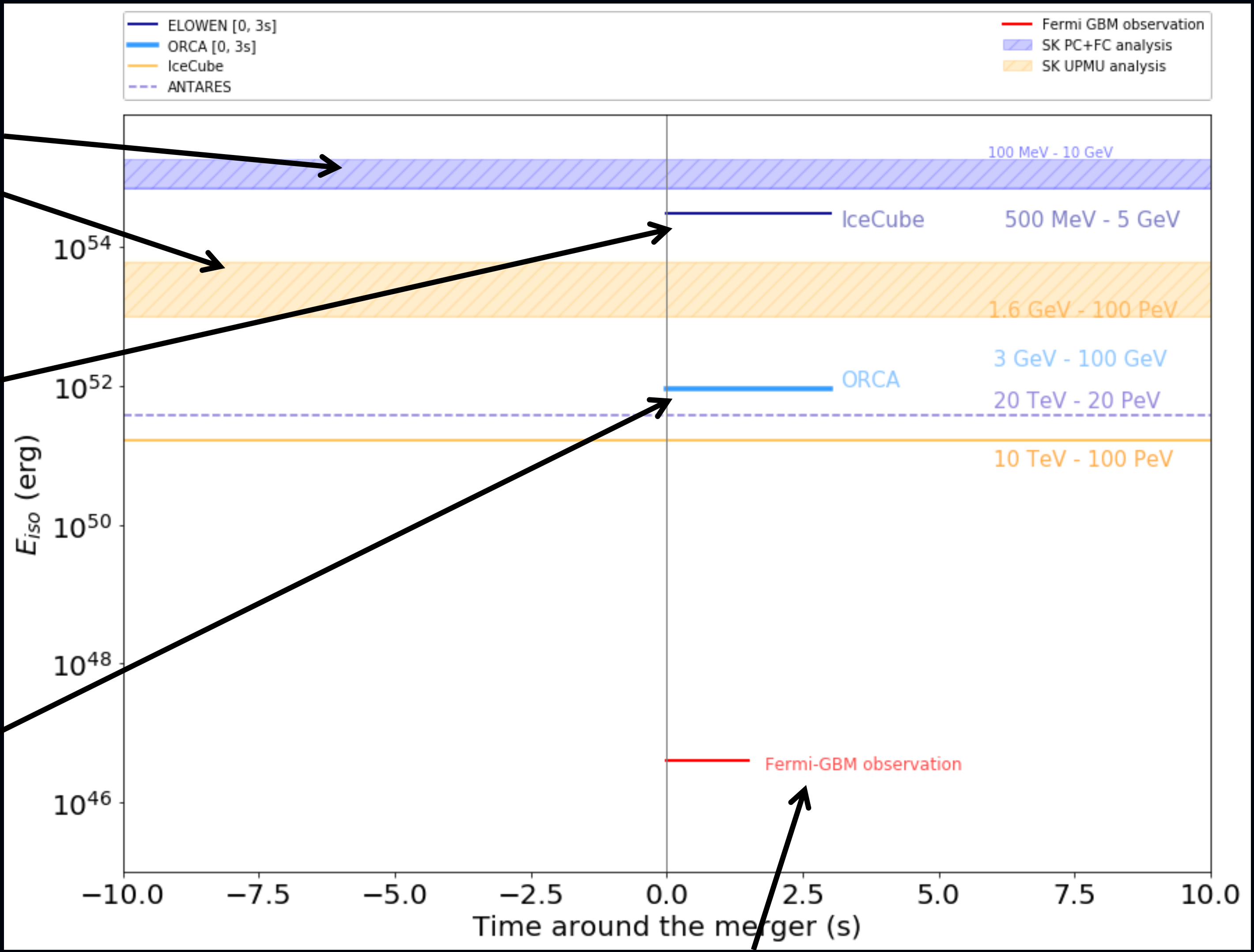
For all events

Search in an extended time window

$[t_0-500, t_0+500]$ s

GW170817 Compact binary mergers





Upper limit

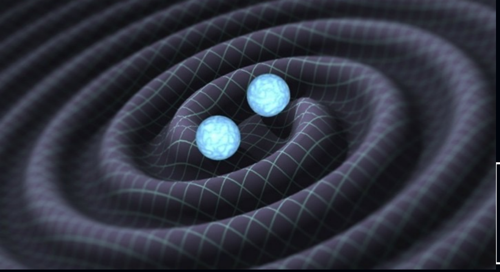
Upper limit

Sensitivity

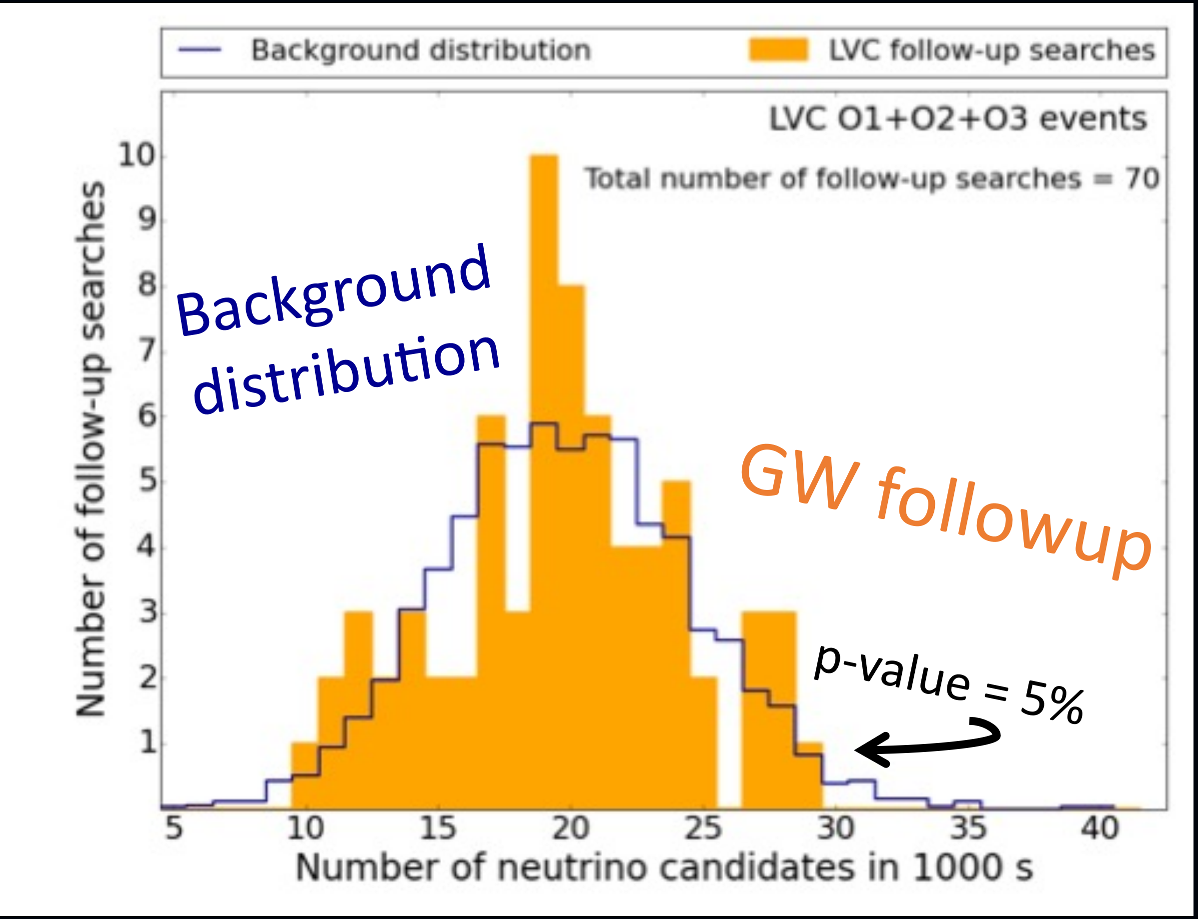
Gamma ray observation

https://arxiv.org/abs/2105.13160

Compact binary mergers



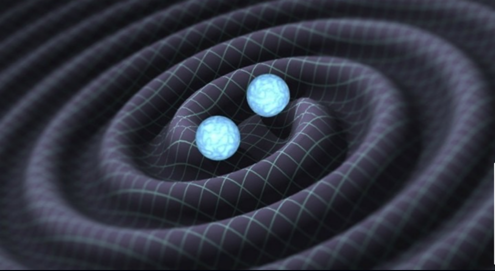
LVC O1+O2+O3 events



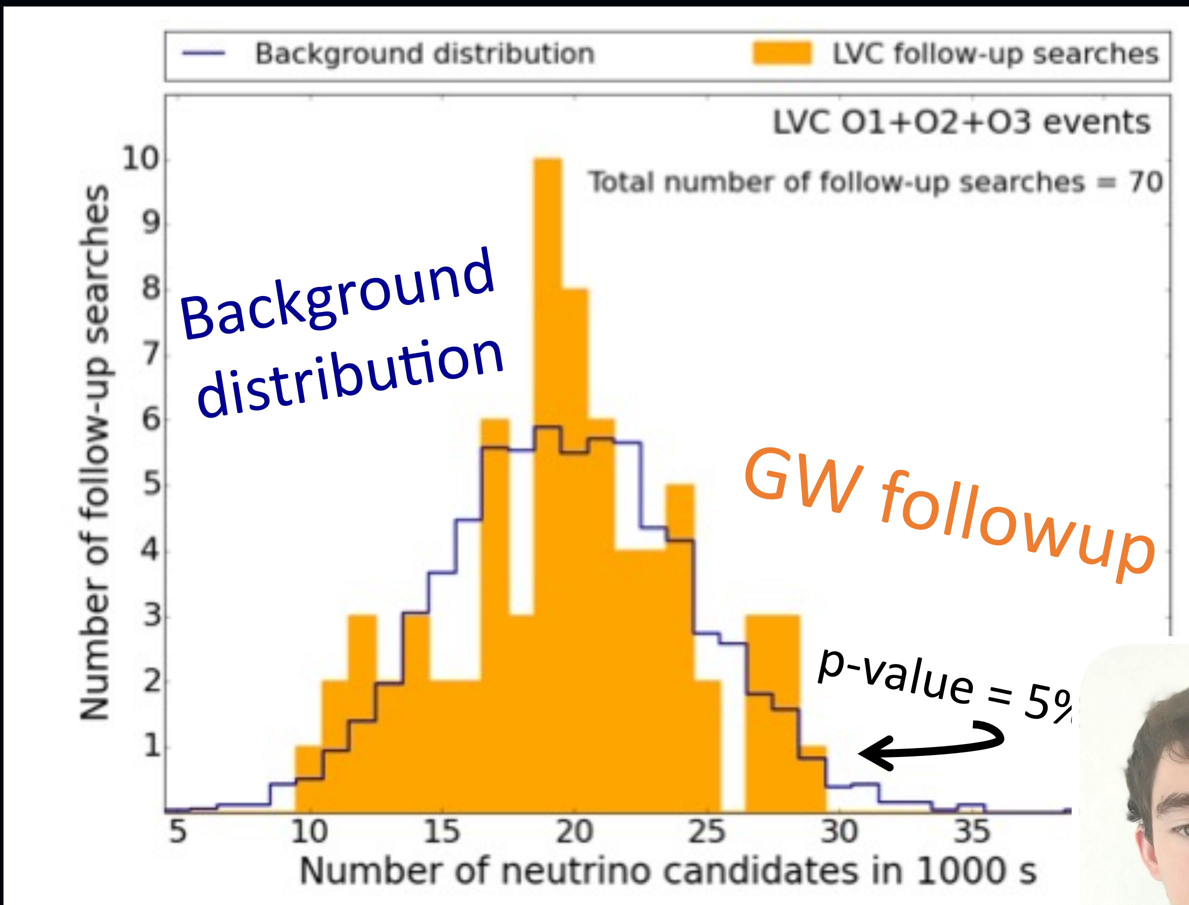
Distribution of Kolomogorov-Smirnov test to evaluate the compatibility between the two distributions: p-value = 0.3

https://arxiv.org/abs/2105.13160

Compact binary mergers



LVC O1+O2+O3 events



Distribution of Kolomogorov-Smirnov test to evaluate the compatibility between the two distributions: p-value = 0.3

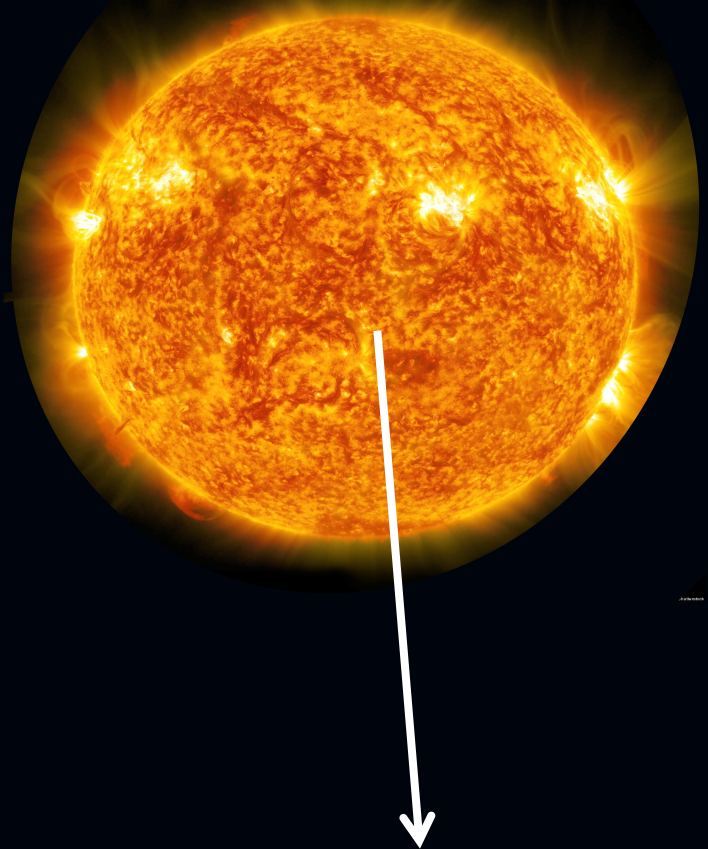
ICECUBE

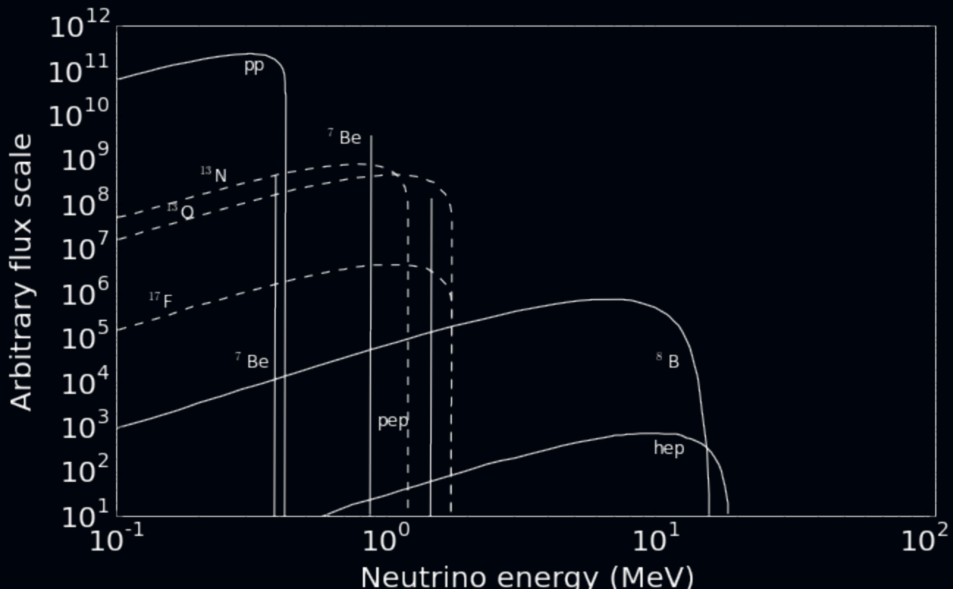
KM3NeT

https://arxiv.org/abs/2105.13160

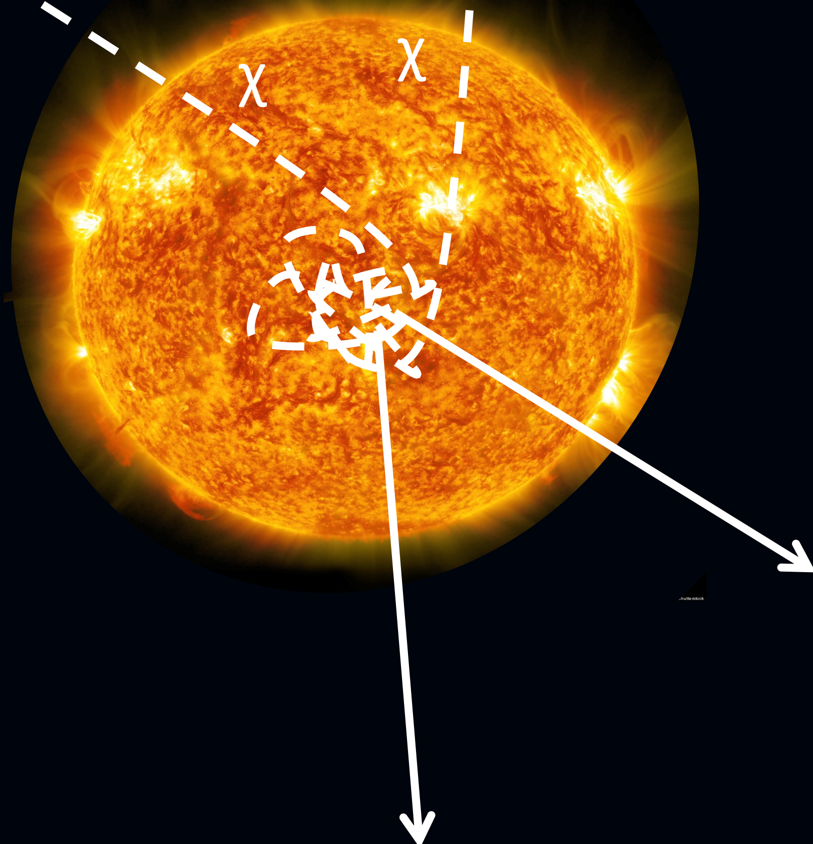
Bonus

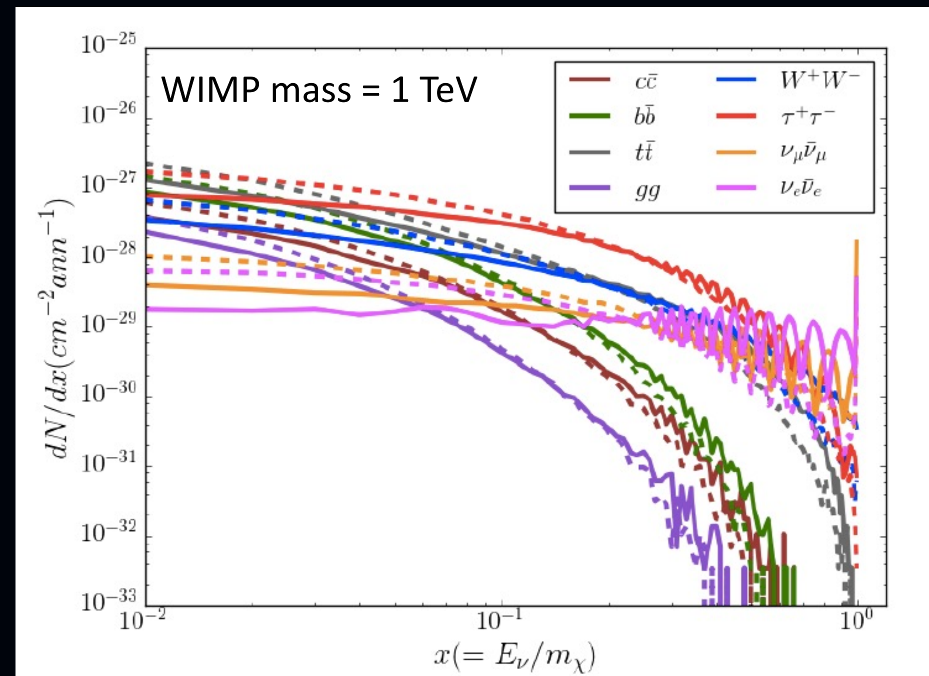
Solar neutrinos

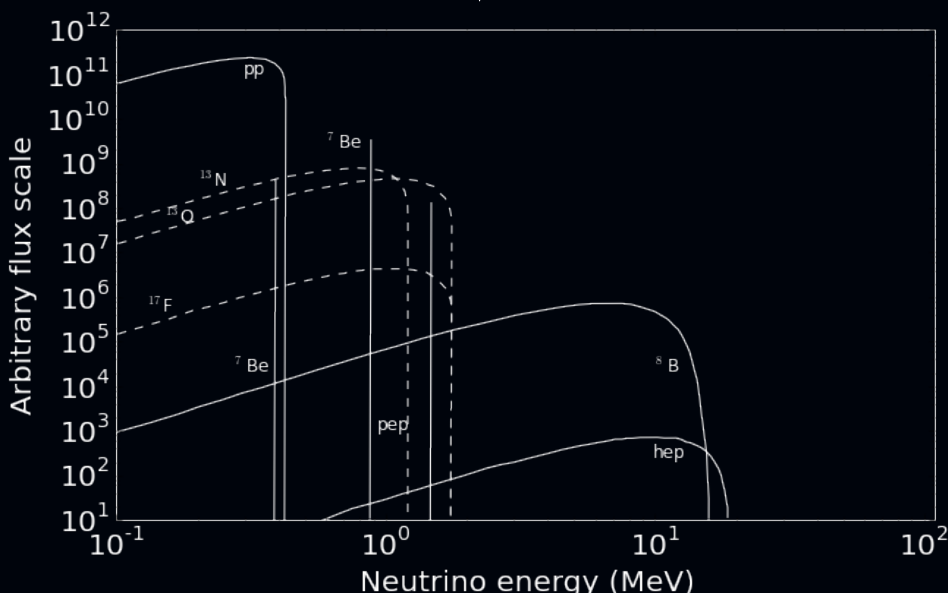




Solar neutrinos

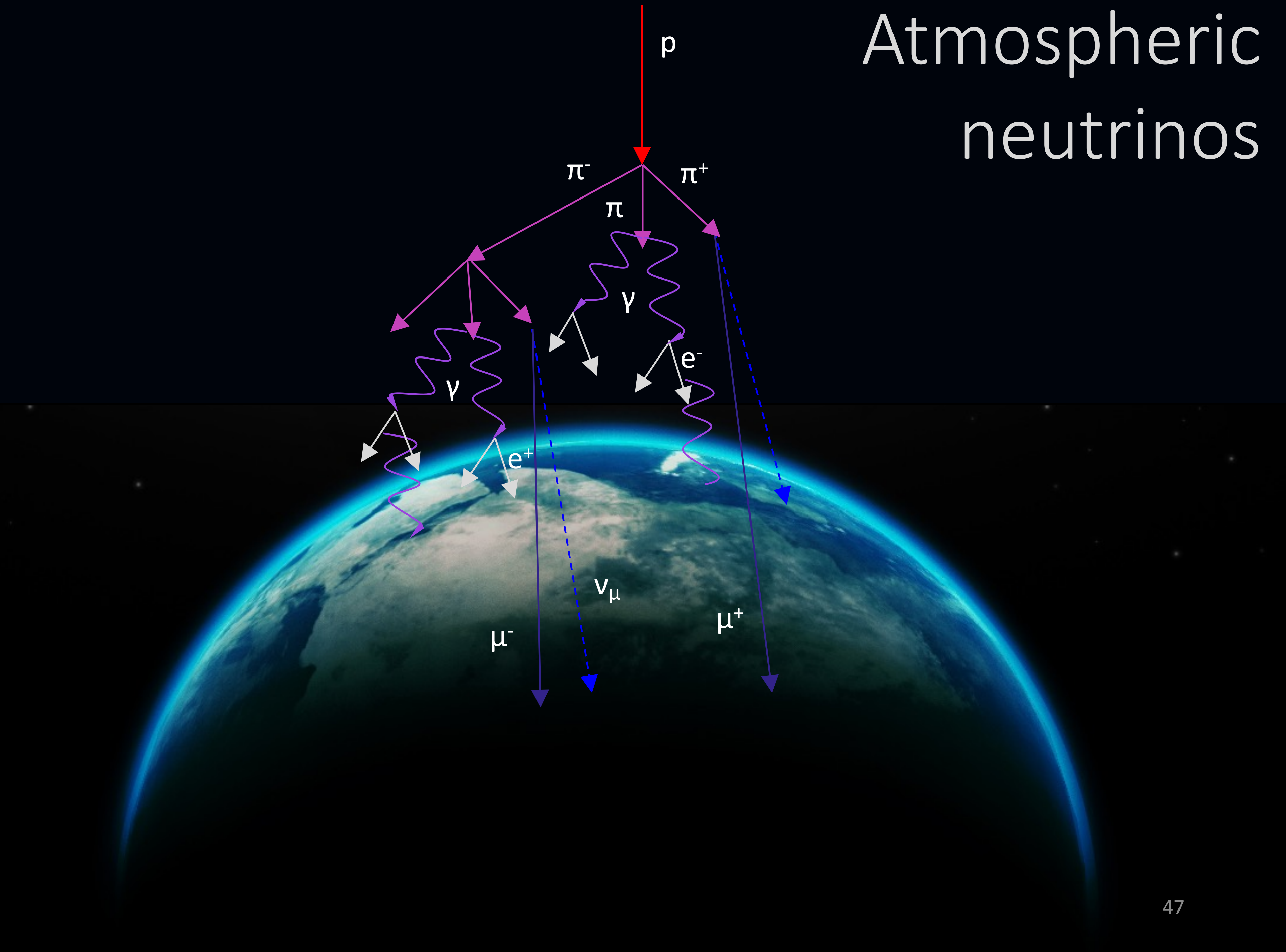




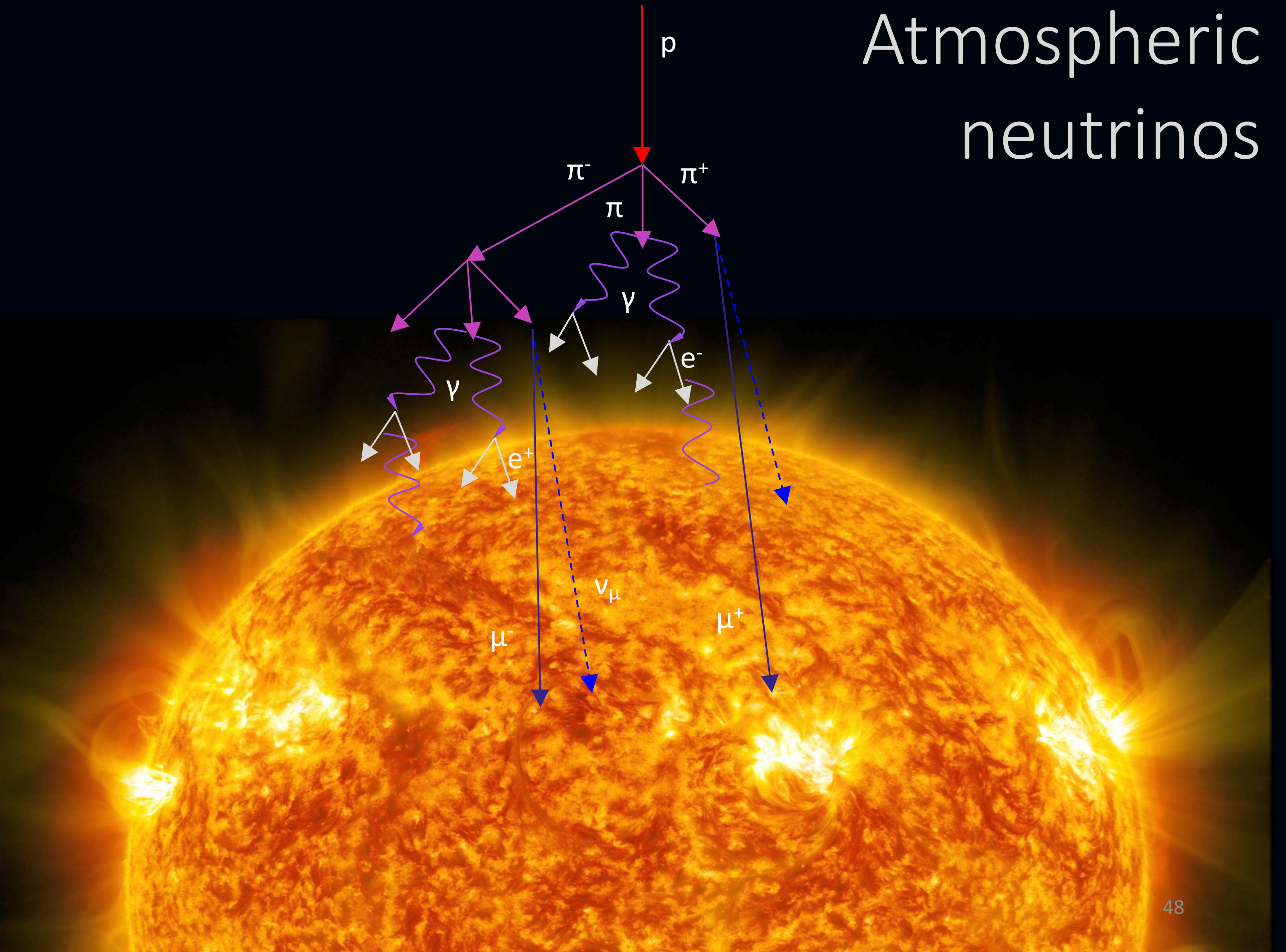


Eur. Phys. J. C (2017) 77: 146

Atmospheric neutrinos



Atmospheric neutrinos

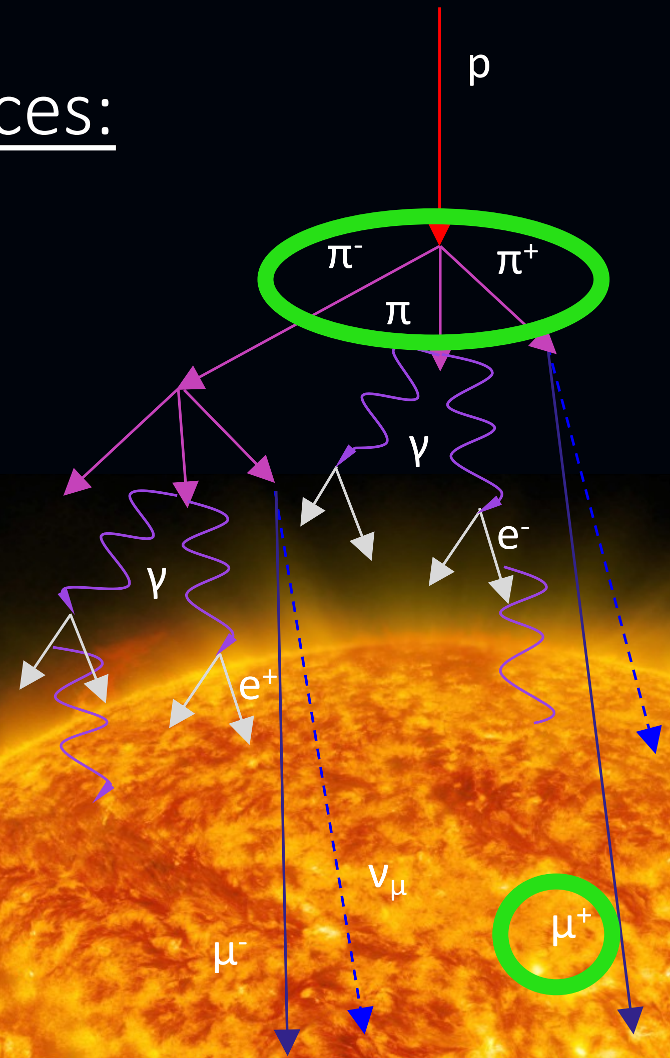


Atmospheric neutrinos

<u>A few differences:</u>

1. π, K decay

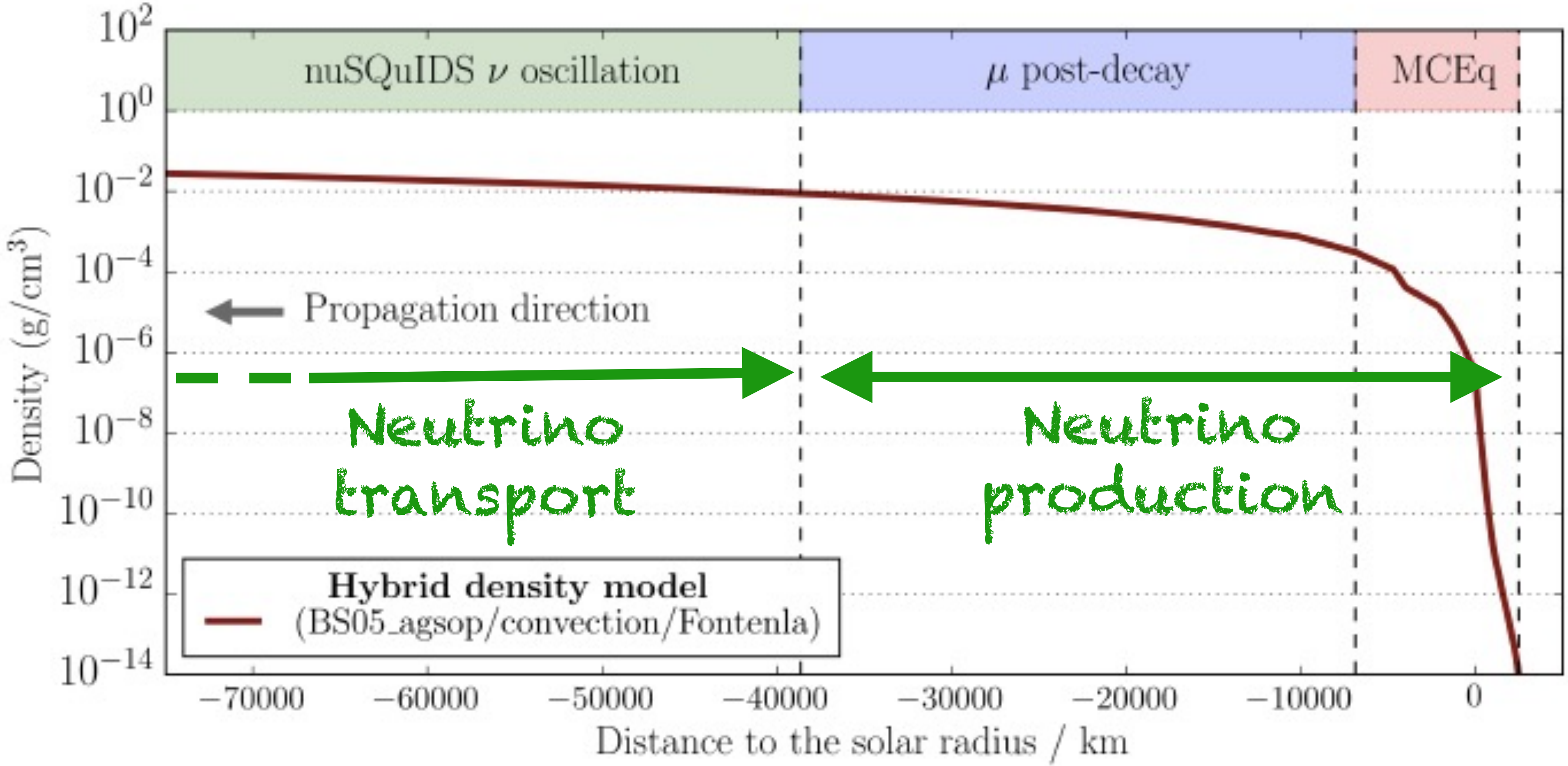
2. μ decay



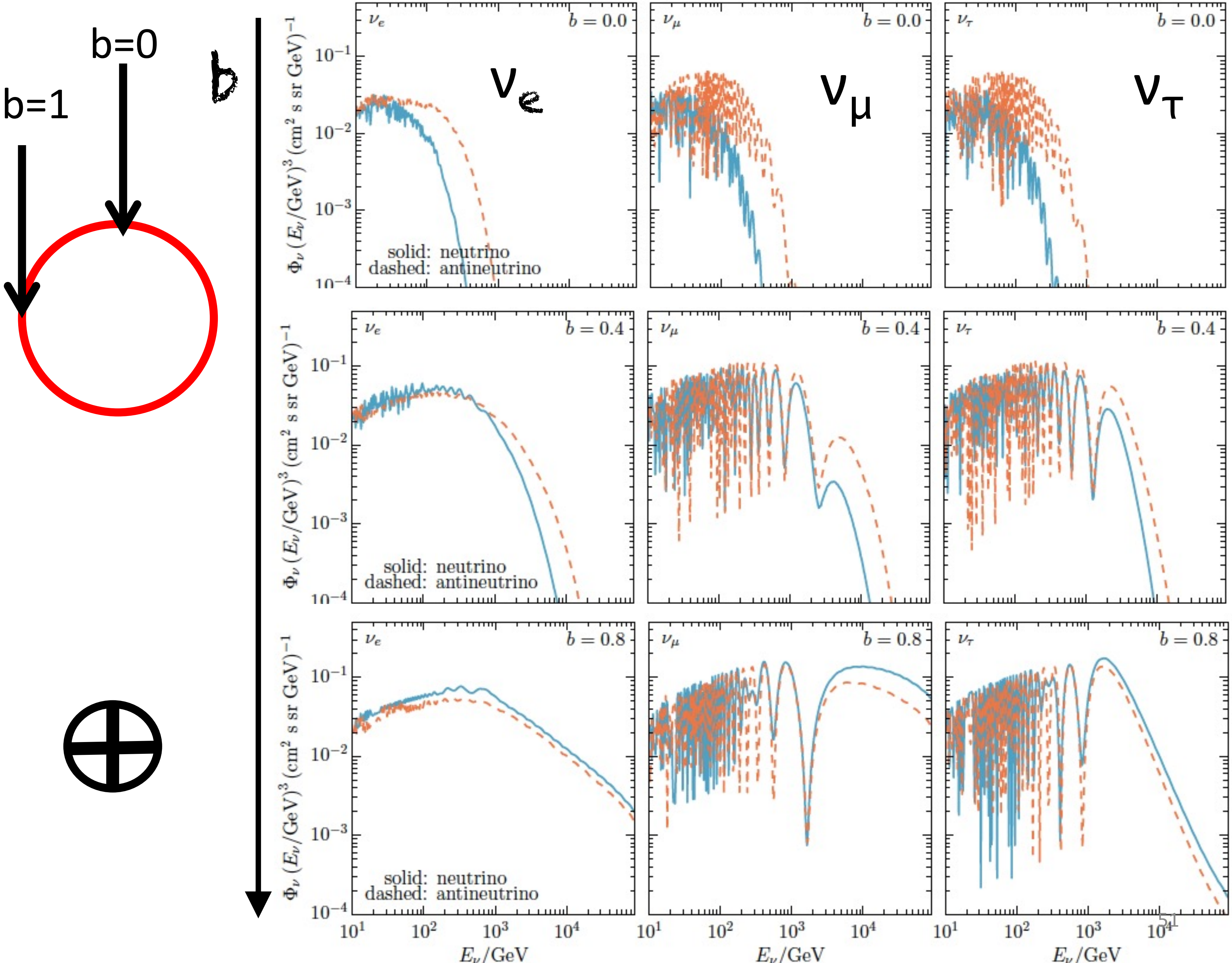
Why interesting?

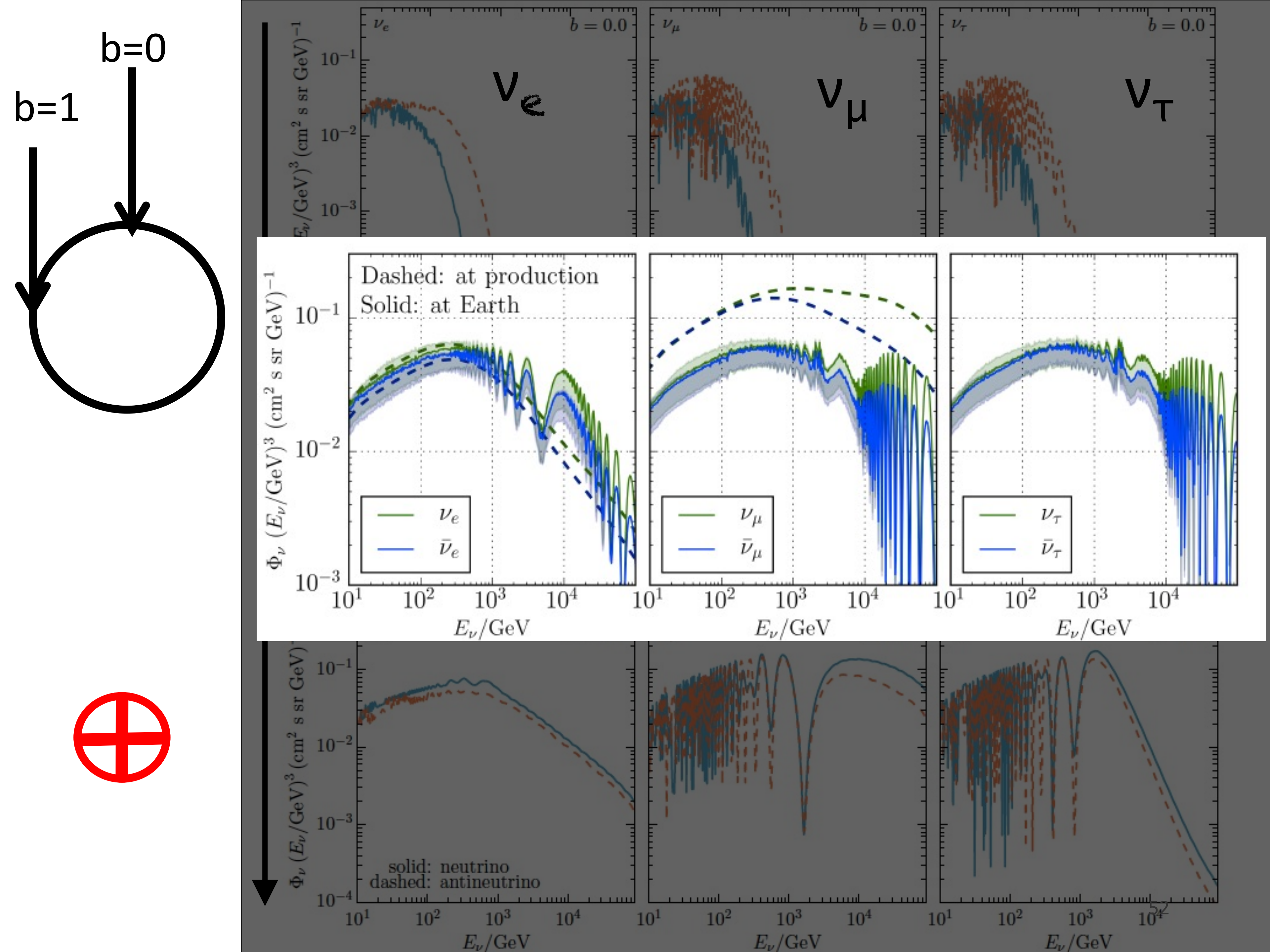
Solar density profile

1

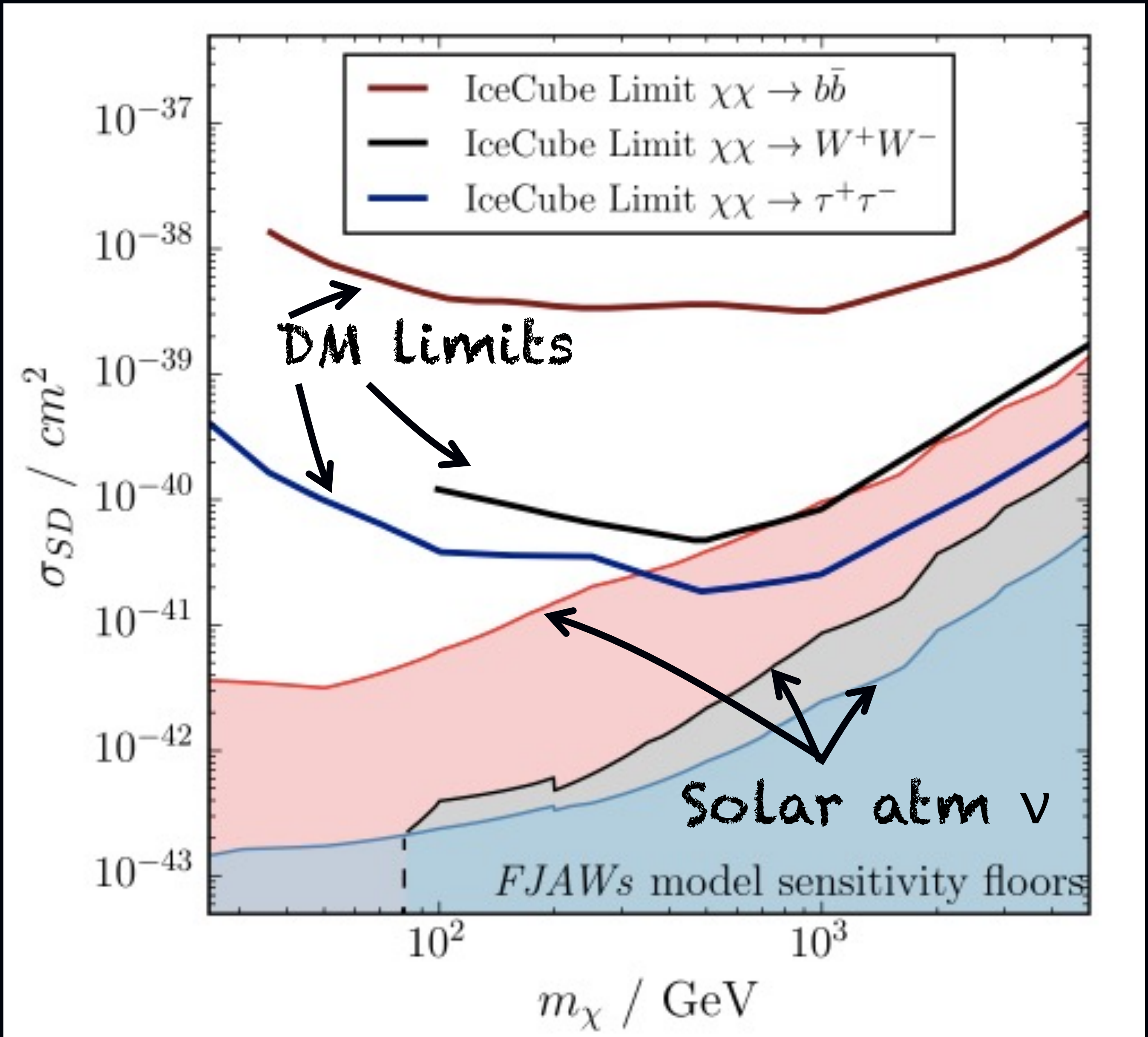


C.A. Argüelles, GDW, A. Fedynitch, B.J.P. Jones (2017)


b=0
b=1
b
ν_e
ν_μ
ν_τ
$b = 0.0$
$b = 0.4$
$b = 0.8$
solid: neutrino
dashed: antineutrino
$\Phi_\nu \, (E_\nu/\mathrm{GeV})^3 \, (\mathrm{cm}^2 \, \mathrm{s} \, \mathrm{sr} \, \mathrm{GeV})^{-1}$
E_ν/GeV


b=0
b=1
ν_e
ν_μ
ν_τ
$b = 0.0$
Dashed: at production
Solid: at Earth
ν_e
$\bar{\nu}_e$
ν_μ
$\bar{\nu}_\mu$
ν_τ
$\bar{\nu}_\tau$
$\Phi_\nu\ (E_\nu/\mathrm{GeV})^3\ (\mathrm{cm}^2\ \mathrm{s\ sr\ GeV})^{-1}$
E_ν/GeV
solid: neutrino
dashed: antineutrino

Neutrino floor

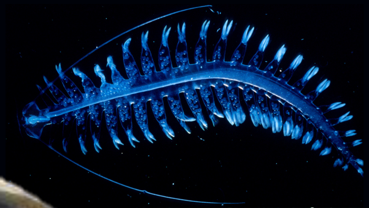


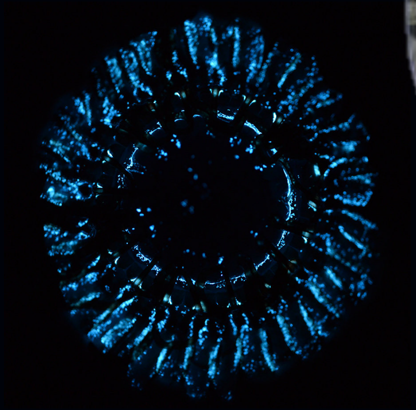
~1 order of magnitude

C.A. Argüelles, GDW, A. Fedynitch, B.J.P. Jones (2017) See also Ng. et al. and Edsjö et al. (2017)

Understanding the *noise* from the Deep Sea

Understanding the *noise* from the Deep Sea

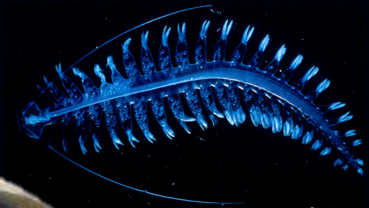


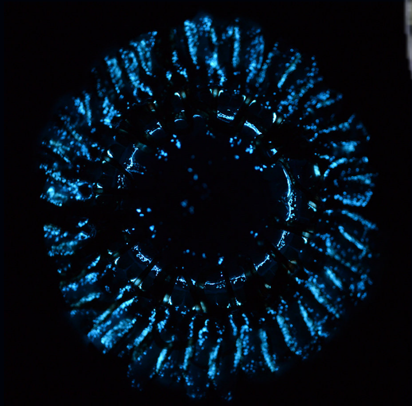


Steven Haddock/Monterey Bay Aquarium Research Institute

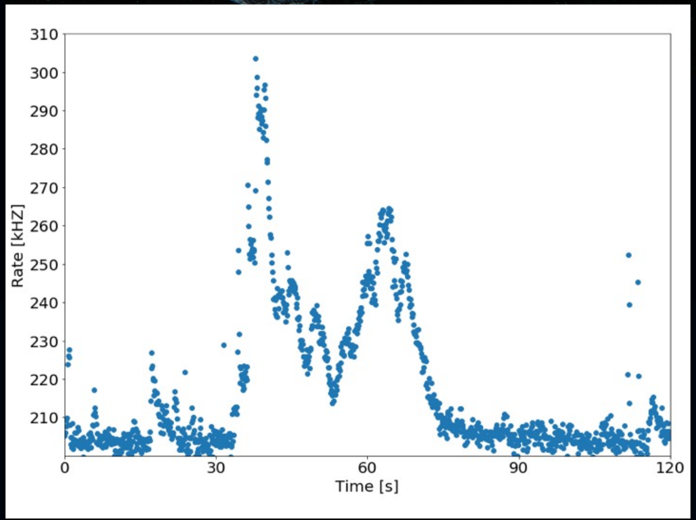
Not to scale!

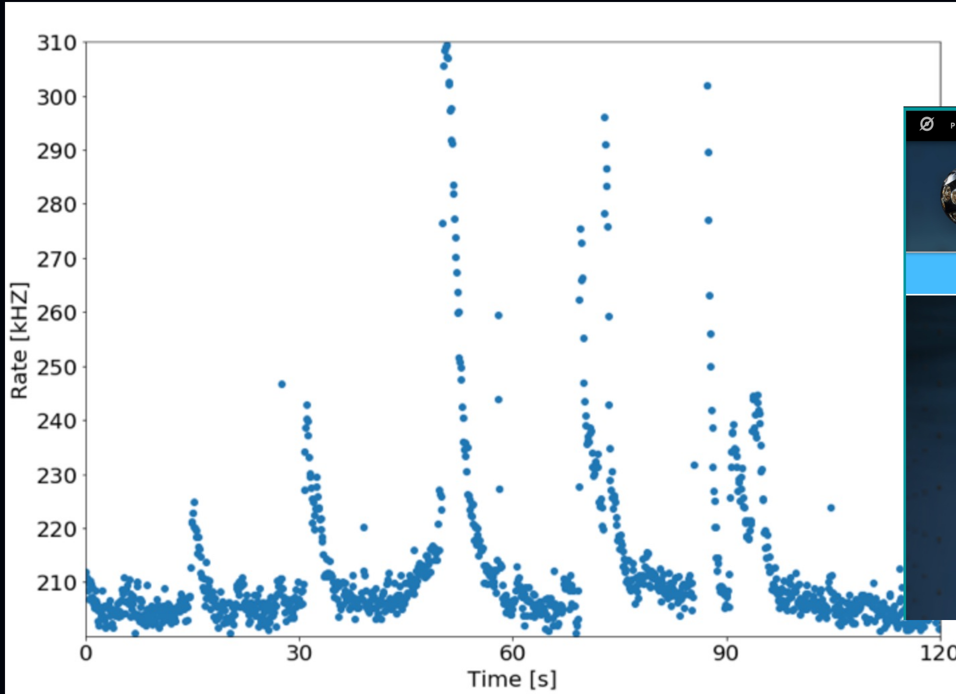
Understanding the *noise* from the Deep Sea

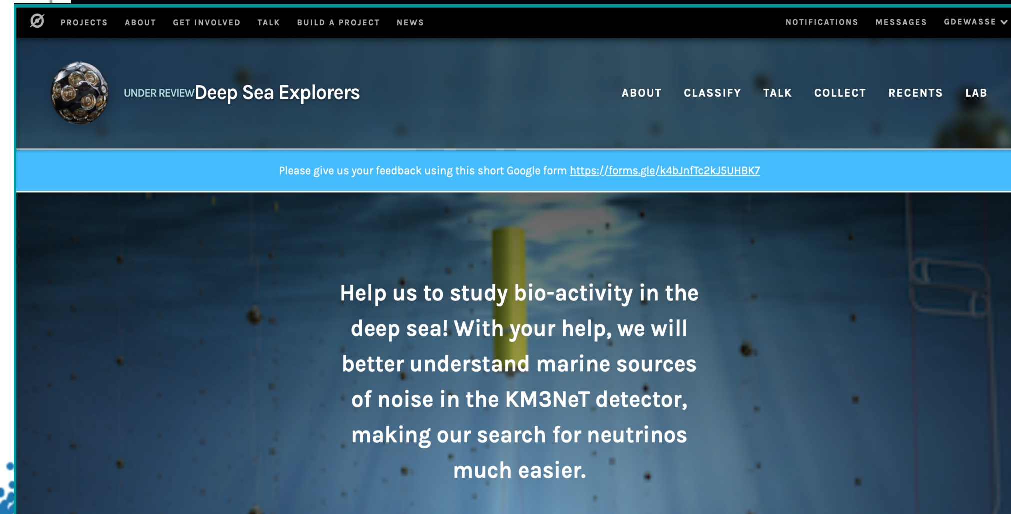


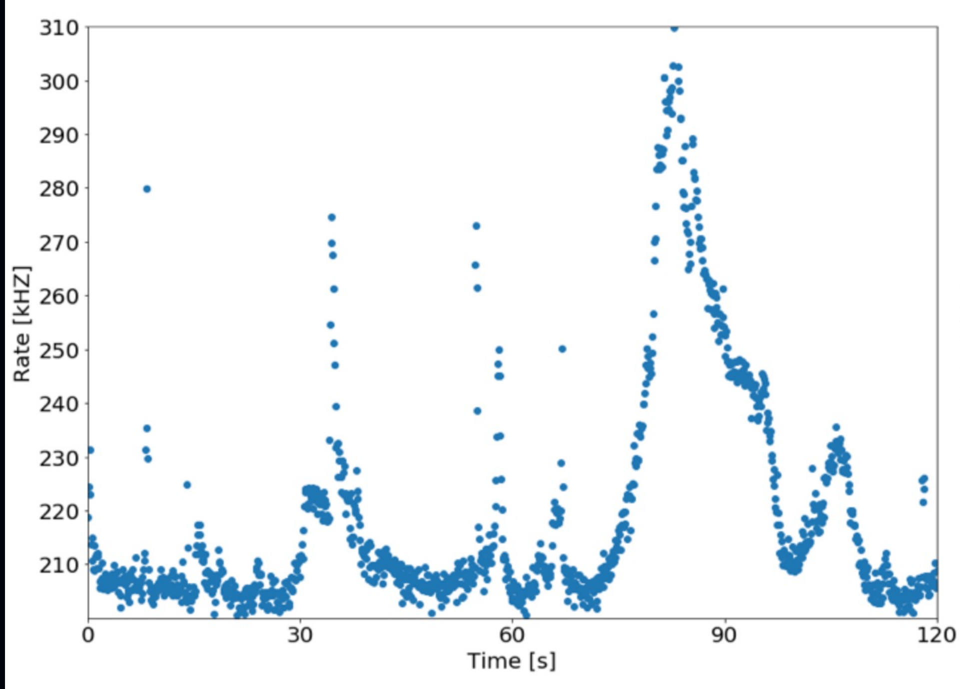


Data recorded




Rate [kHZ]
Time [s]
310
300
290
280
270
260
250
240
230
220
210
0
30
60
90
120


PROJECTS ABOUT GET INVOLVED TALK BUILD A PROJECT NEWS
NOTIFICATIONS MESSAGES GDEWASSE
UNDER REVIEW Deep Sea Explorers
ABOUT CLASSIFY TALK COLLECT RECENTS LAB
Please give us your feedback using this short Google form https://forms.gle/k4bJnfTc2kJ5UHBK7
Help us to study bio-activity in the deep sea! With your help, we will better understand marine sources of noise in the KM3NeT detector, making our search for neutrinos much easier.


Rate [kHZ]
Time [s]
310
300
290
280
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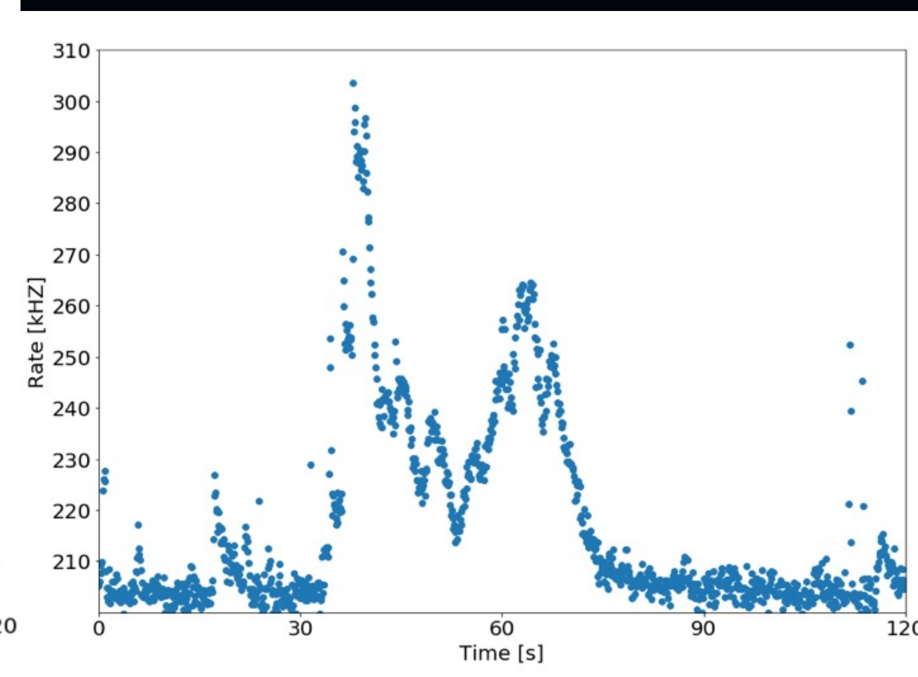
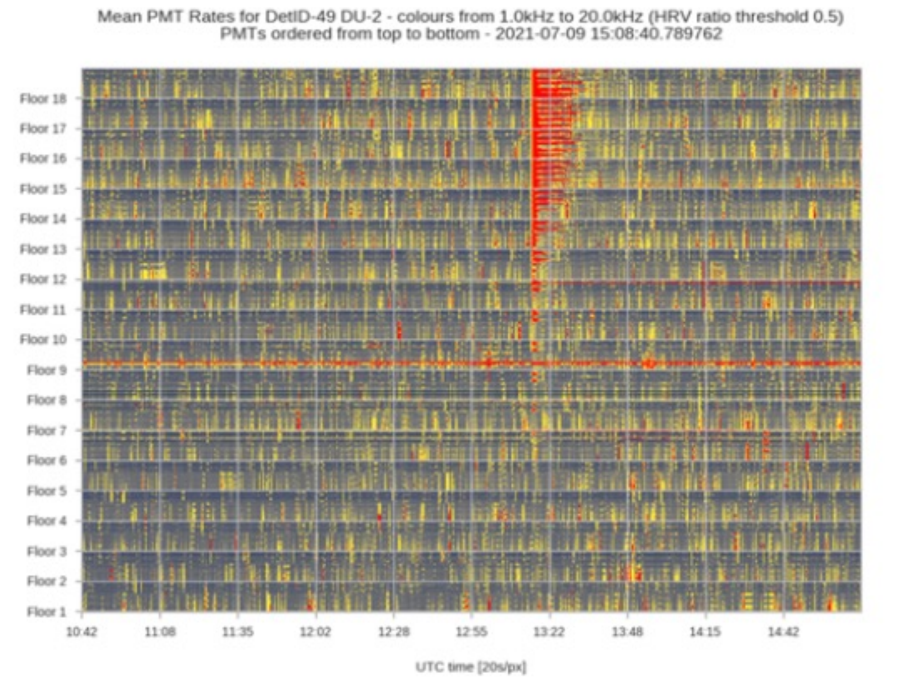
240
230
220
210
0
30
60
90
120


Rate [kHZ]
Time [s]
310
300
290
280
270
260
250
240
230
220
210
0
30
60
90
120


Mean PMT Rates for DetID-49 DU-2 - colours from 1.0kHz to 20.0kHz (HRV ratio threshold 0.5)
PMTs ordered from top to bottom - 2021-07-09 15:08:40.789762
Floor 18
Floor 17
Floor 16
Floor 15
Floor 14
Floor 13
Floor 12
Floor 11
Floor 10
Floor 9
Floor 8
Floor 7
Floor 6
Floor 5
Floor 4
Floor 3
Floor 2
Floor 1
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11:08
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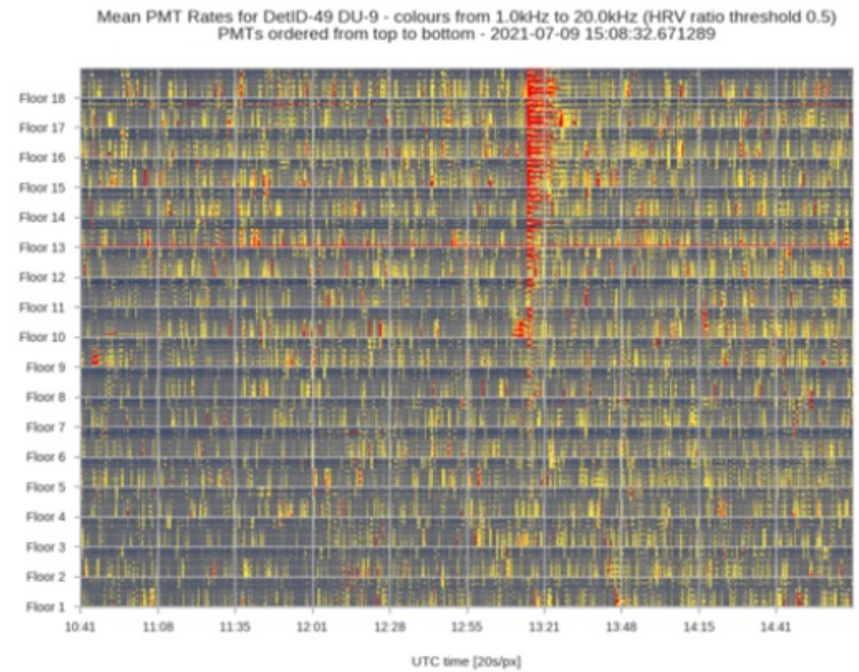
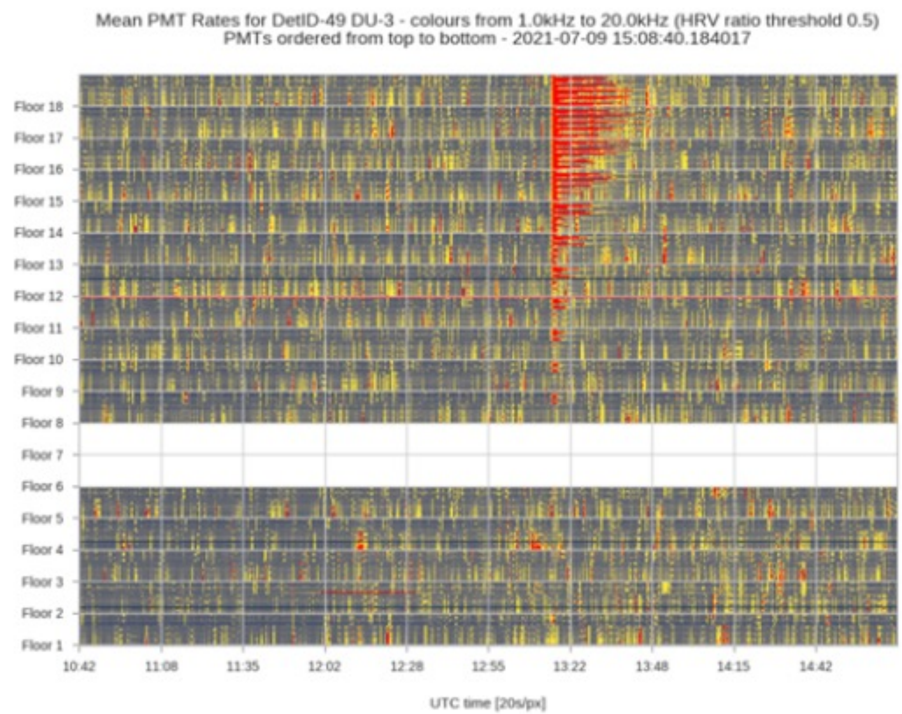
12:02
12:28
12:55
13:22
13:48
14:15
14:42
UTC time [20s/px]


Mean PMT Rates for DetID-49 DU-9 - colours from 1.0kHz to 20.0kHz (HRV ratio threshold 0.5)
PMTs ordered from top to bottom - 2021-07-09 15:08:32.671289
Floor 18
Floor 17
Floor 16
Floor 15
Floor 14
Floor 13
Floor 12
Floor 11
Floor 10
Floor 9
Floor 8
Floor 7
Floor 6
Floor 5
Floor 4
Floor 3
Floor 2
Floor 1
10:41
11:08
11:35
12:01
12:28
12:55
13:21
13:48
14:15
14:41
UTC time [20s/px]


Mean PMT Rates for DetID-49 DU-3 - colours from 1.0kHz to 20.0kHz (HRV ratio threshold 0.5)
PMTs ordered from top to bottom - 2021-07-09 15:08:40.184017
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Floor 12
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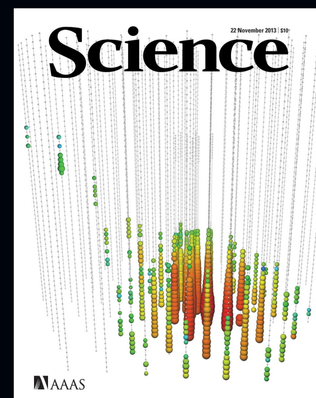
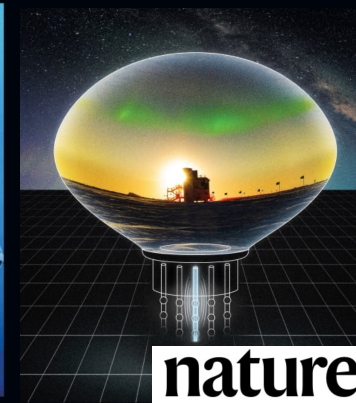
Floor 9
Floor 8
Floor 7
Floor 6
Floor 5
Floor 4
Floor 3
Floor 2
Floor 1
10:42
11:08
11:35
12:02
12:28
12:55
13:22
13:48
14:15
14:42
UTC time [20s/px]

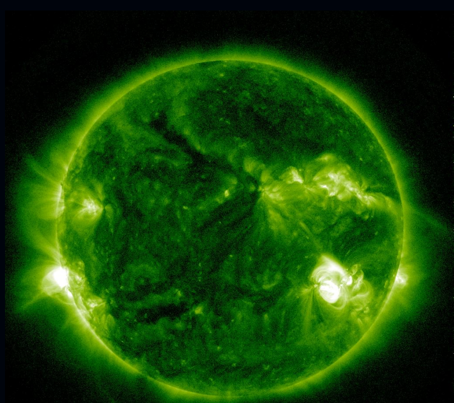
Discovering Neutrino Astronomy

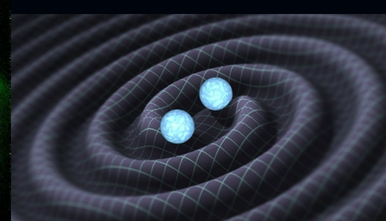
ICECUBE

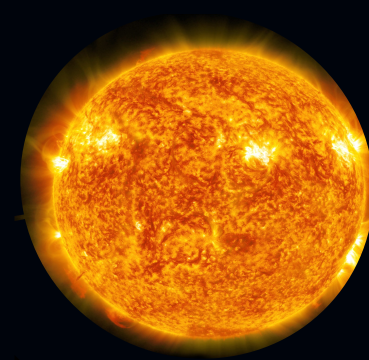
KM3NeT





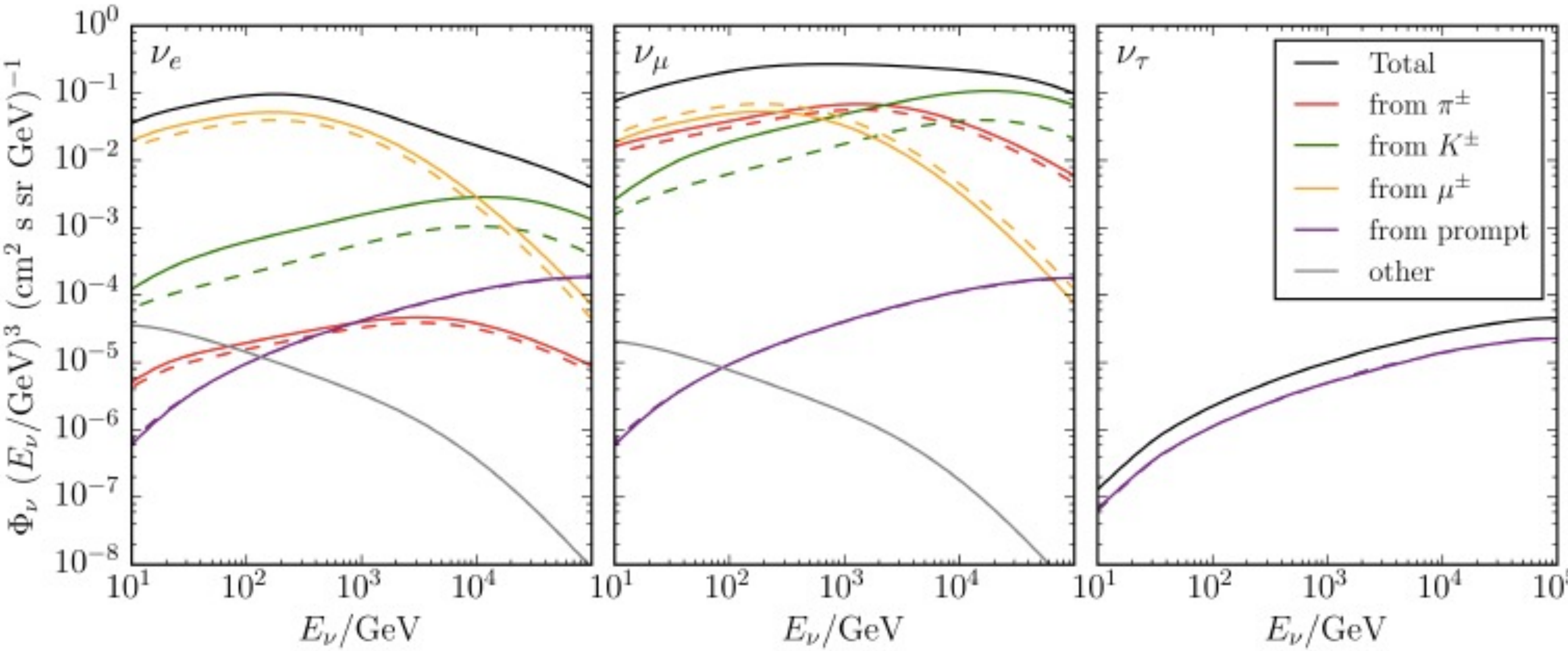






Thanks!

Solar atmospheric flux



C.A. Argüelles, GDW, A. Fedynitch, B.J.P. Jones (2017)