High Energy Neutrinos in IceCube: How can we find them?

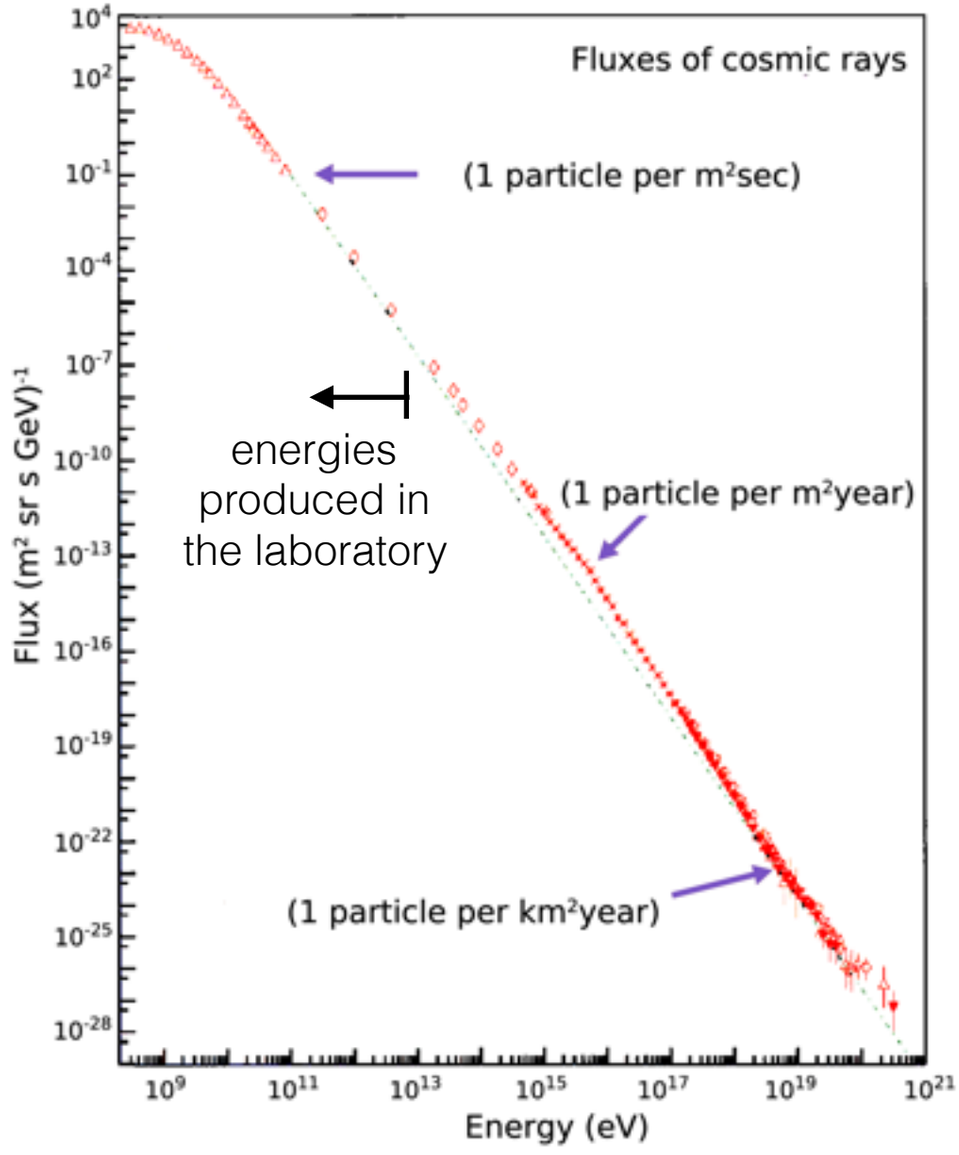
Masterclasses 2015

Nancy Wandkowsky

What do we know about neutrinos?

Why do we search for neutrinos?

1912: Hess discovers
“Cosmic Rays” (mainly p)



Where do they come from and how are they accelerated?

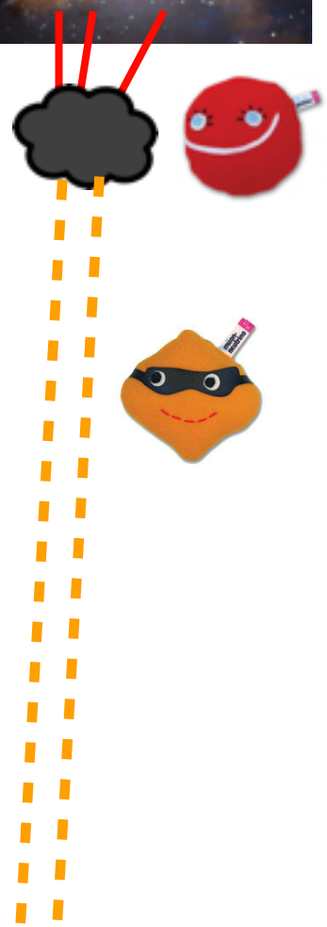
Why do we search for neutrinos?

Ingredients for cosmic neutrinos:

Why do we search for neutrinos?

Ingredients for cosmic neutrinos:

- cosmic proton accelerator
- nearby target, ’beam dump’



$$p + \gamma \rightarrow \pi^+ + n \rightarrow \mu^+ + \nu_\mu + n$$

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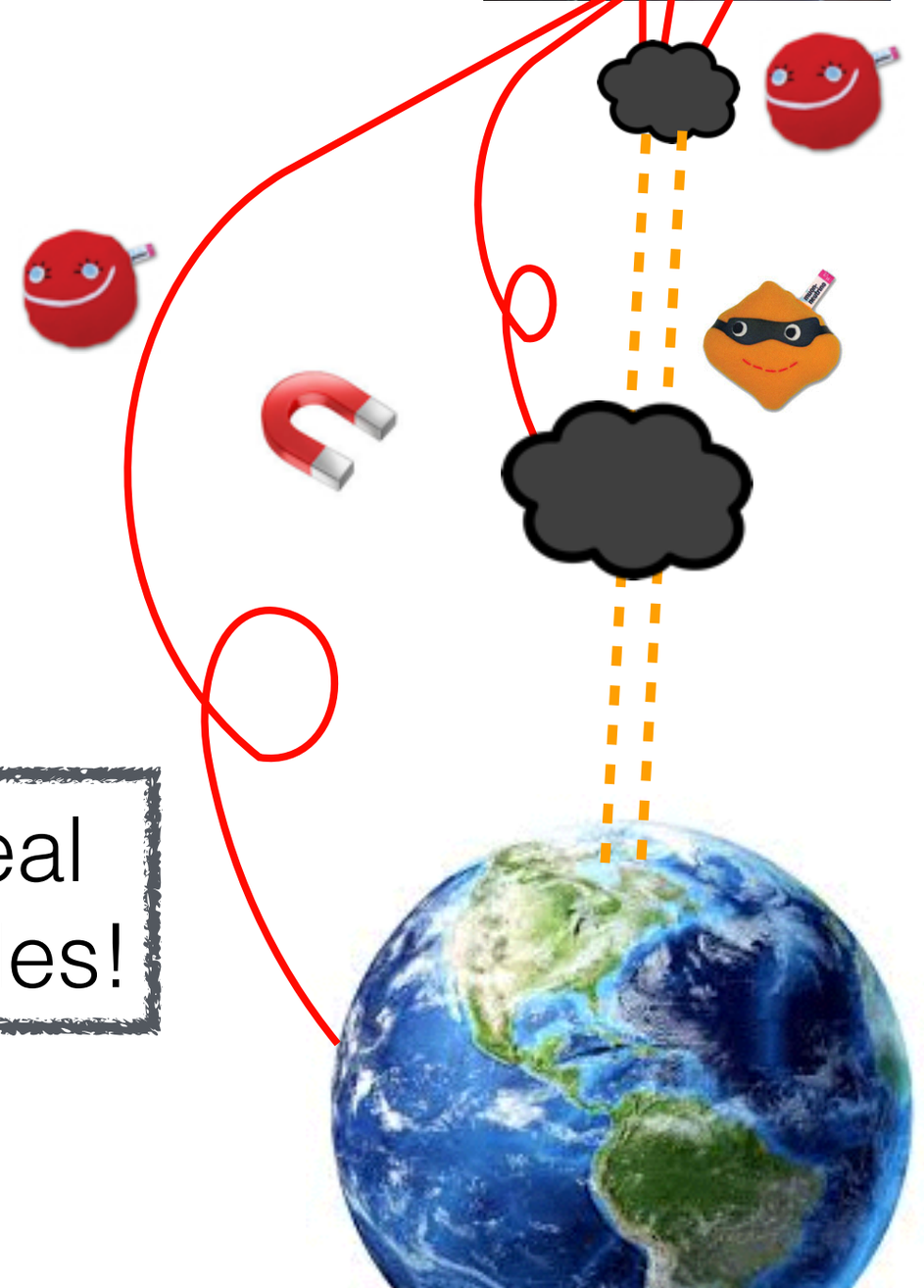
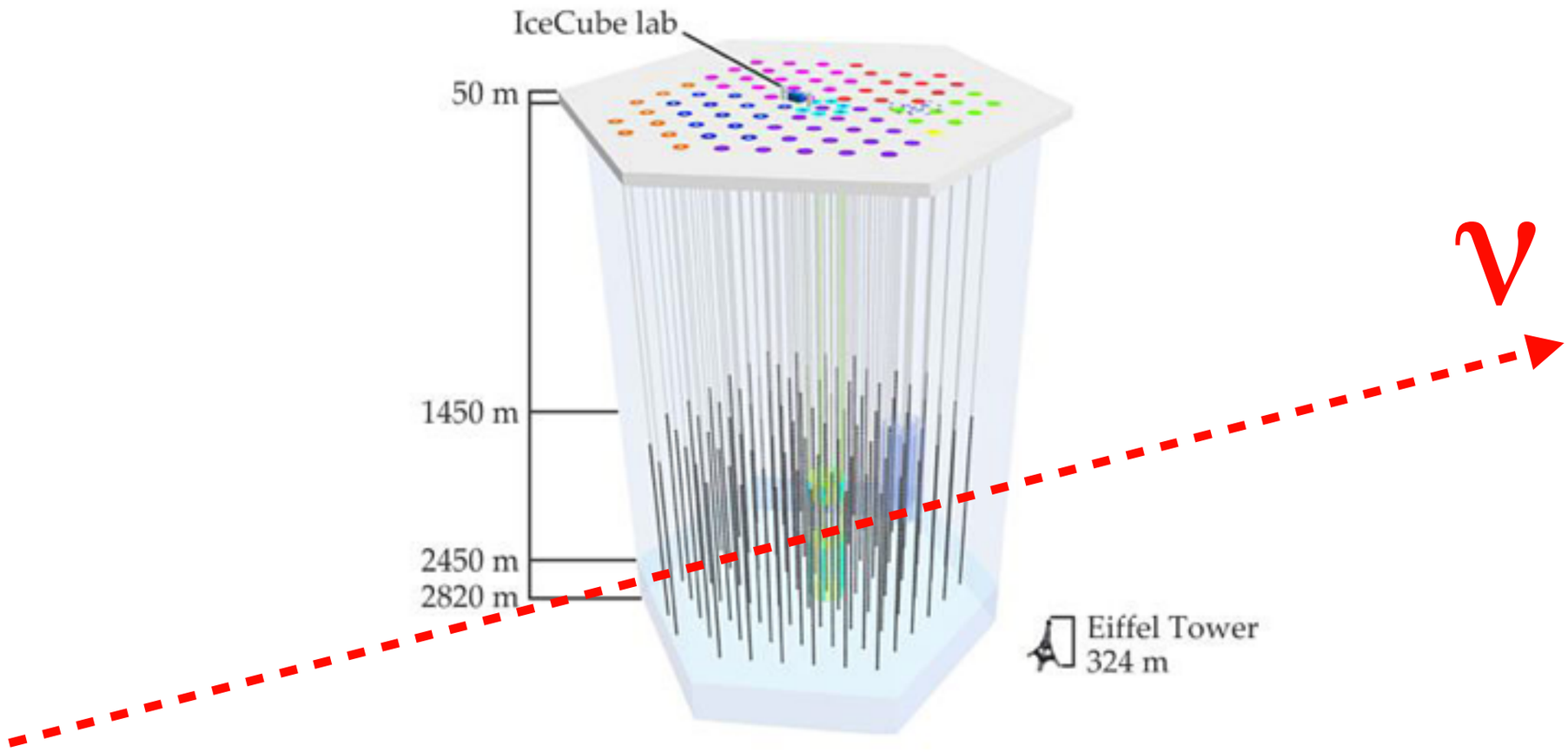


$$p + \gamma \rightarrow \pi^+ + n \rightarrow \mu^+ + \nu_\mu + n$$

Neutrinos are ideal messenger particles!

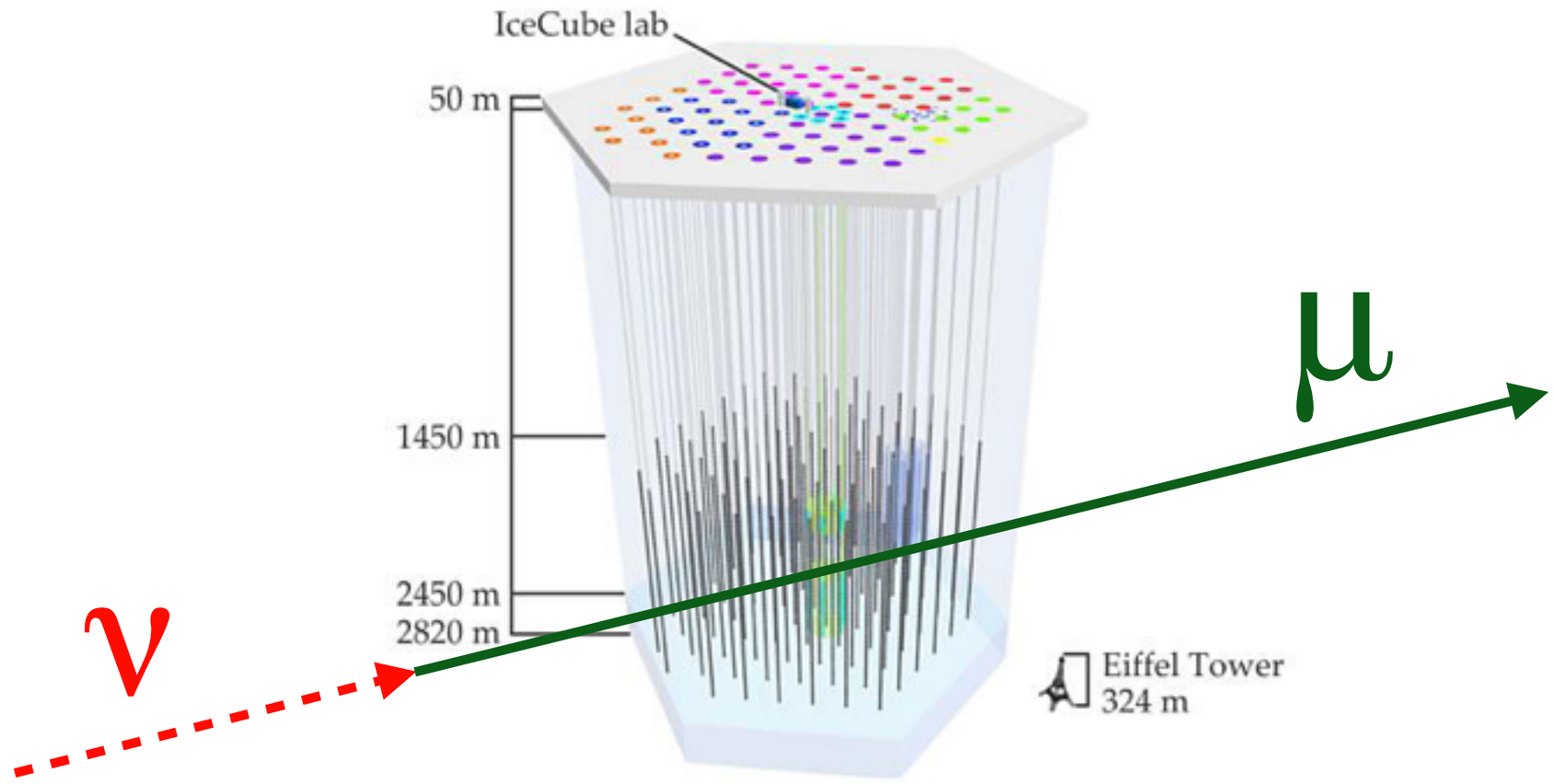
How does IceCube detect neutrinos?



neutrinos themselves leave no trace → 10^{20} neutrinos pass through IceCube every second, undetected!

so what is IceCube measuring?

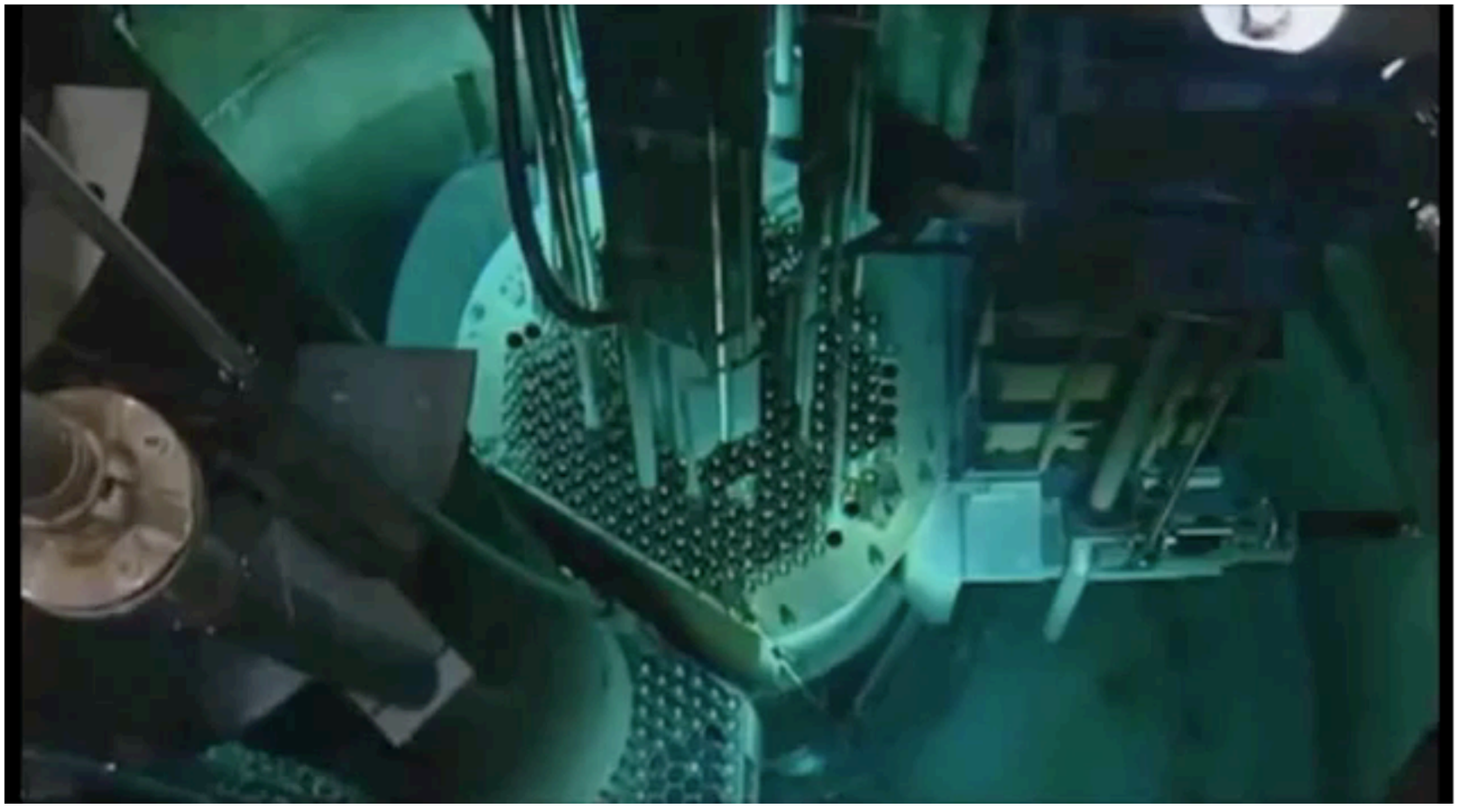
How does IceCube detect neutrinos?



first, the neutrino has to interact with the ice, producing charged particles such as muons

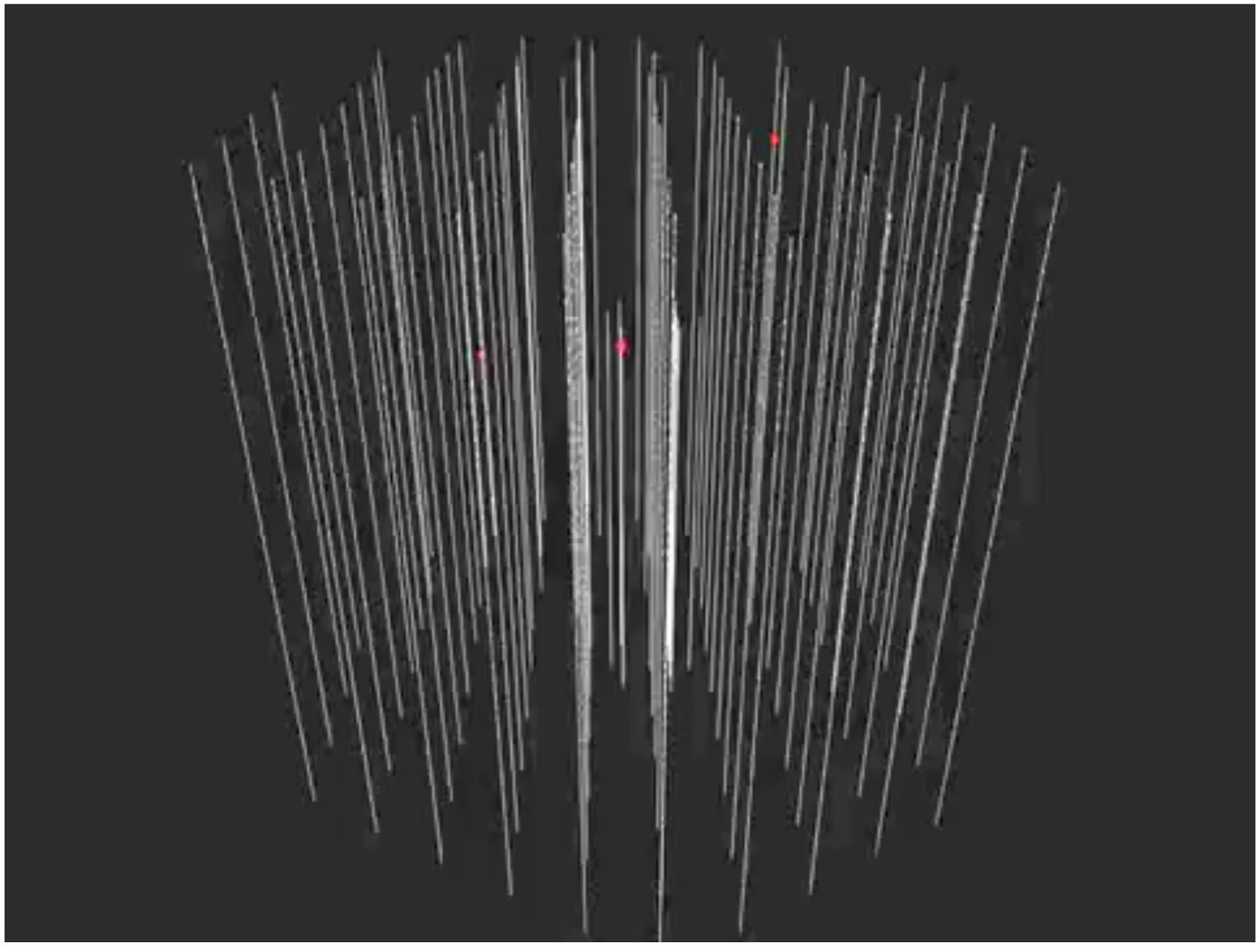
muons pass us at a rate of 1 per cm^2 and minute:
why don't we see them, but the detector can?

How does IceCube detect neutrinos?



high-energy charged particles traveling in a **medium** produce Cherenkov light!

How does IceCube detect neutrinos?



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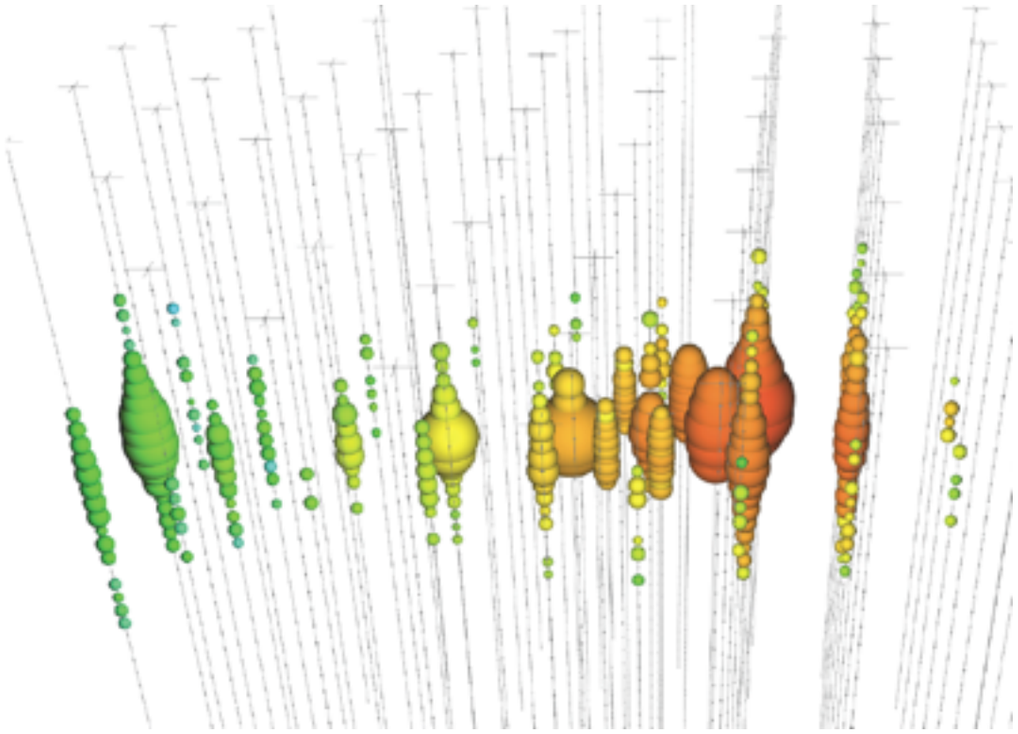
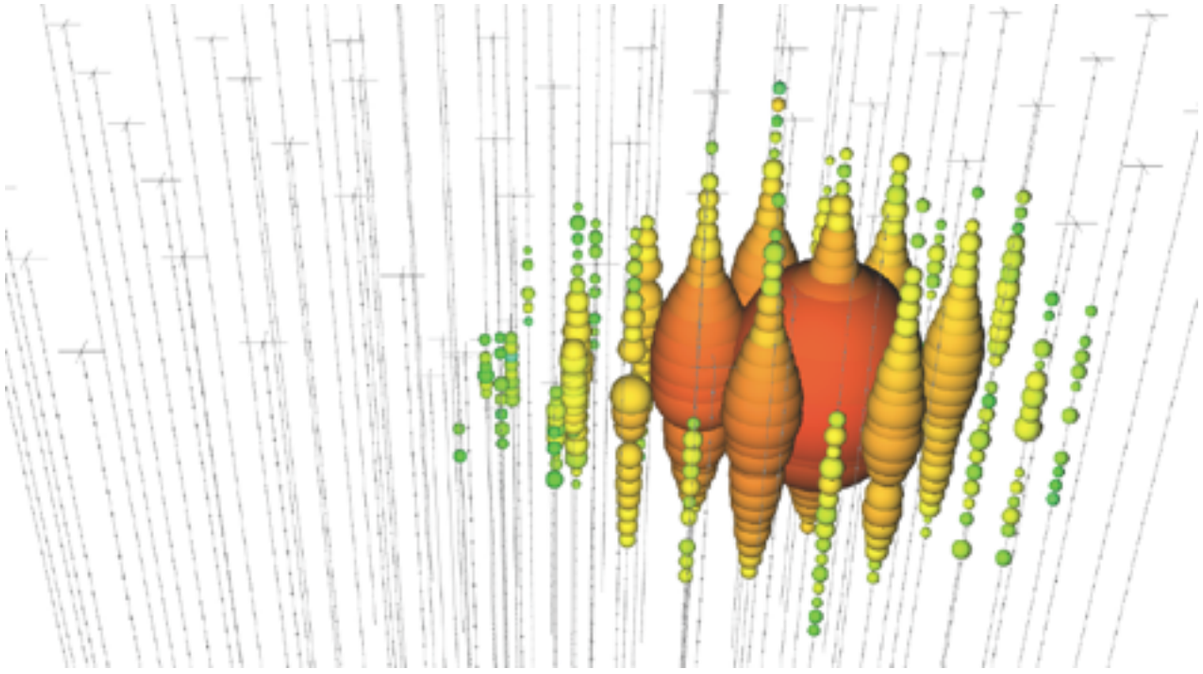
What do neutrinos look like in IceCube?

track



$\nu_\mu + N \rightarrow \mu + X$

cascade



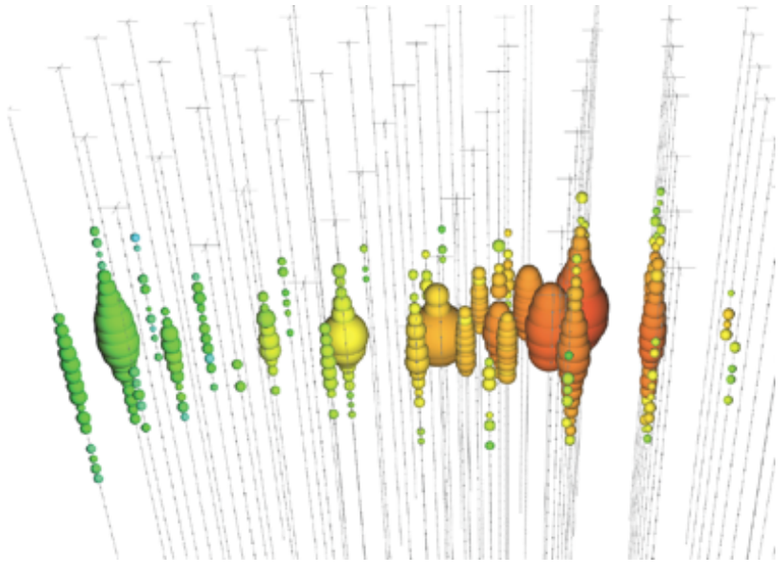
$\nu_e + N \rightarrow e + X$

$\nu_x + N \rightarrow \nu_x + N$

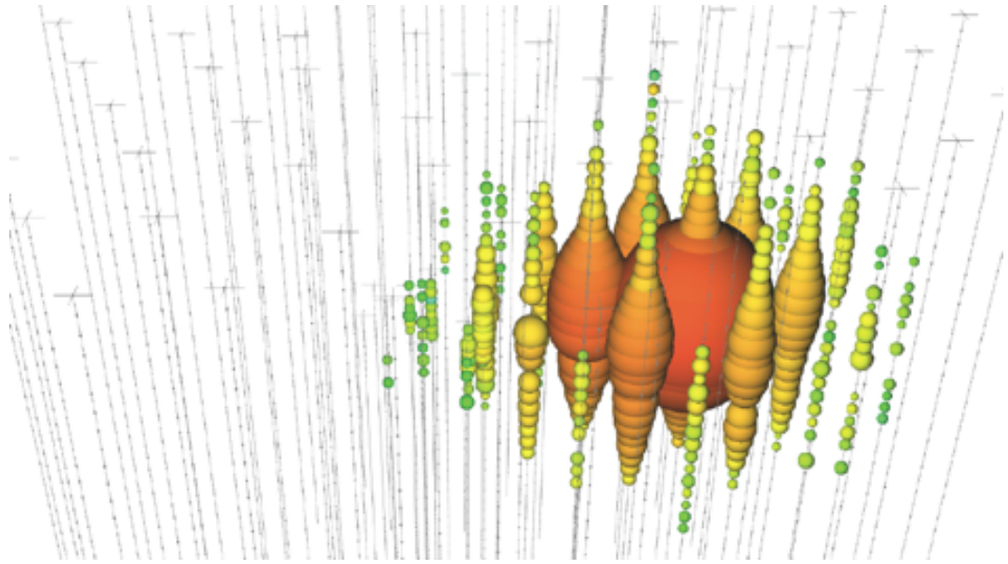
x = any flavor

What is IceCube seeing?

- For each event, we want to know the energy and direction: how good does this work for tracks/ cascades?



good direction resolution
bad energy resolution



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What do neutrinos look like in IceCube?

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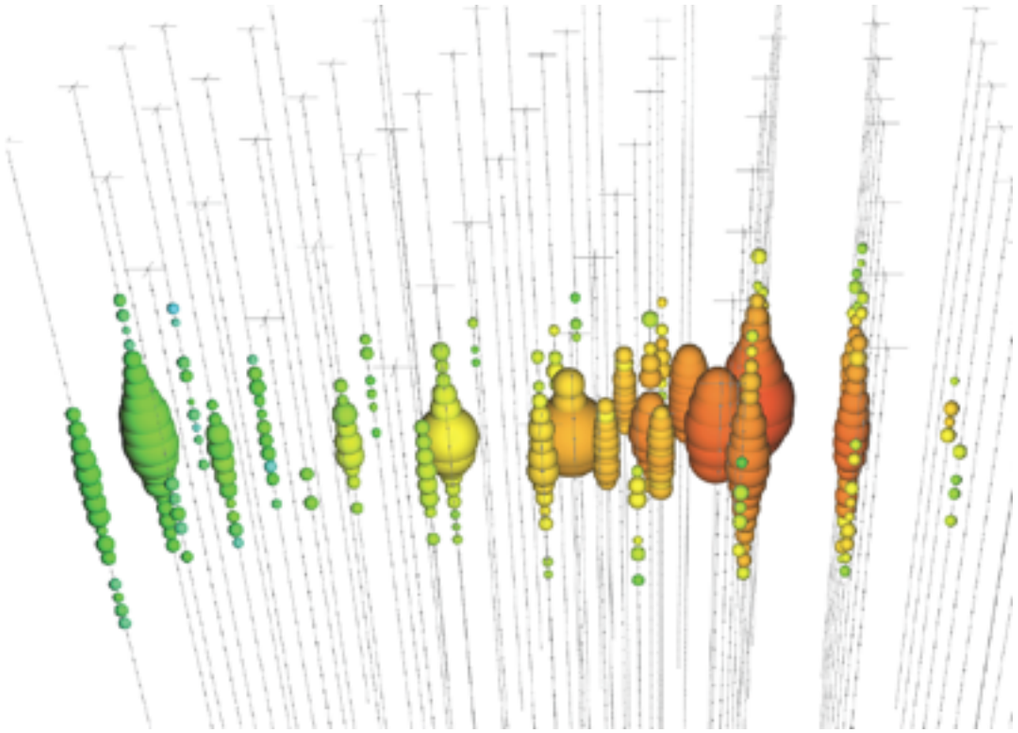

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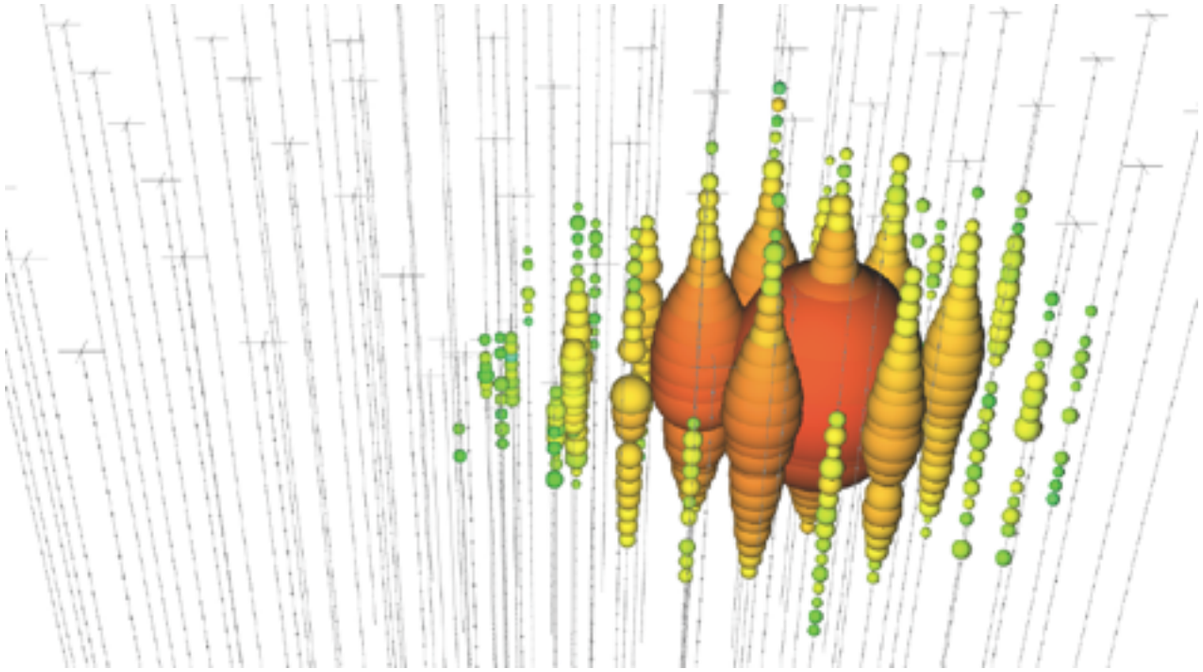

- each coloured dot represents a sensor detecting light
- size scales with the amount of recorded light
- color indicates arrival time: red first, green last

Particles in the IceCube detector

now it's your turn to identify events in this IceCube event display

http://icecube.wisc.edu/viewer/quiz

(Particle ID Quiz)

Particles in the IceCube detector

now it's your turn to identify events in this IceCube event display

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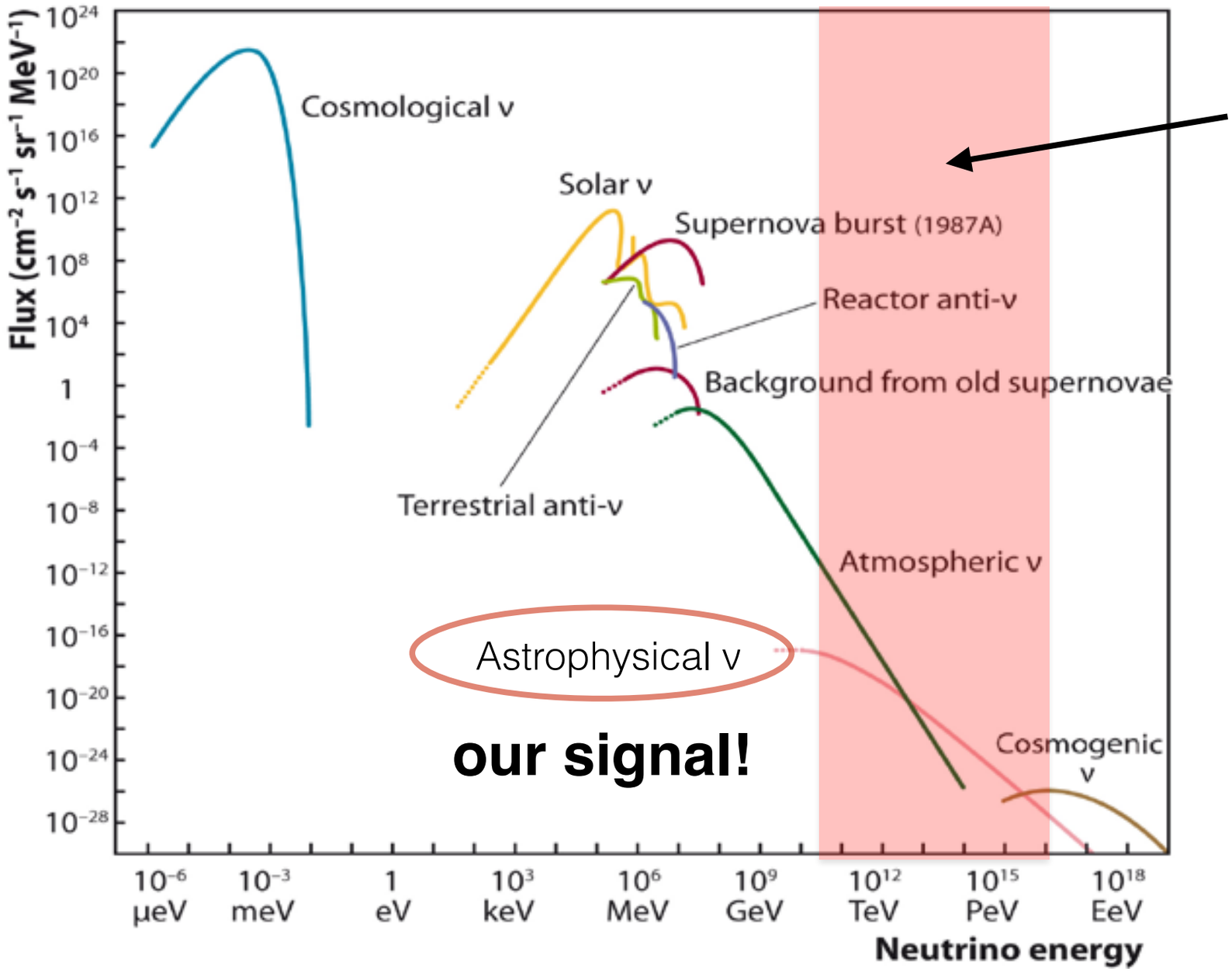
Are all of the events you just saw astrophysical neutrinos?

Particles in the IceCube detector



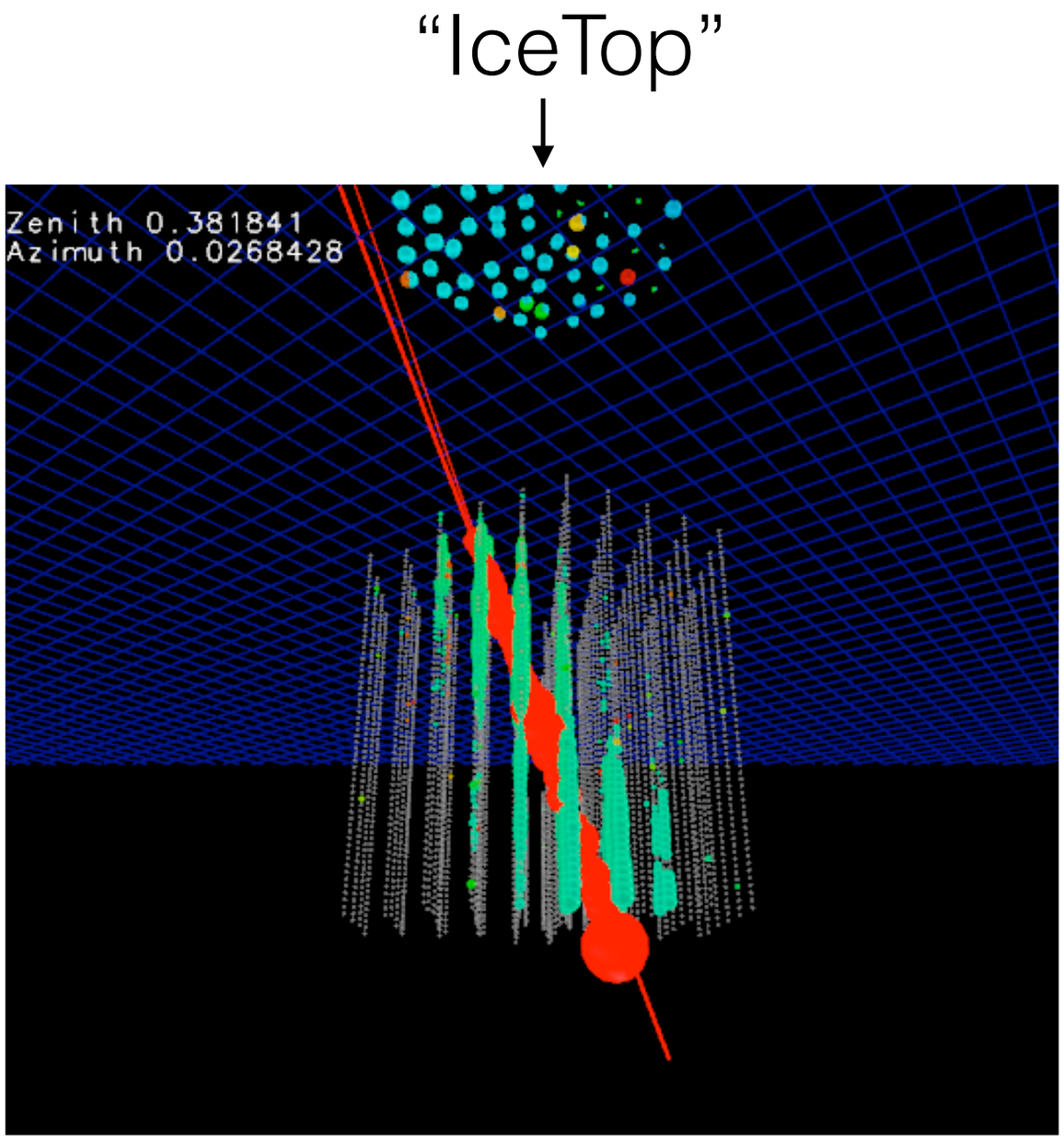
can be detected by IceCube

signal: astrophysical ν; **background**: everything else

Particles in the IceCube detector

Background:

- atmospheric neutrinos
- atmospheric muons (many! can get two at the same time: coincident event)



challenge: select only signal events!

How can we distinguish signal from background?

can you guess what is signal and what is background?

http://icecube.wisc.edu/viewer/background_signal

(Background vs Signal)

How can we select signal events?

Finding needles in a haystack

275 million atmospheric muons are detected daily, created by interactions of cosmic rays with the earth's atmosphere

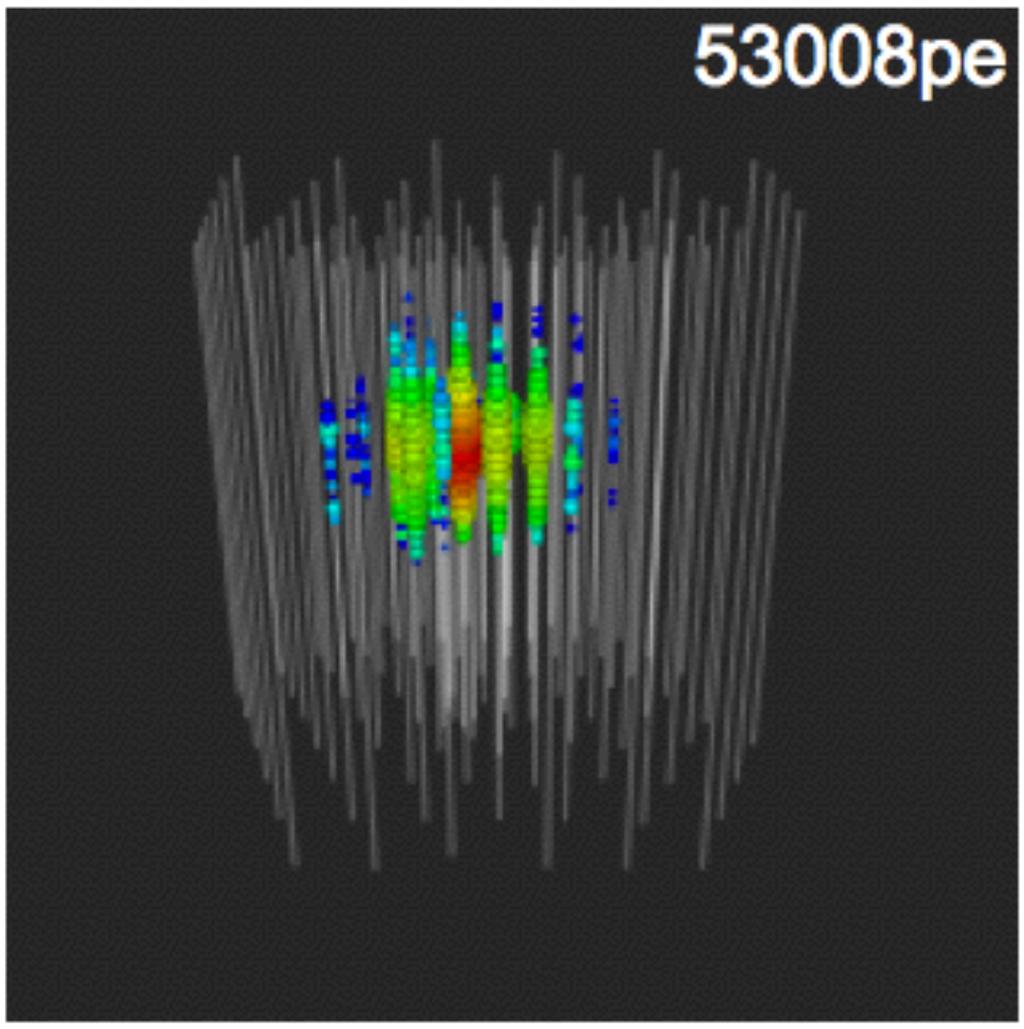
8,250 atmospheric neutrinos are detected monthly

only 10s of cosmic neutrinos are detected per year

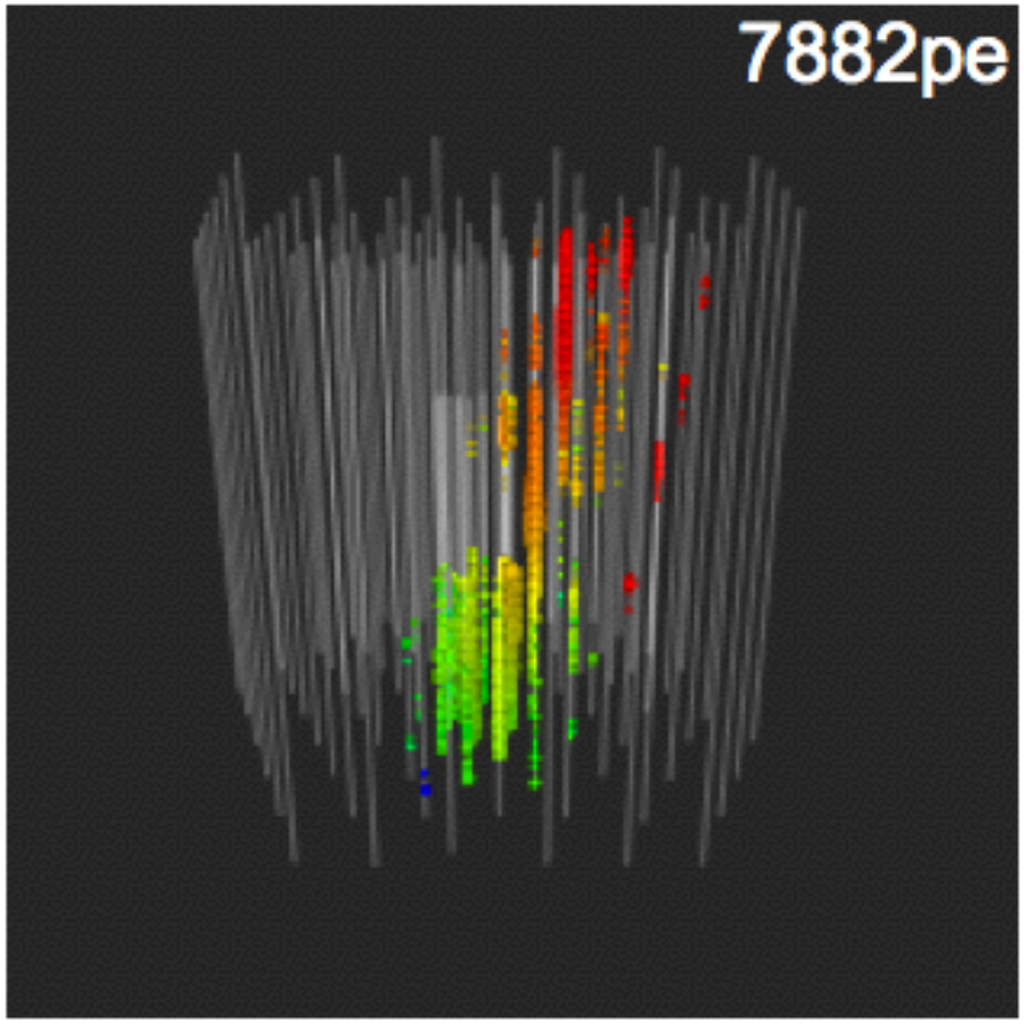
Any ideas how to select the signal events?

How can we select signal events?

typical signal

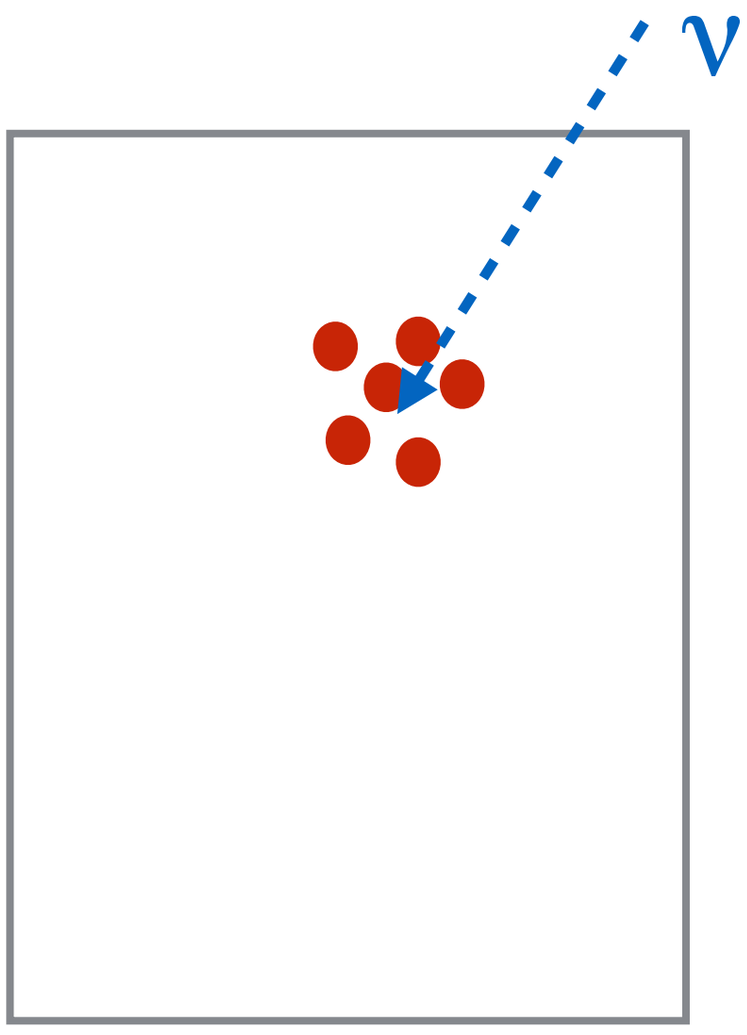


typical background

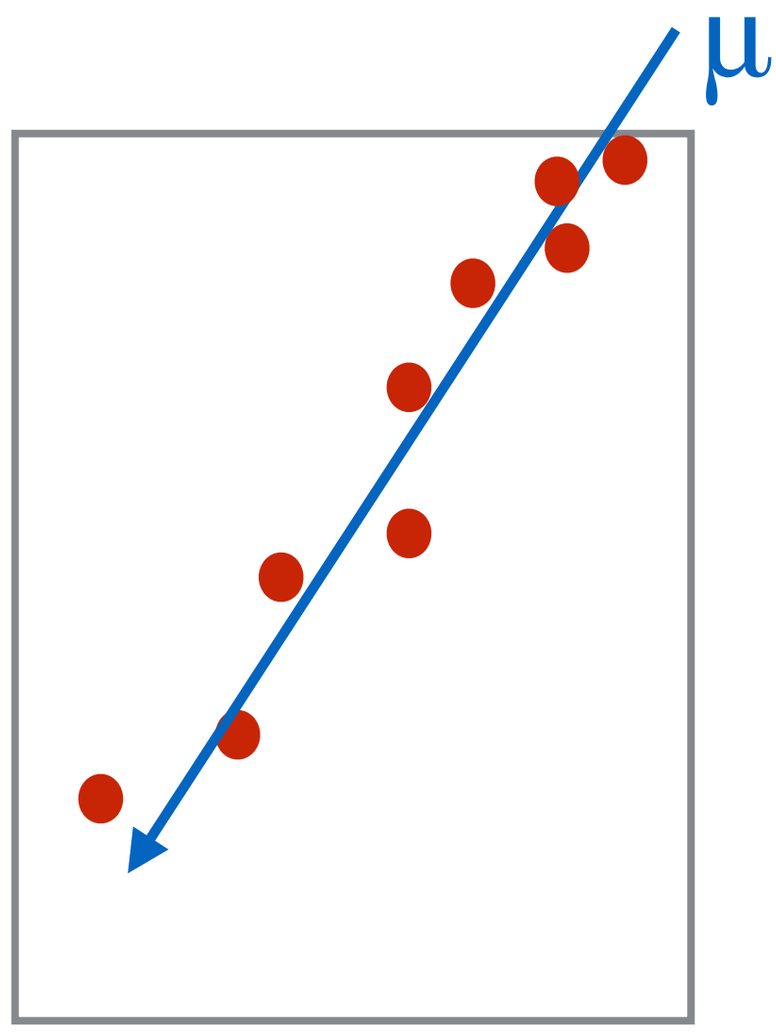


How can we select signal events?

typical signal



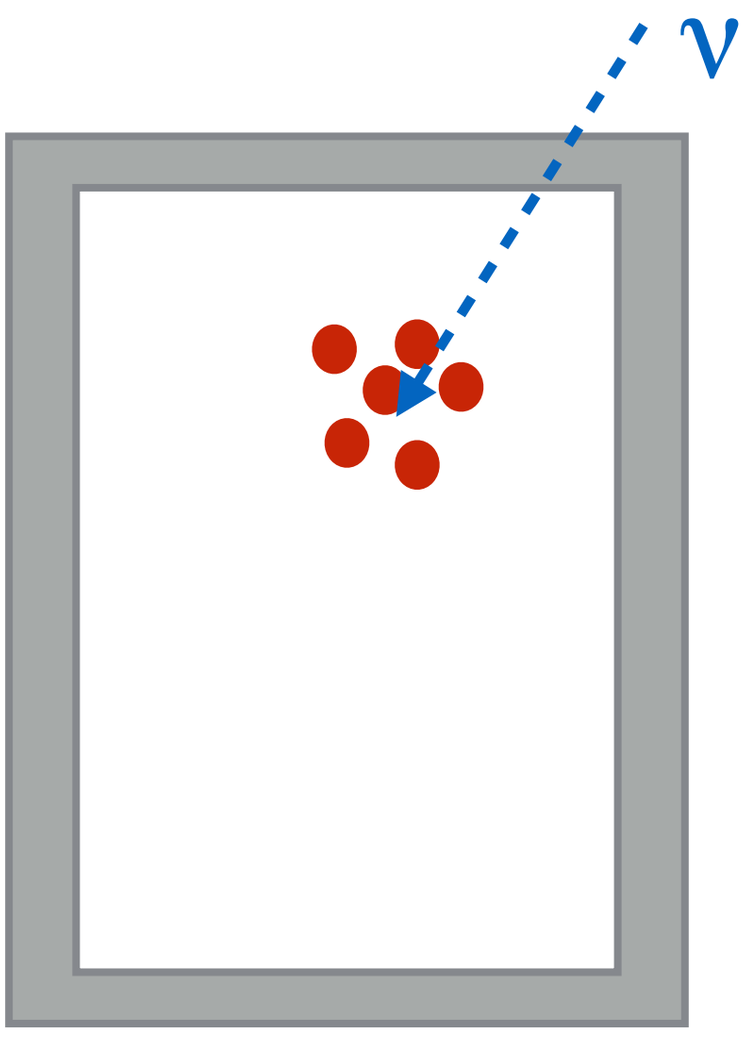
typical background



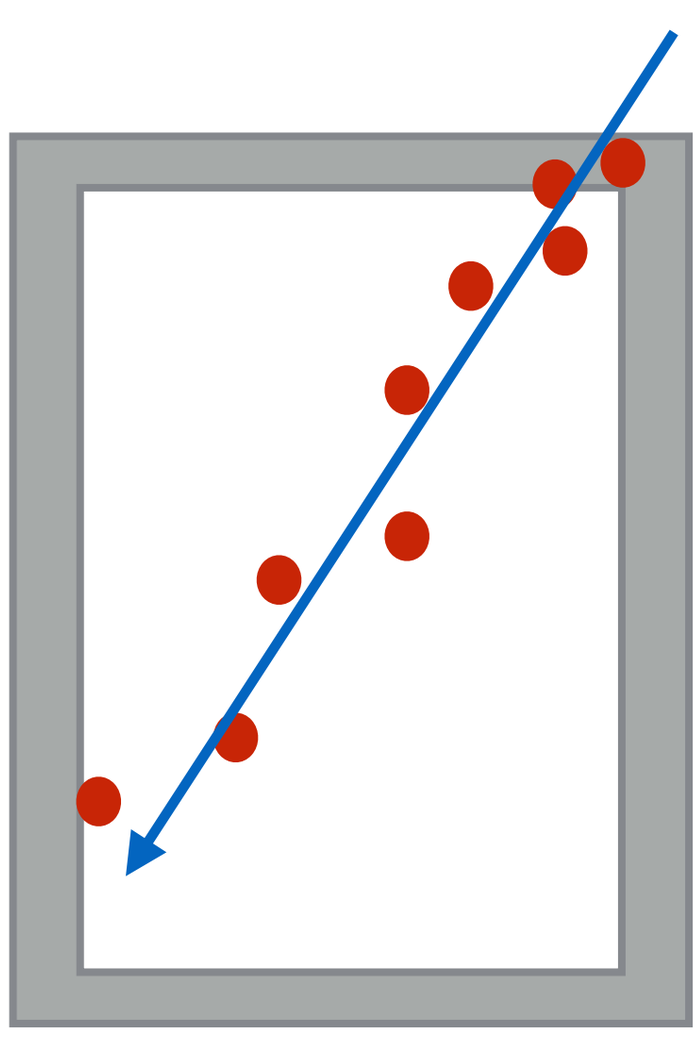
Idea: events starting in the detector have to be neutrinos

How can we select signal events?

typical signal

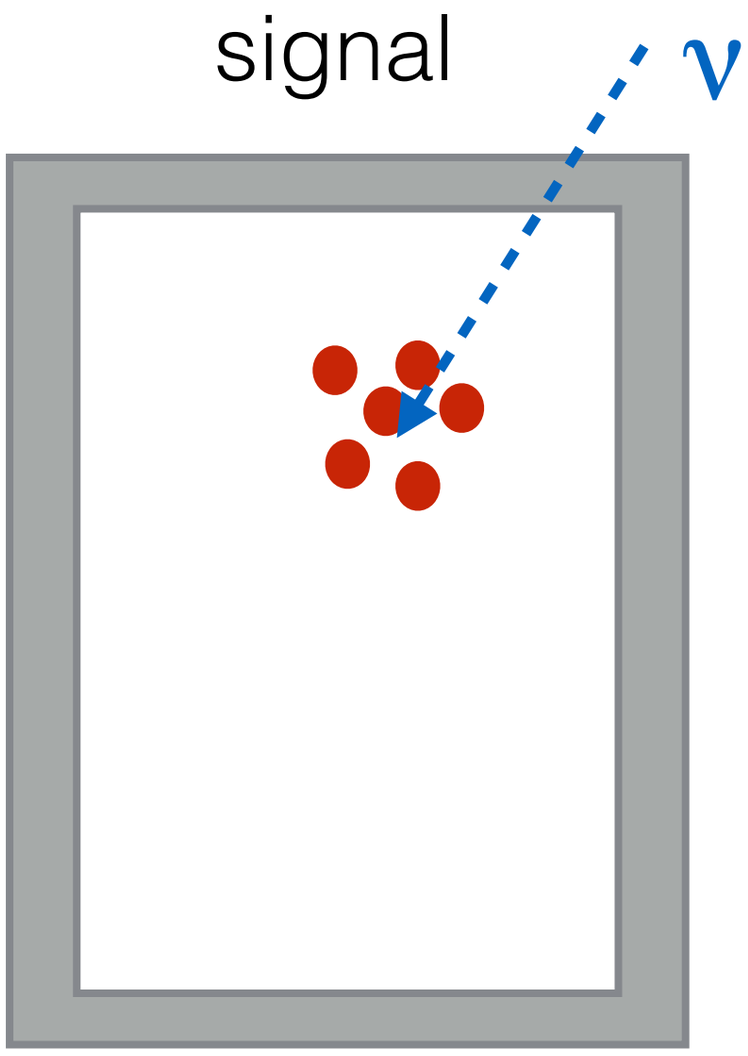


typical background



use DOMs on outer layer as veto!

How can we select signal events?

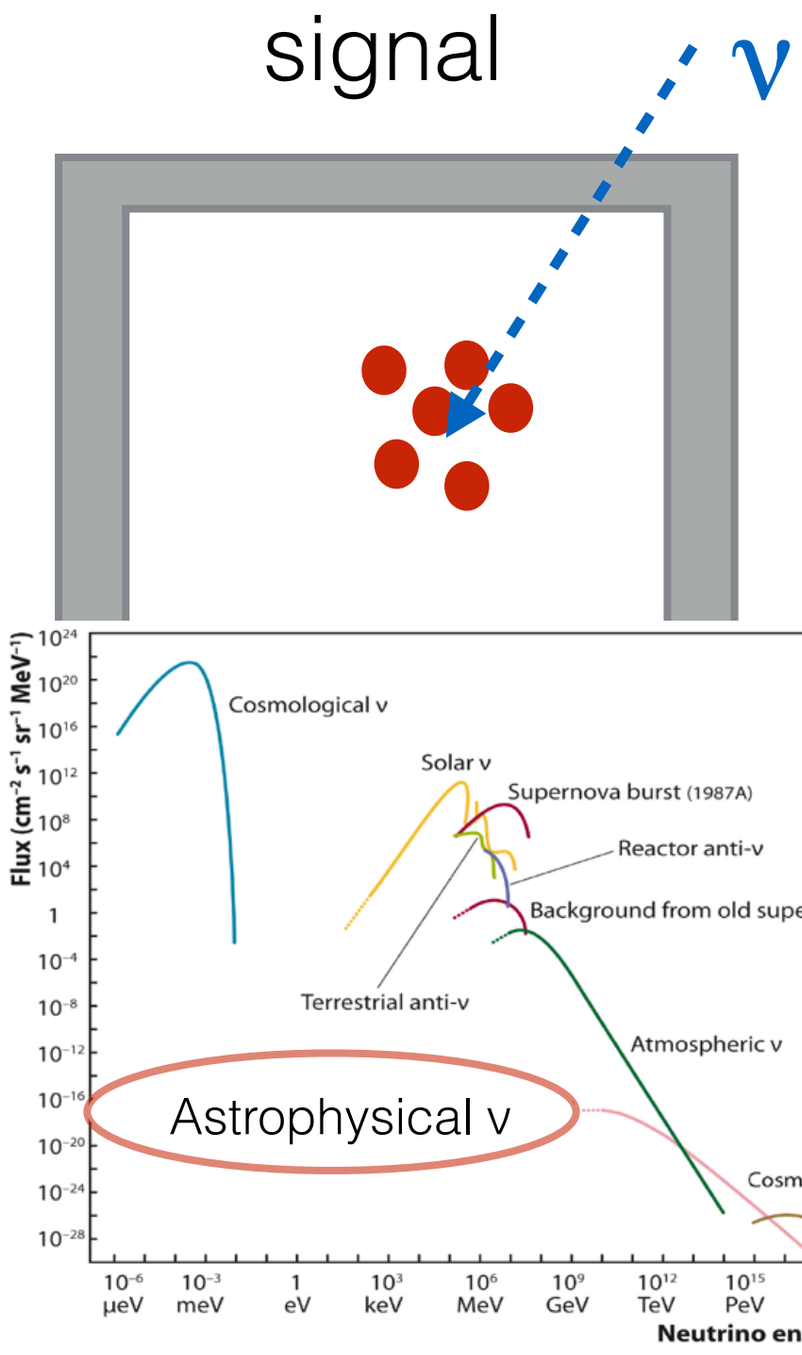


an event is marked as signal if:

- less than 3 of the first 250 photoelectrons were recorded in the veto region

→ removes atmospheric muon background

How can we select signal events?



an event is marked as signal if:

- less than 3 of the first 250 photoelectrons were recorded in the veto region

→ removes atmospheric muon background

- it deposits more than 6000 PE

→ removes some atmospheric neutrino background

How can we select signal events?

now it’s your turn: which events pass/fail the veto?

http://icecube.wisc.edu/viewer/training

(Selecting neutrinos)

What did IceCube find?

when opening up the box, we found 28 events
in 2 years of measurement

have a closer look at the individual events:

http://icecube.wisc.edu/viewer/hese

(28 very high energy events)

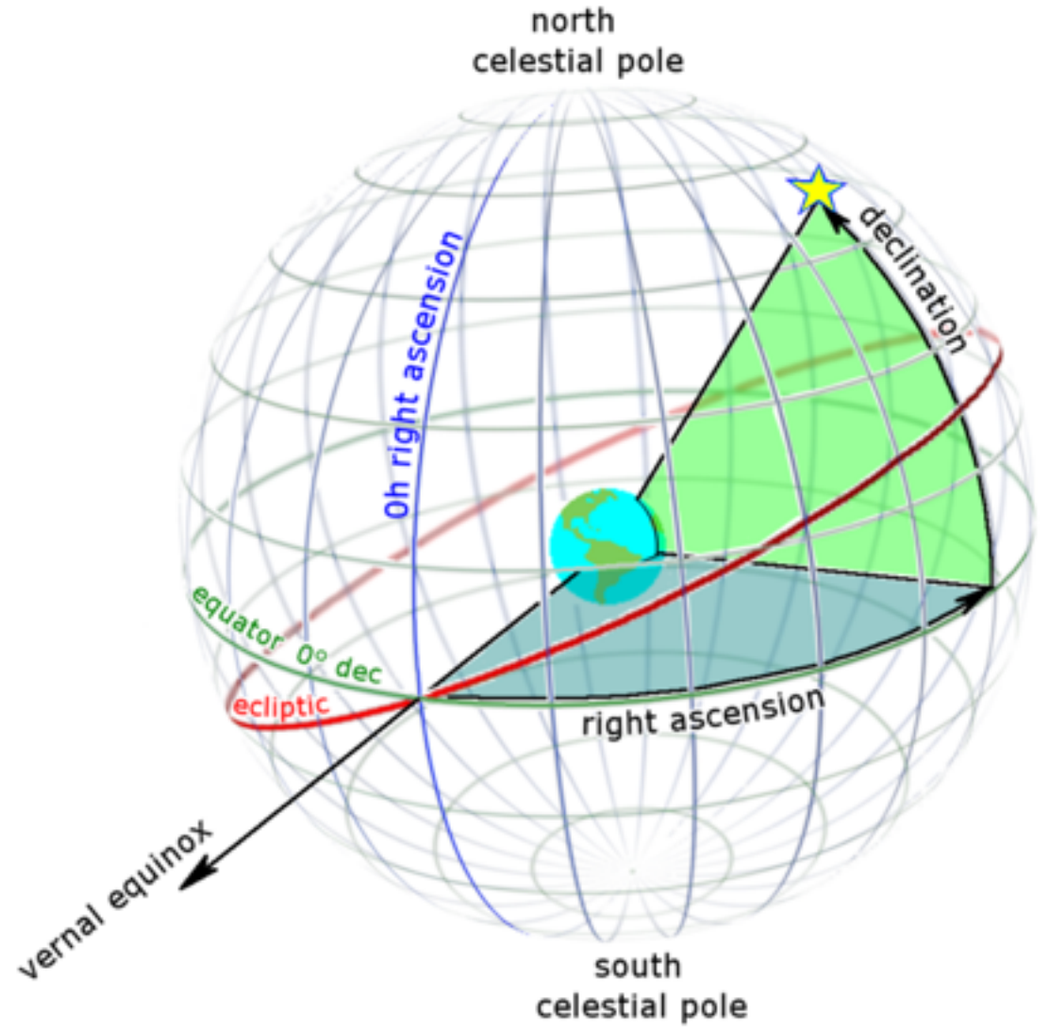
What did IceCube find?

when opening up the box, we found 28 events
in 2 years of measurement

we are interested in the following properties:

- energy
- time of event (MJD)
- arrival direction (RA, Dec)
- angular error
- event type

MJD: days since 0h Nov 17, 1858
(now: ~57099.6)



What did IceCube find?

when opening up the box, we found 28 events
in 2 years of measurement

can you guess which ones have the highest energy?

http://icecube.wisc.edu/viewer/hese_all

(The highest energy events)

What did IceCube find?

when opening up the box, we found 28 events
in 2 years of measurement

can you guess which ones have the highest energy?

http://icecube.wisc.edu/viewer/hese_all

why is it not easy to identify the highest energy events by eye?

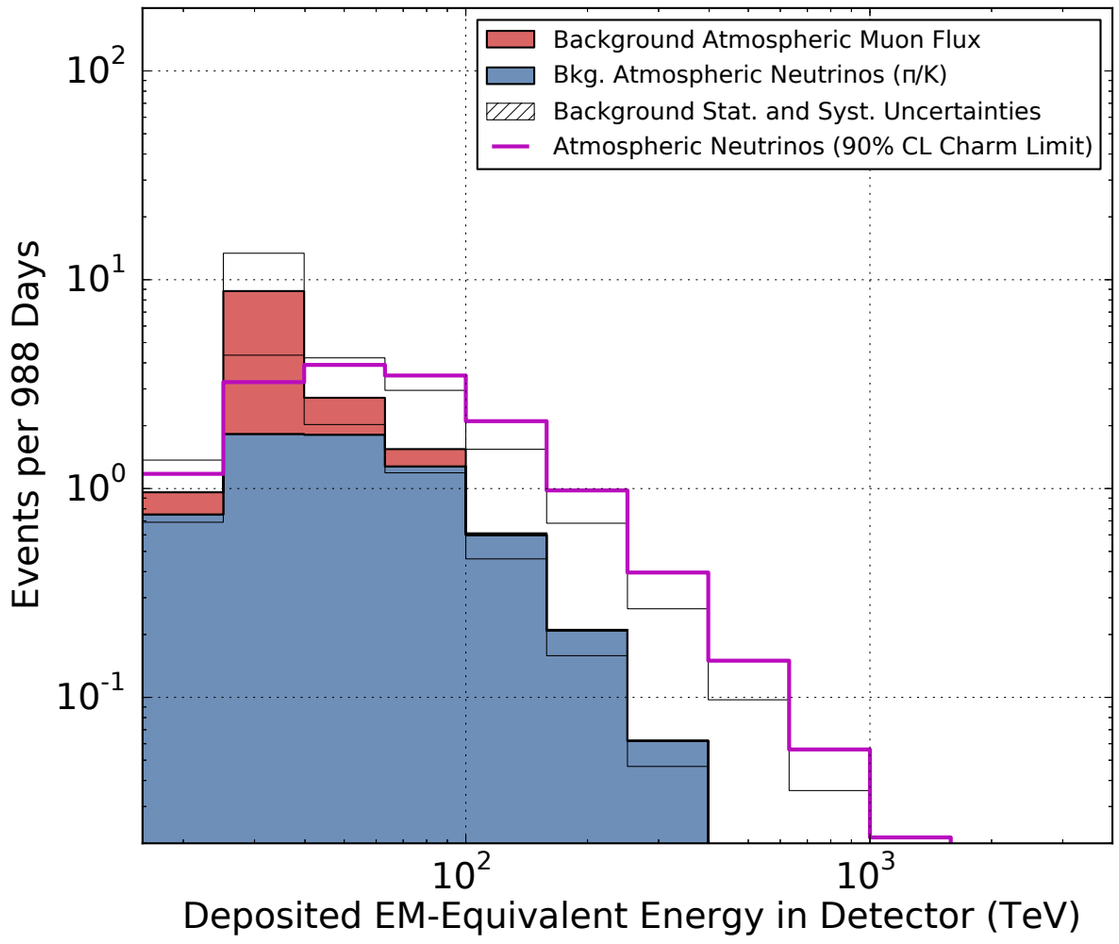
- ice is not the same everywhere
- energy can be deposited outside the detector
- …

we call these “systematic effects”

Did we find astrophysical neutrinos?

"How significant is our result?"

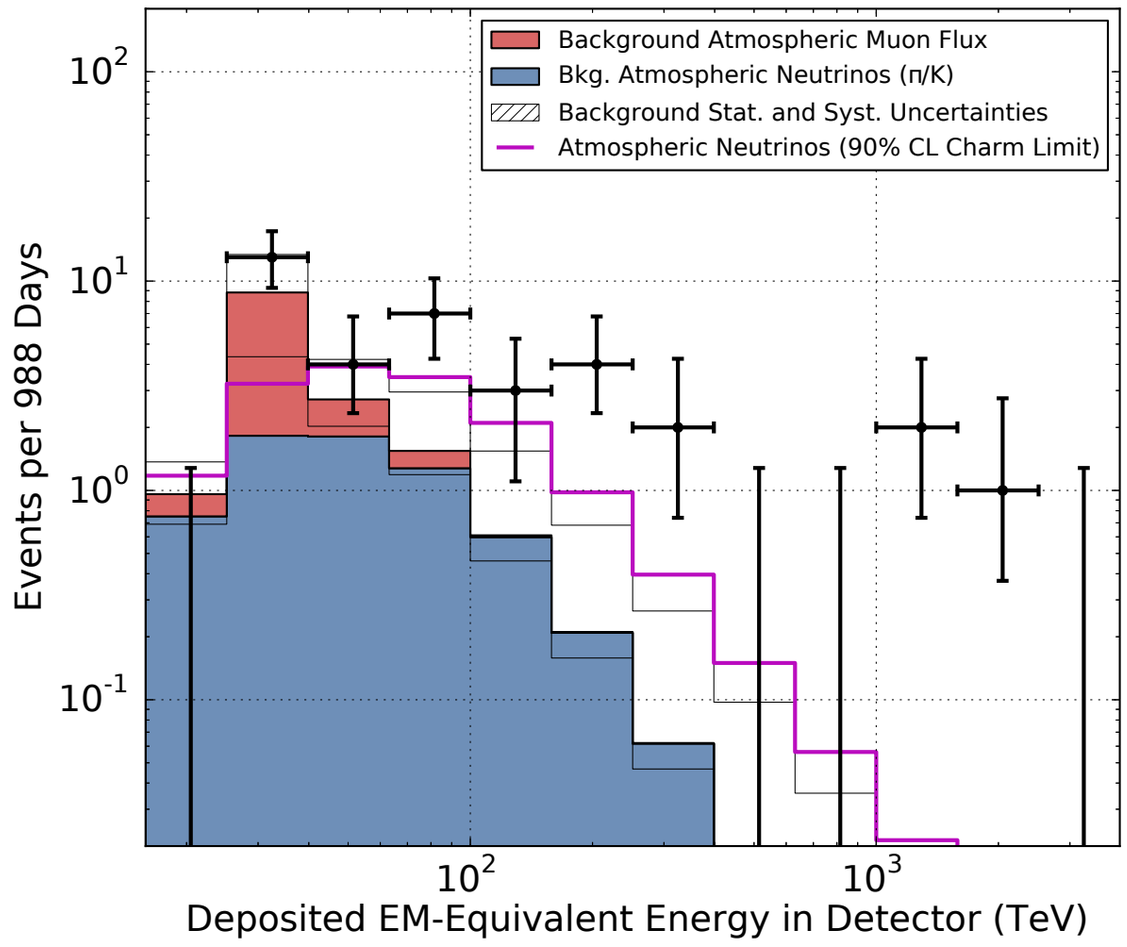
How much background did we expect?
→ needs precise computer models



Did we find astrophysical neutrinos?

"How significant is our result?"

How many events did we actually find?
→ can this be explained by a background-only hypothesis?



Did we find astrophysical neutrinos?

“How significant is our result?”

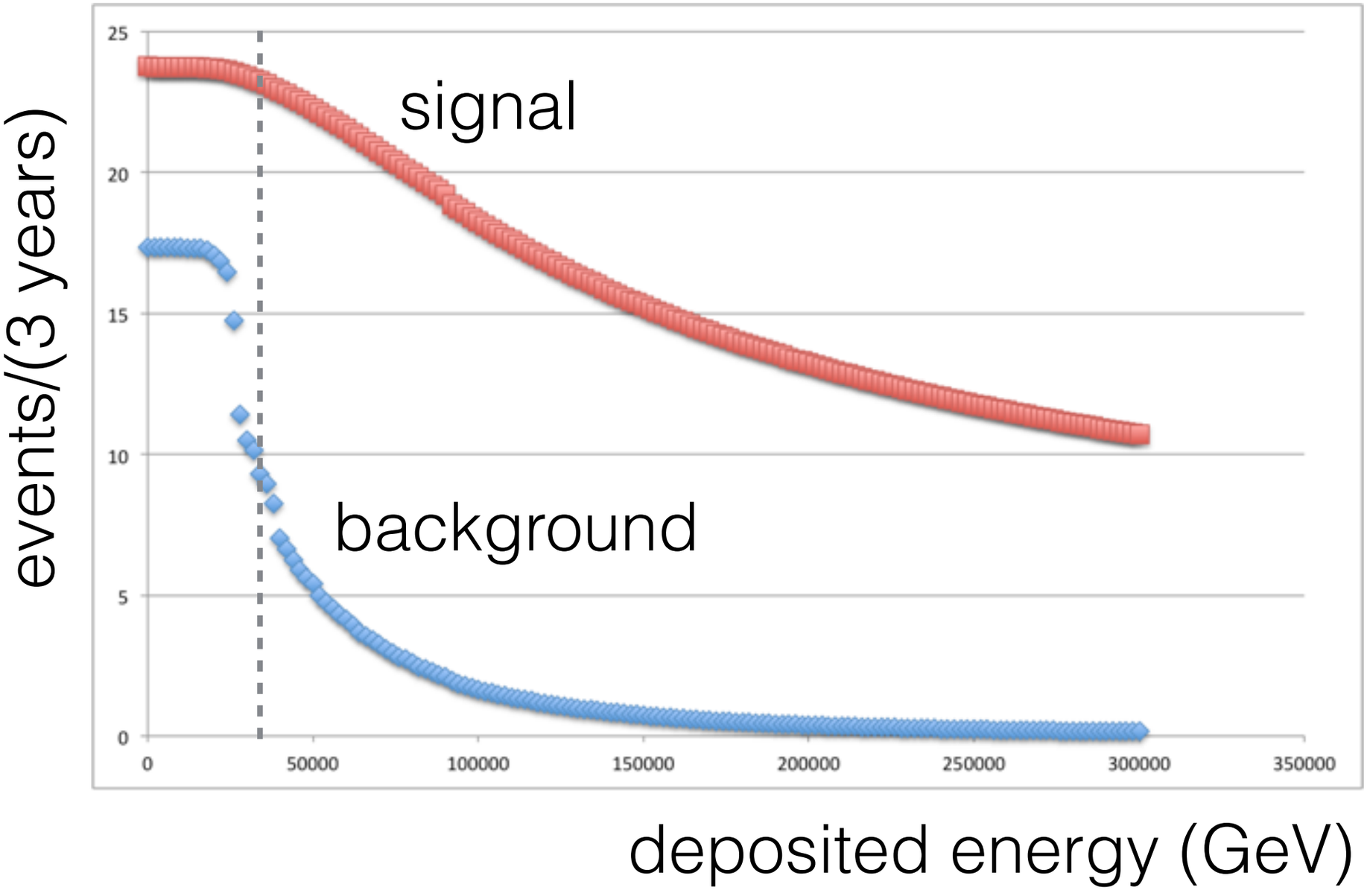
To achieve the best results, we have to tune the event selection:

http://icecube.wisc.edu/masterclass/tuning

(Tuning the event selection)

Did we find astrophysical neutrinos?

"How significant is our result?"



Did we find astrophysical neutrinos?

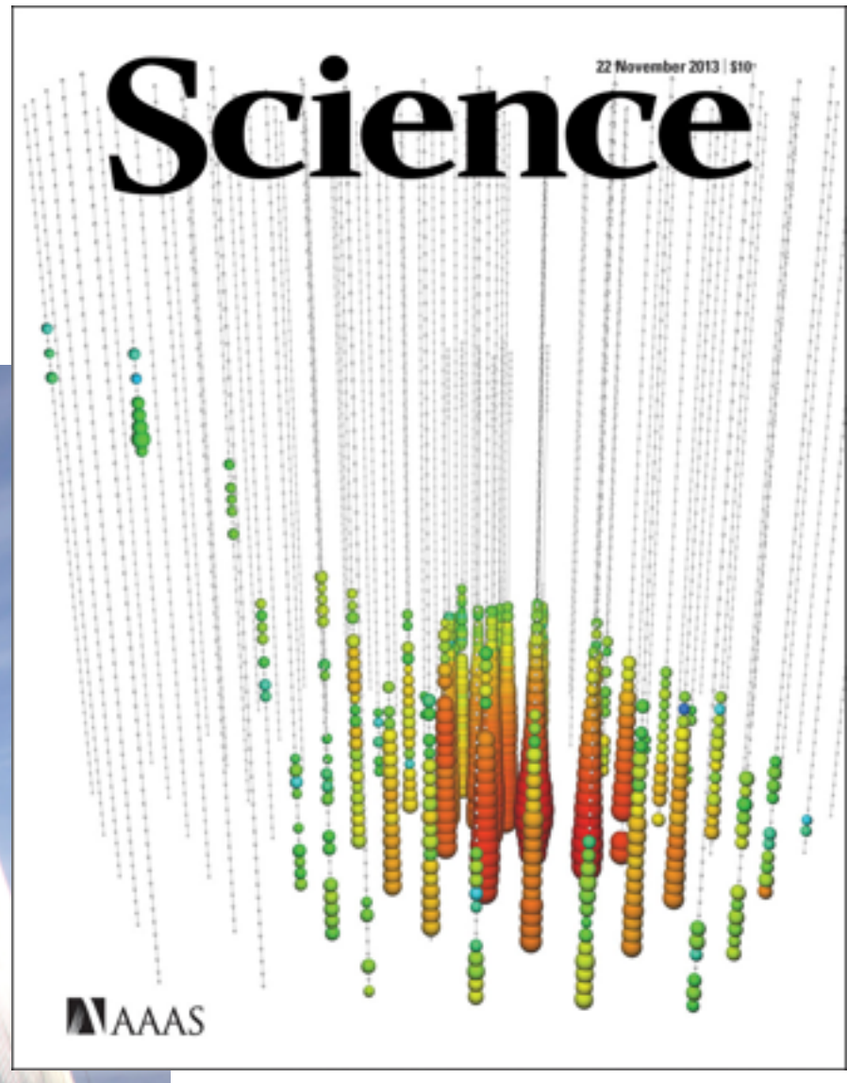
“How significant is our result?”

Can you think of another tuning parameter?

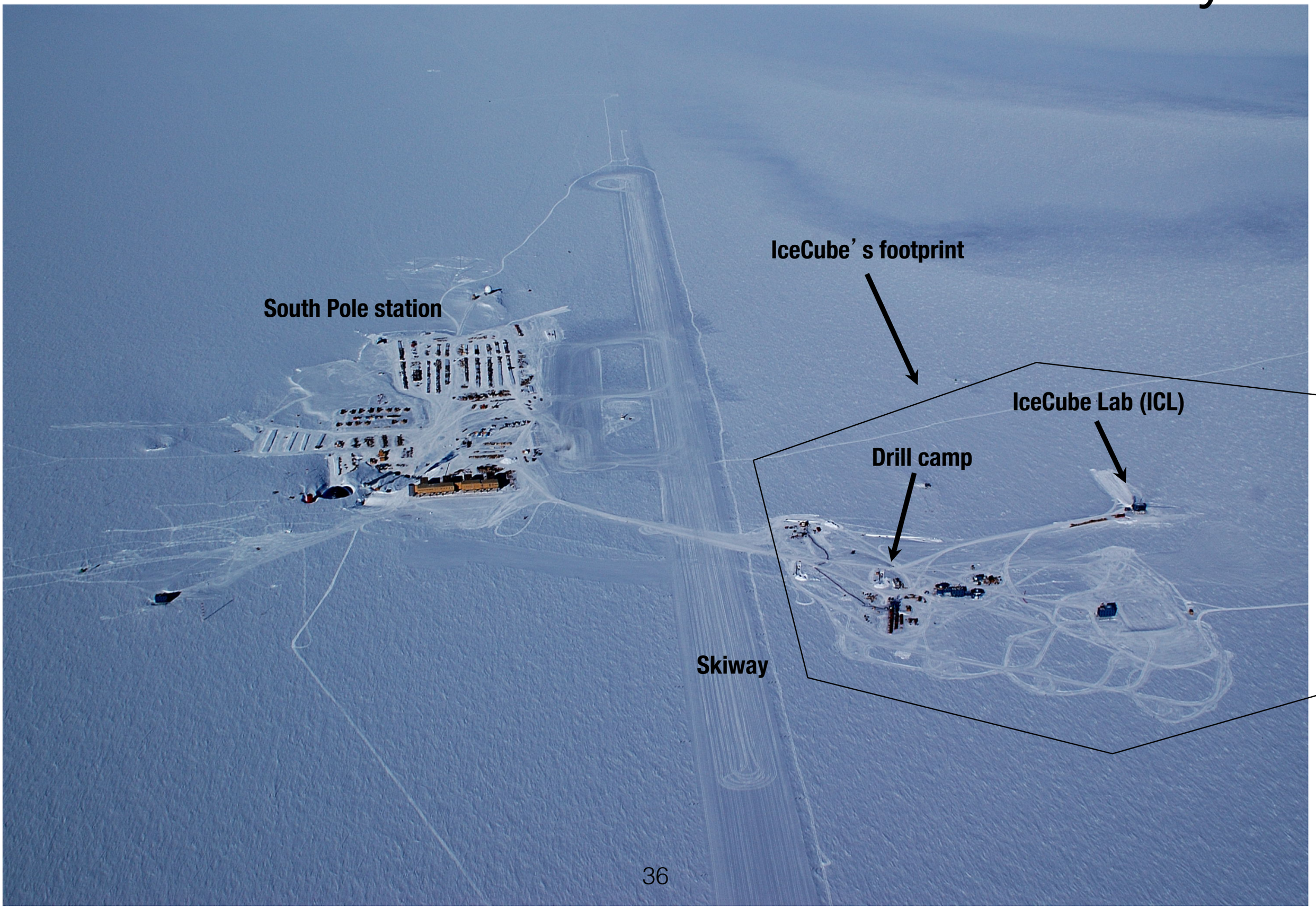
http://icecube.wisc.edu/masterclass/tuning_zen

Did we find astrophysical neutrinos?

Yes, we did!

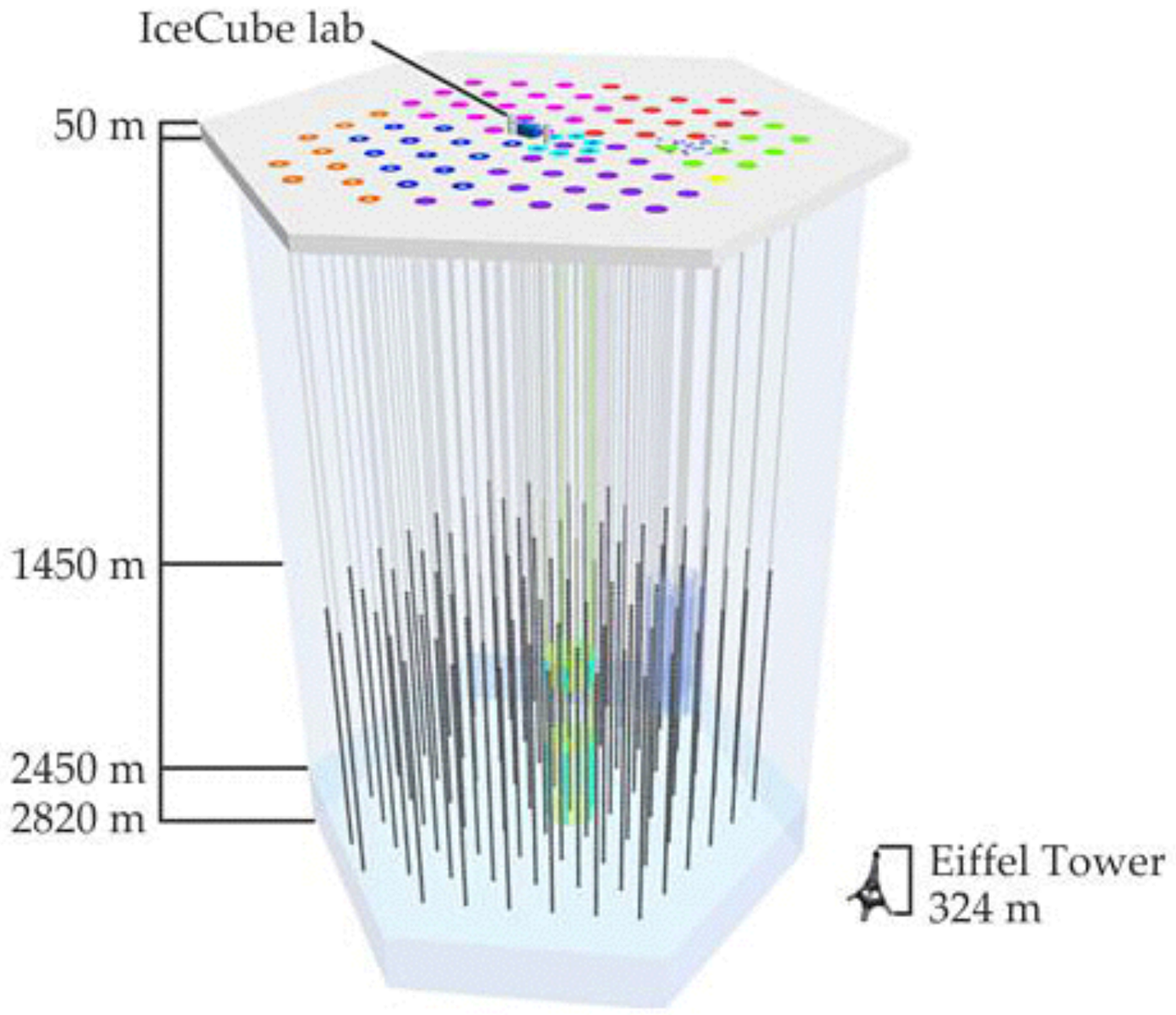


The IceCube Neutrino Observatory



The IceCube Neutrino Observatory

- 5160 light detectors
- 1 km^3 volume
- 86 strings
- 125 m string spacing
- completed in 2010



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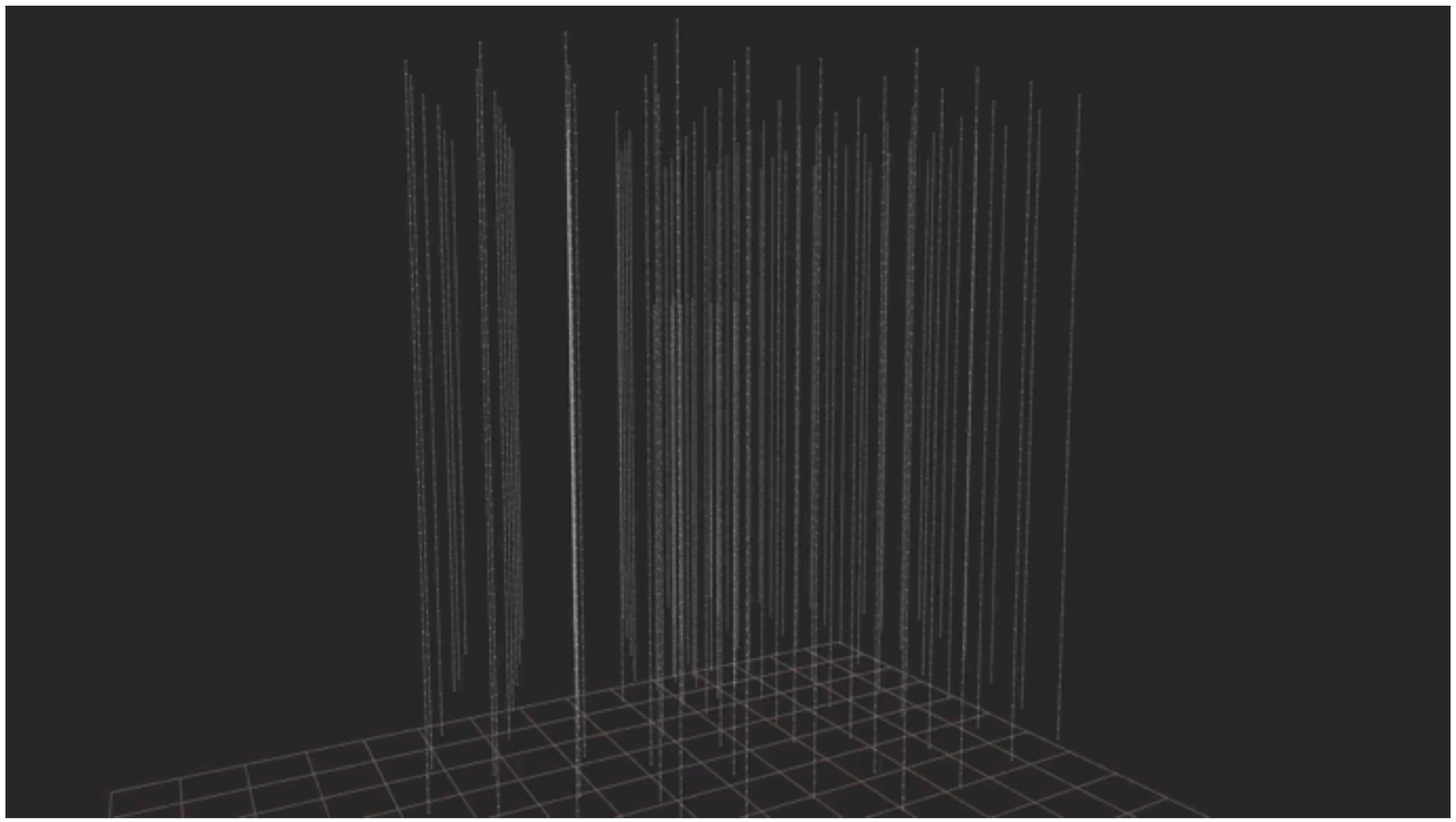
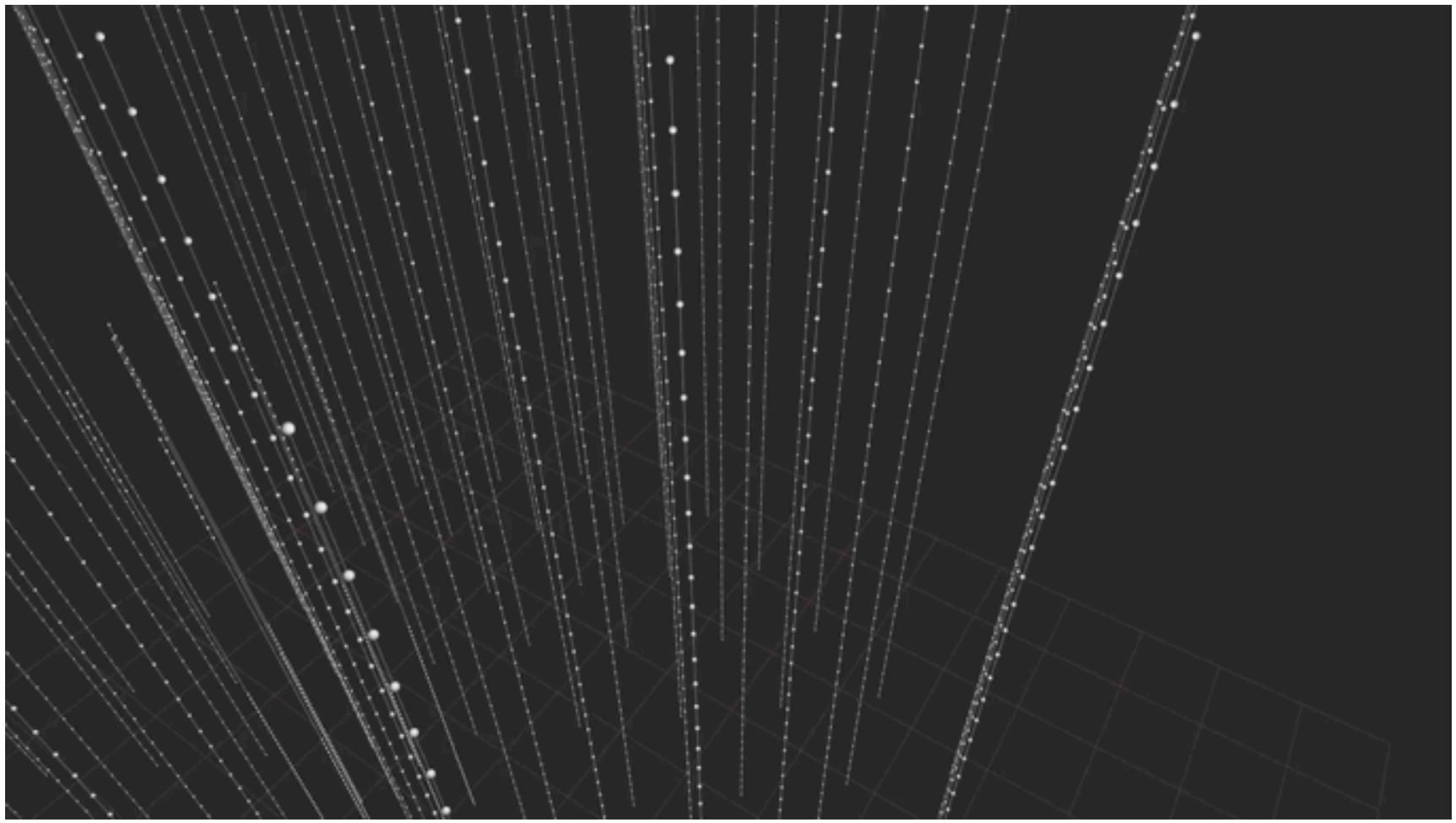


muons: long paths in the detector → **track**

What do neutrinos look like in IceCube?



electrons/hadrons: shower of light → **cascade**