@andres0l1

andres181192@gmail.com

Neutrino Masterclass

Somos Científicos Sácanos de aquí

Durham University

IP3

WHAT ARE NEUTRINOS?

- **They are fundamental particles**

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10^{12} per sec

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10^{12} per sec

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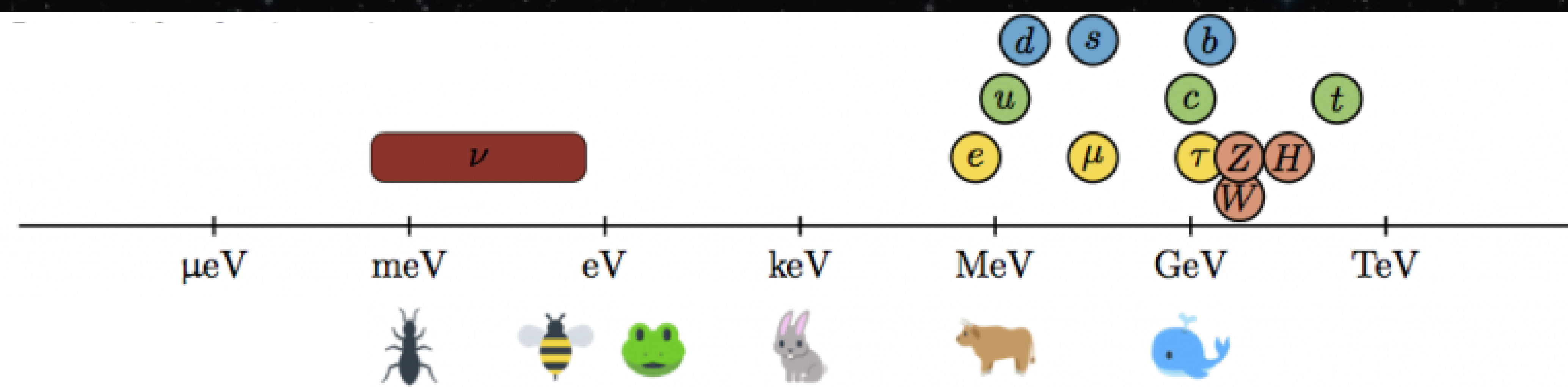

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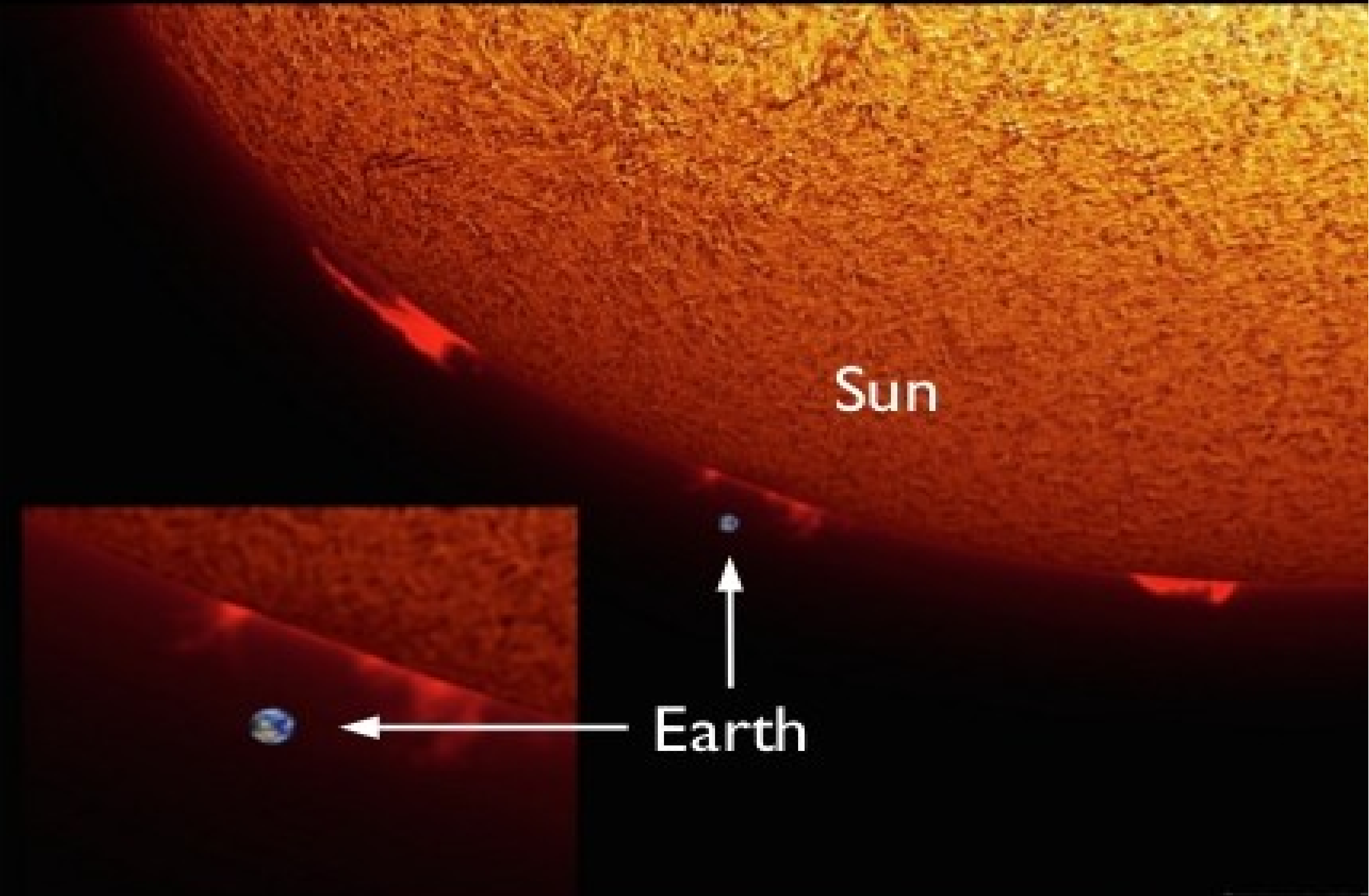
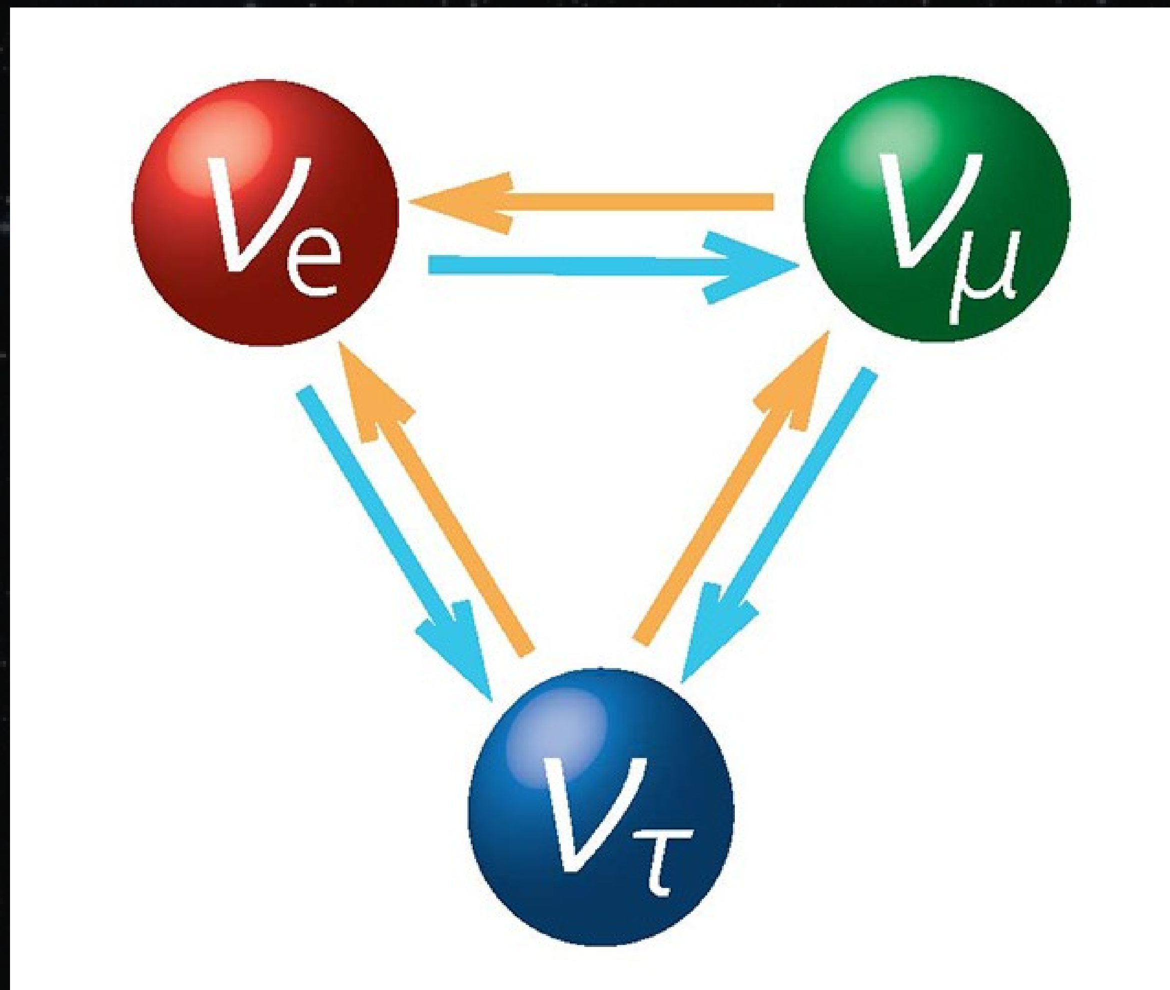


NEUTRINOS OSCILLATE

There are three types of neutrinos



10^{12}
por sec

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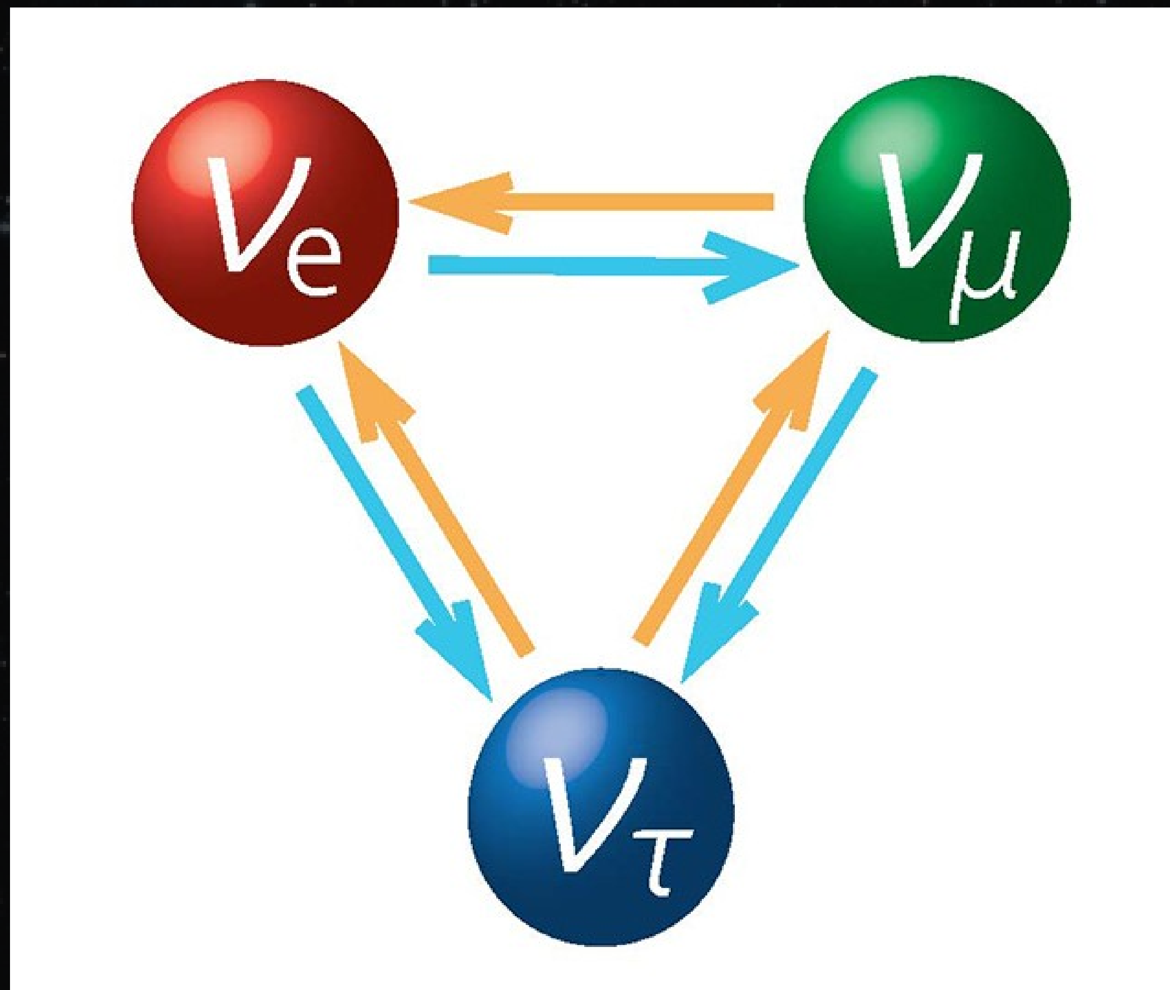

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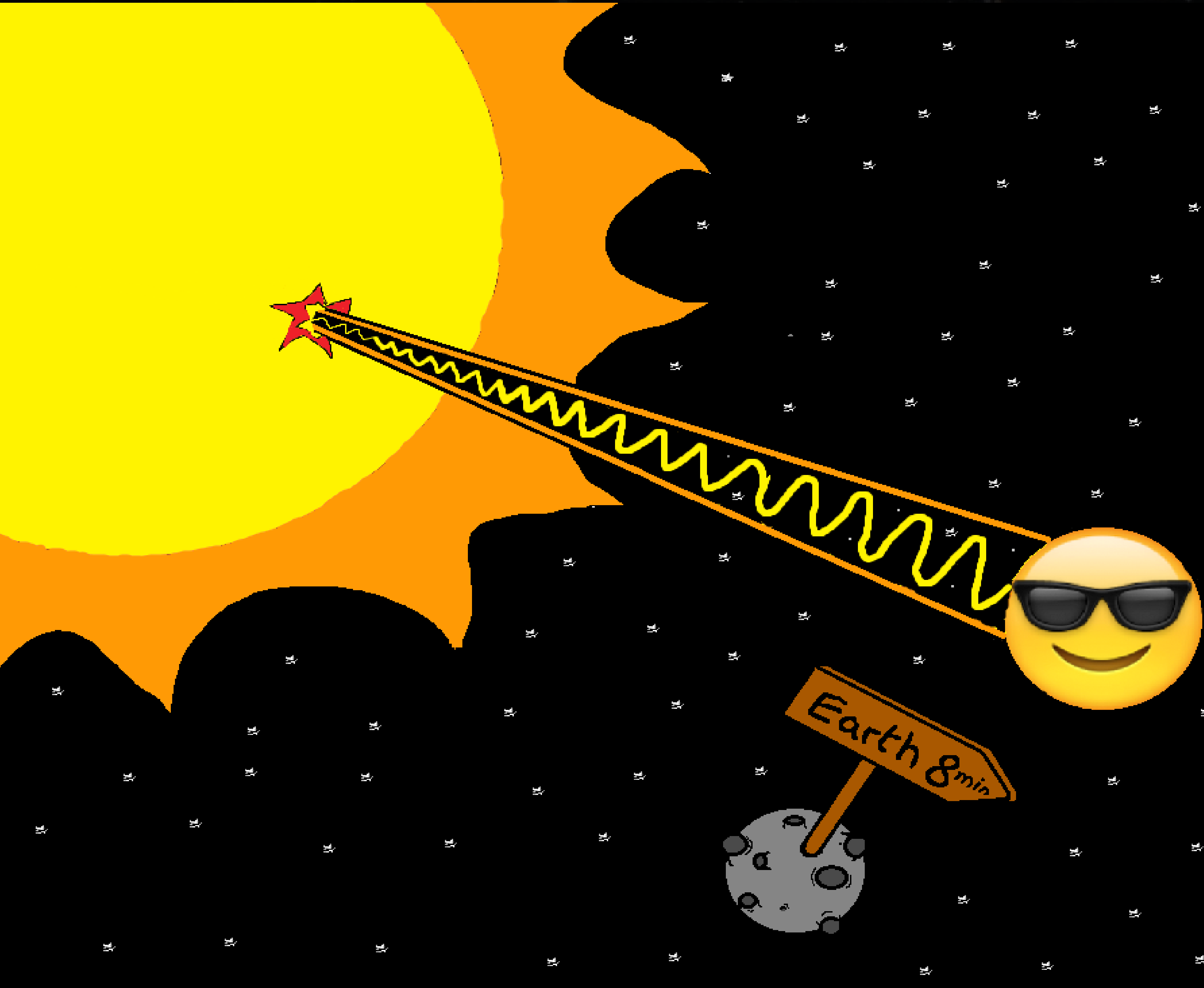
They are called flavours

NEUTRINOS OSCILLATE



NEUTRINOS OSCILLATE

$$P(\nu_e \to \nu_\mu, L) = 4[\sin(\theta_{13})^2 \sin(\theta_{23})^2 \cos(\theta_{13})^2 \cos(\theta_{12})^2 + J\cos\delta] \sin^2\left(\frac{\Delta m_{31}^2 L}{2E}\right)$$
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Neutrinos
have a mass!

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2015

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HOW DO WE KNOW THEY EXIST?

Beta decay

$$n \rightarrow p + e^{-} + \overline{v}_e$$

10^{12}
por sec

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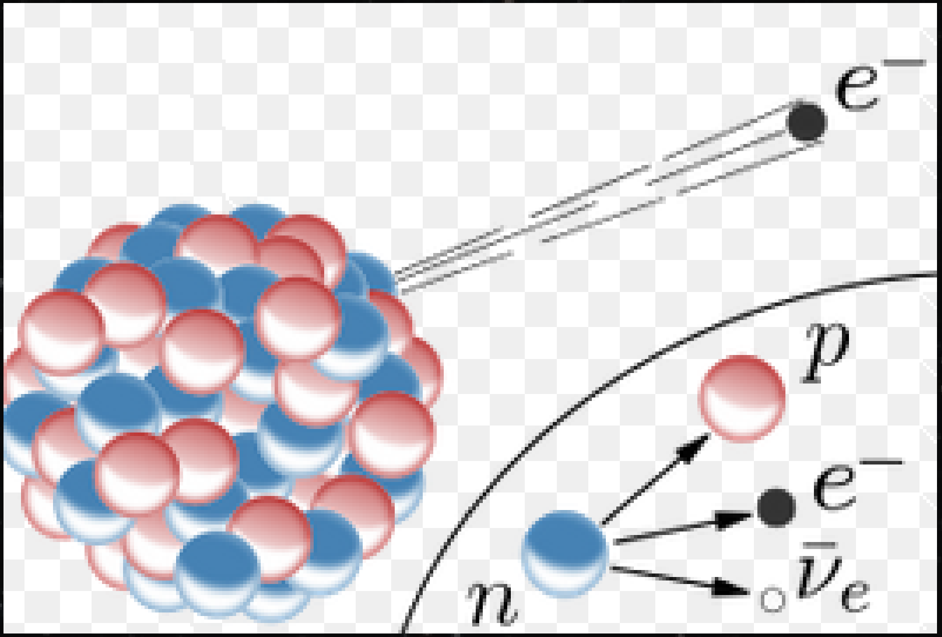

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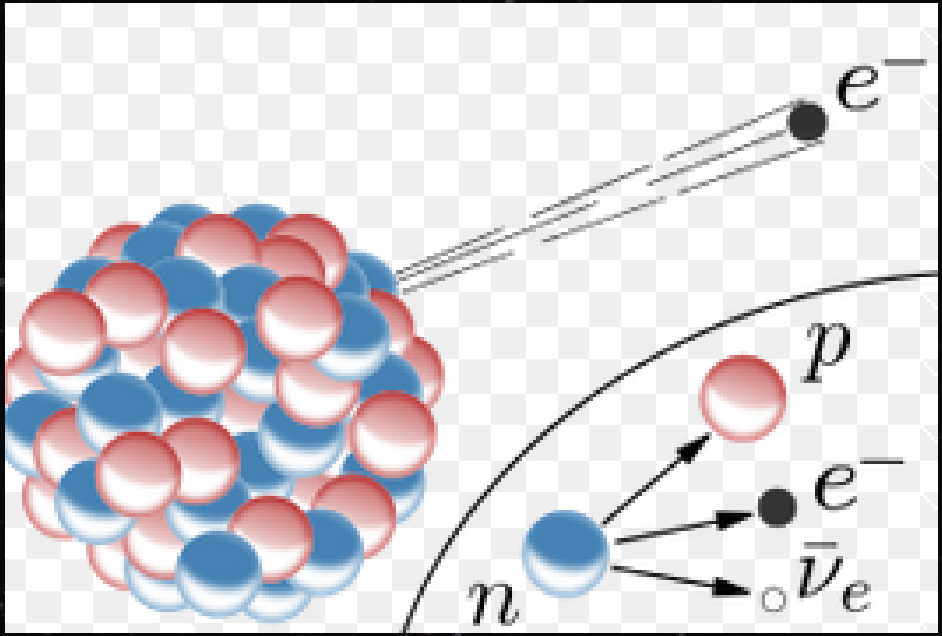

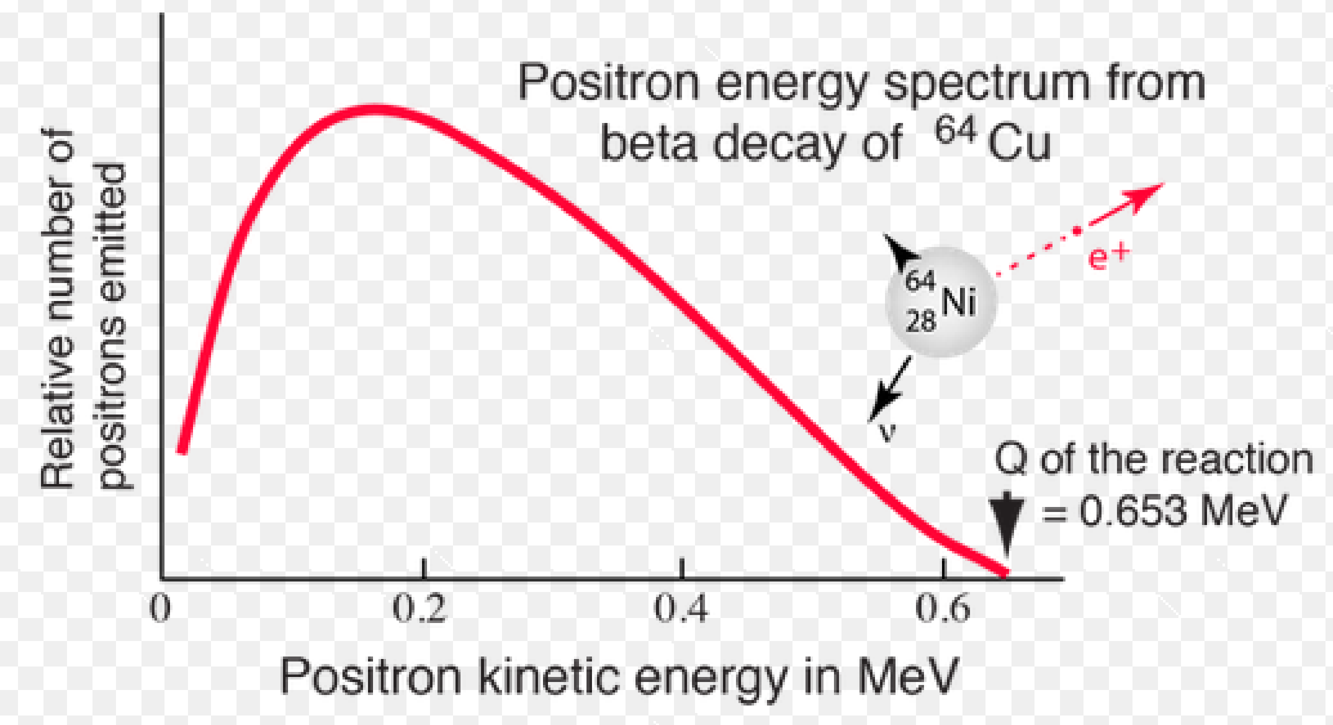

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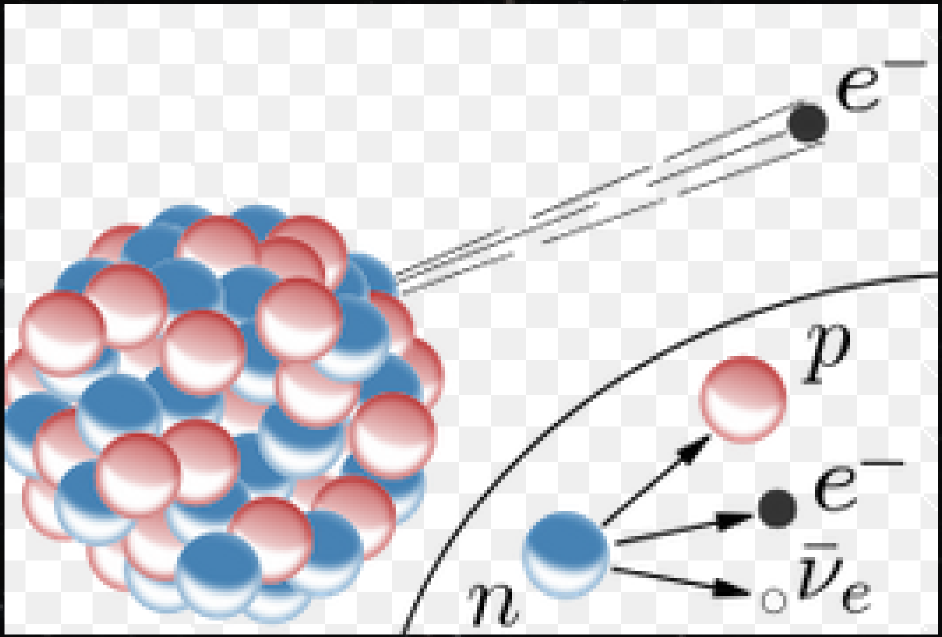

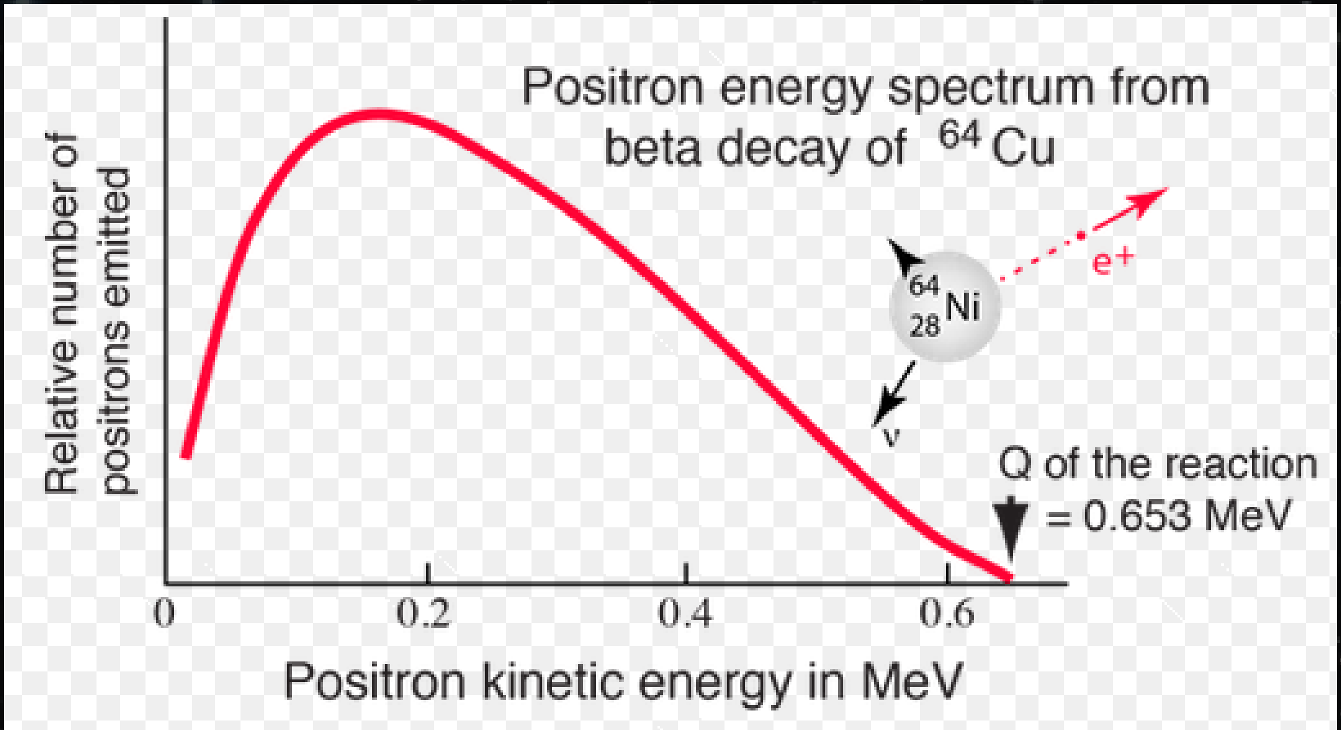

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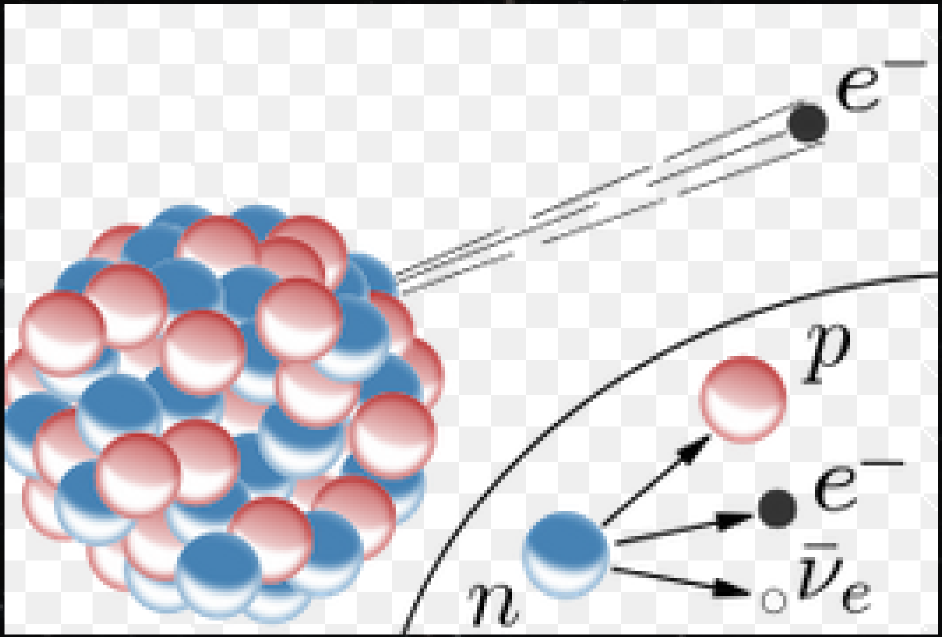

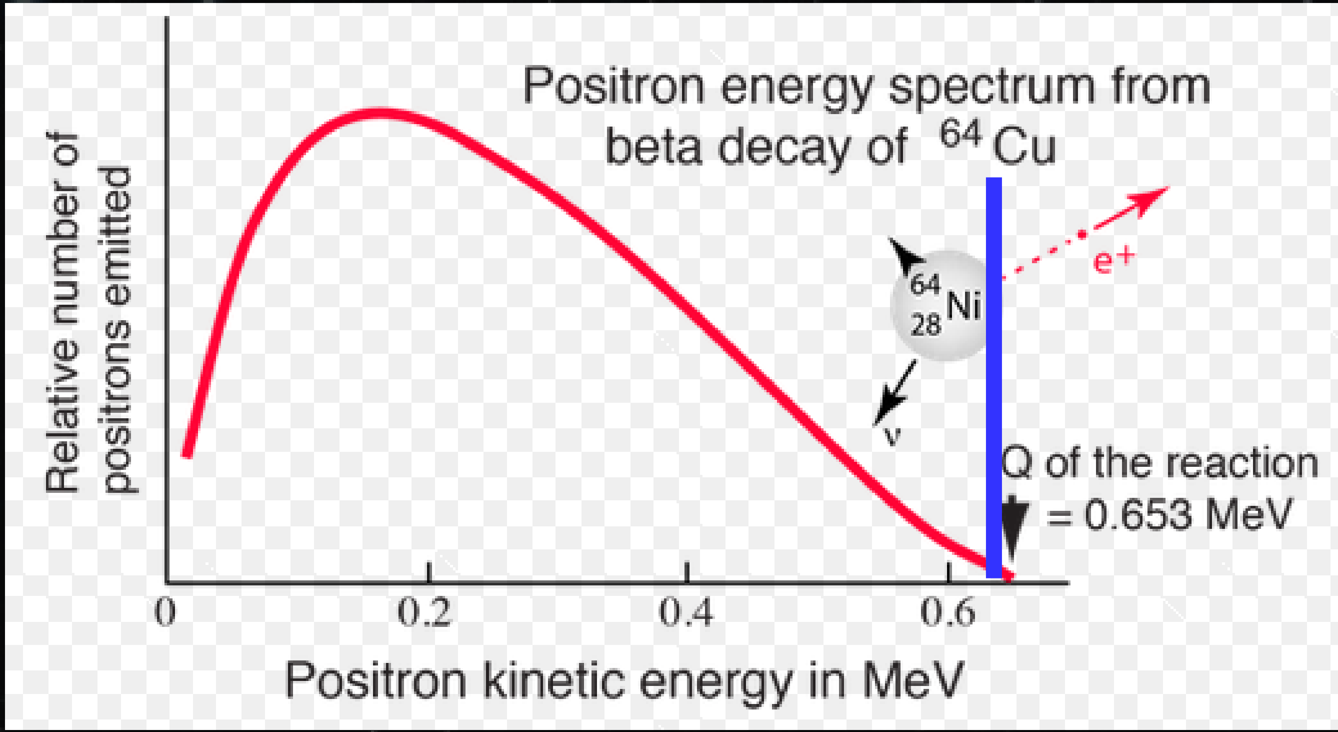

HOW DO WE KNOW THEY EXIST?

"Dear Radioactive Ladies and Gentlemen, I have hit upon a desperate remedy to save the "exchange theorem" of statistics and the law of conservation of energy. Namely, the possibility that there could exist in the nuclei electrically neutral particles, that I wish to call neutrons."

-Pauli, 1930

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“The continuous beta spectrum would then become understandable by the assumption that in beta decay a neutron is emitted in addition to the electron such that the sum of the energies of the neutron and the electron is constant.”

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HOW DO WE KNOW THEY EXIST?

- Reines and Cowan discovered the neutrino in 1956

1995

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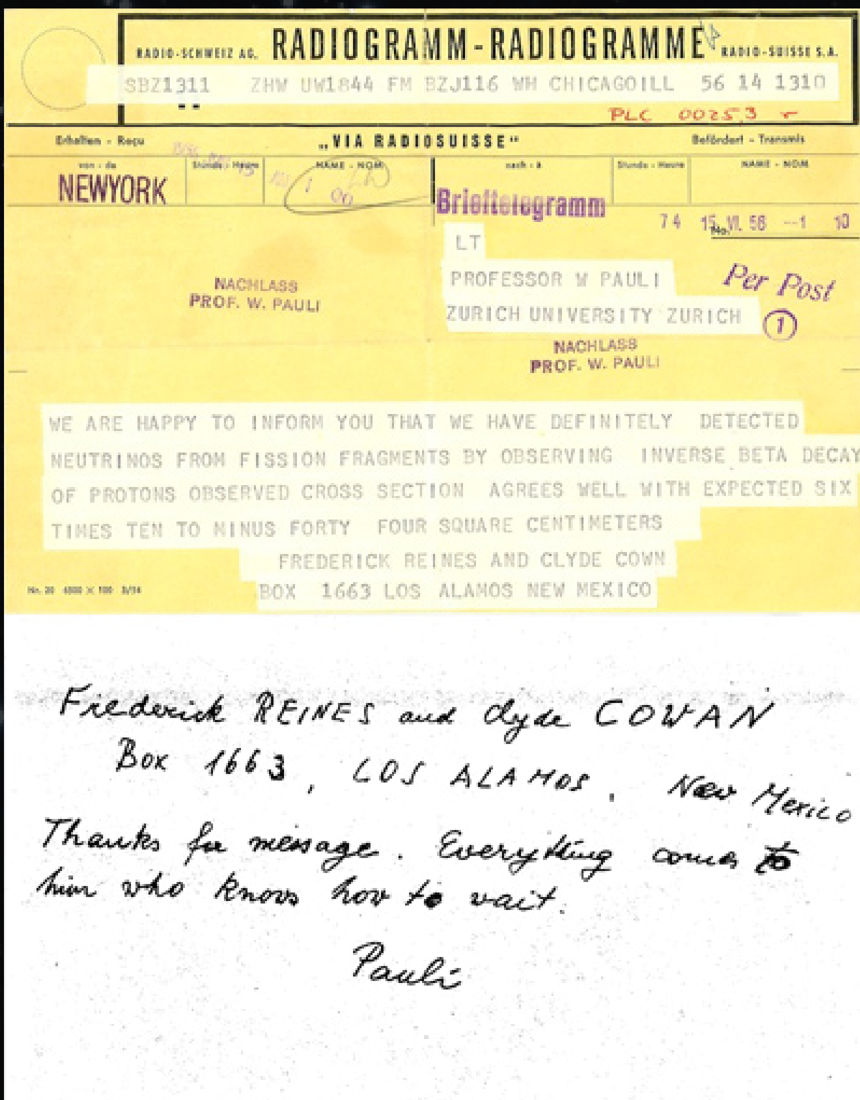
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PROFESSOR W PAULI

ZURICH UNIVERSITY ZURICH

Per Post

NACHLASS PROF. W. PAULI

WE ARE HAPPY TO INFORM YOU THAT WE HAVE DEFINITELY DETECTED NEUTRINOS FROM FISSION FRAGMENTS BY OBSERVING INVERSE BETA DECAY OF PROTONS OBSERVED CROSS SECTION AGREES WELL WITH EXPECTED SIX TIMES TEN TO MINUS FORTY FOUR SQUARE CENTIMETERS

FREDERICK REINES AND CLYDE COWN

BOX 1663 LOS ALAMOS NEW MEXICO

Frederick REINES and Clyde COWAN

Box 1663, LOS ALAMOS, New Mexico

Thanks for message. Everything comes to him who knows how to wait.

Pauli

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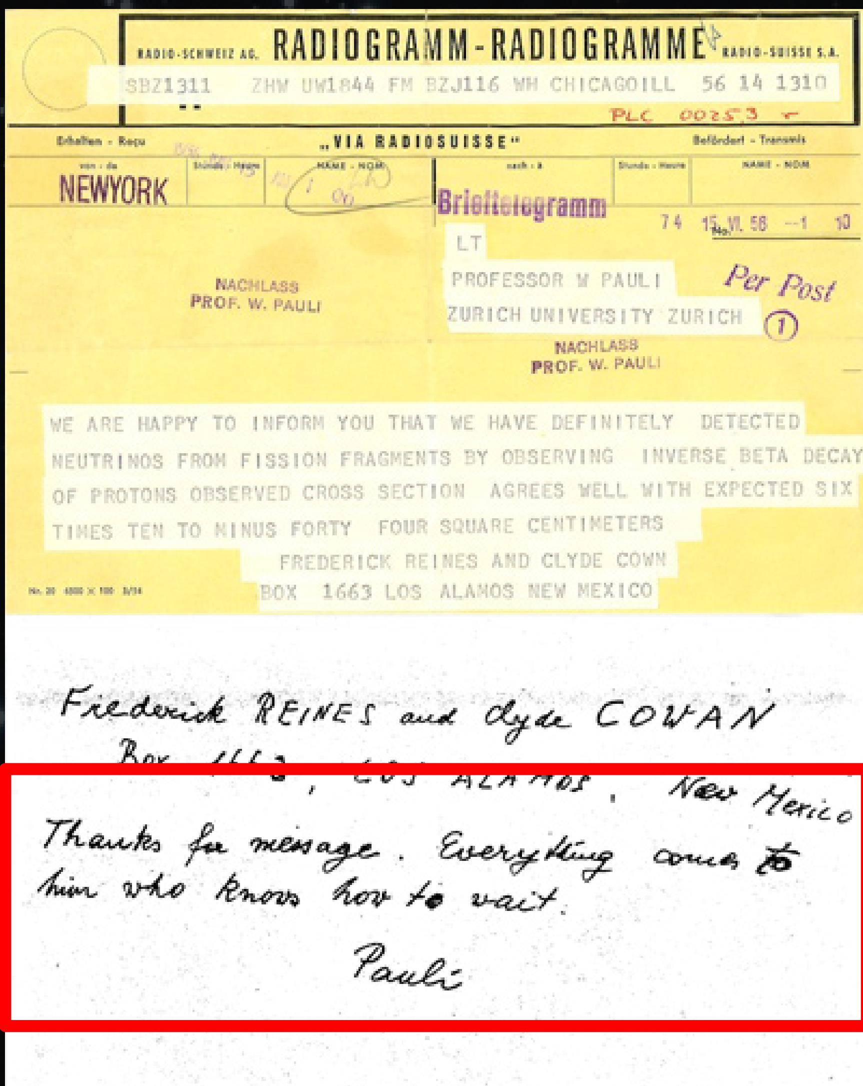
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CRASH COURSE IN PARTICLE PHYSICS

$$E = mc^2$$

$$1\,\mathrm{eV} = 1.6 \times 10^{-19}\,\mathrm{J}$$

10^{12}

por sec

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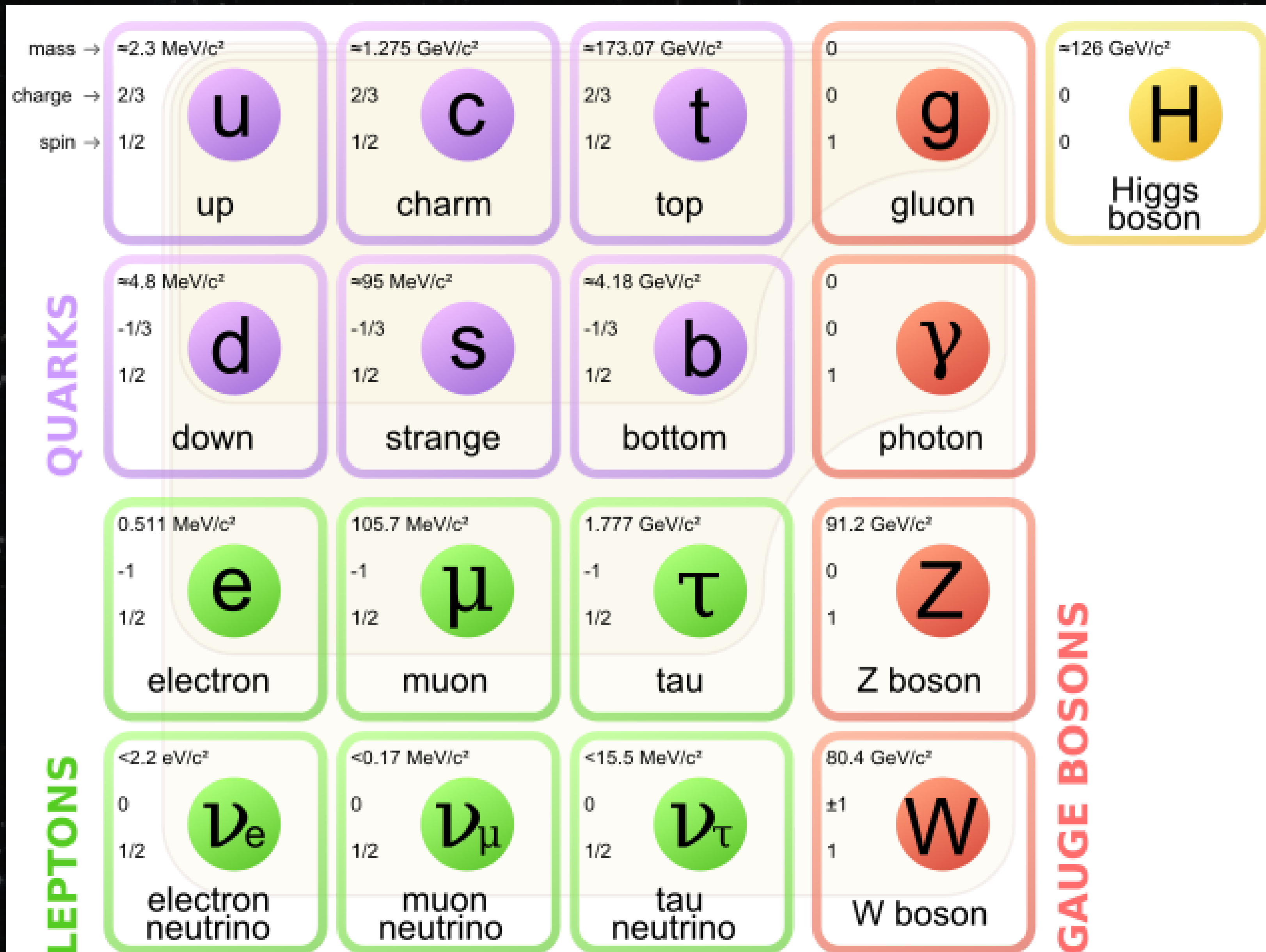
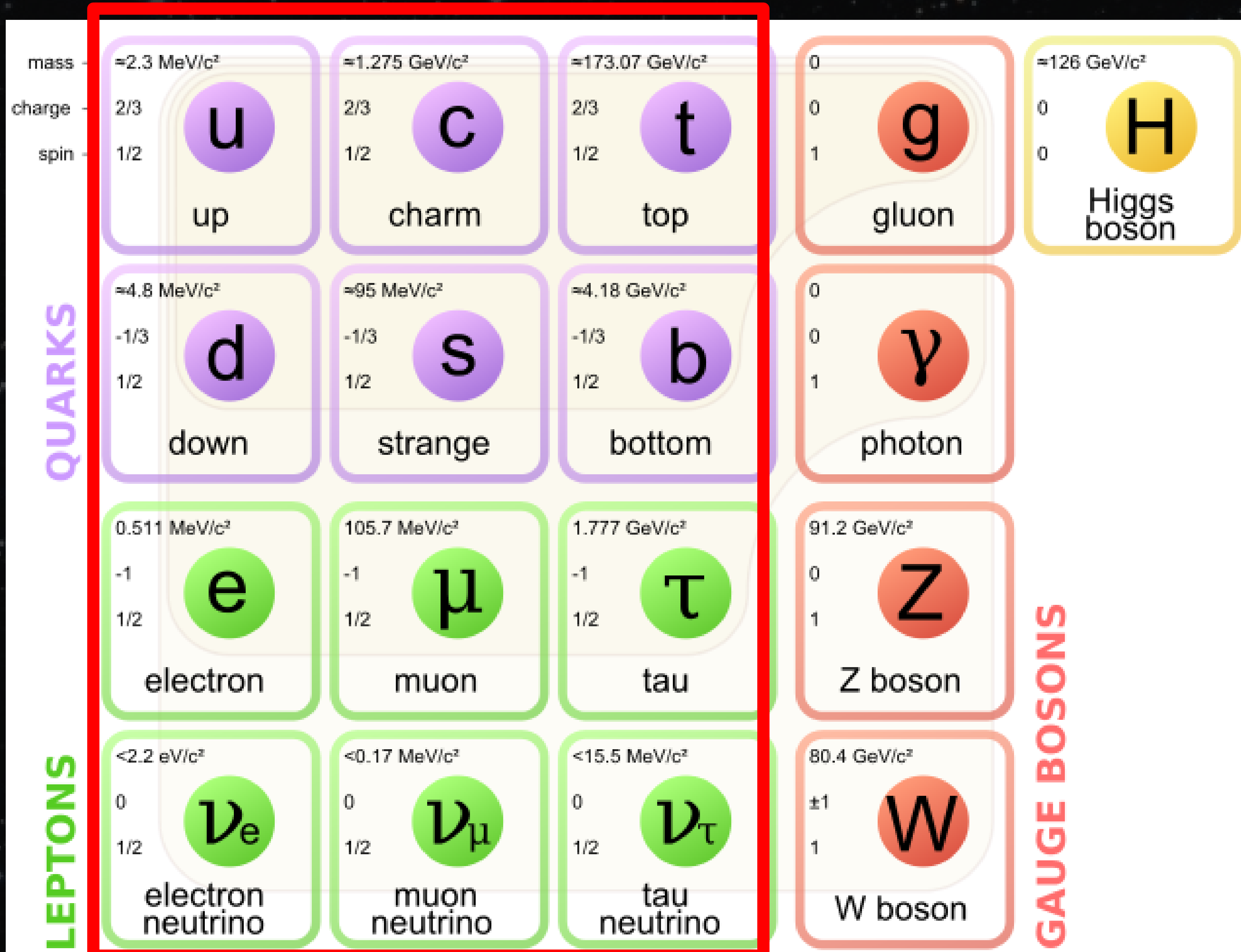


THE STANDARD MODEL

CRASH COURSE IN PARTICLE PHYSICS



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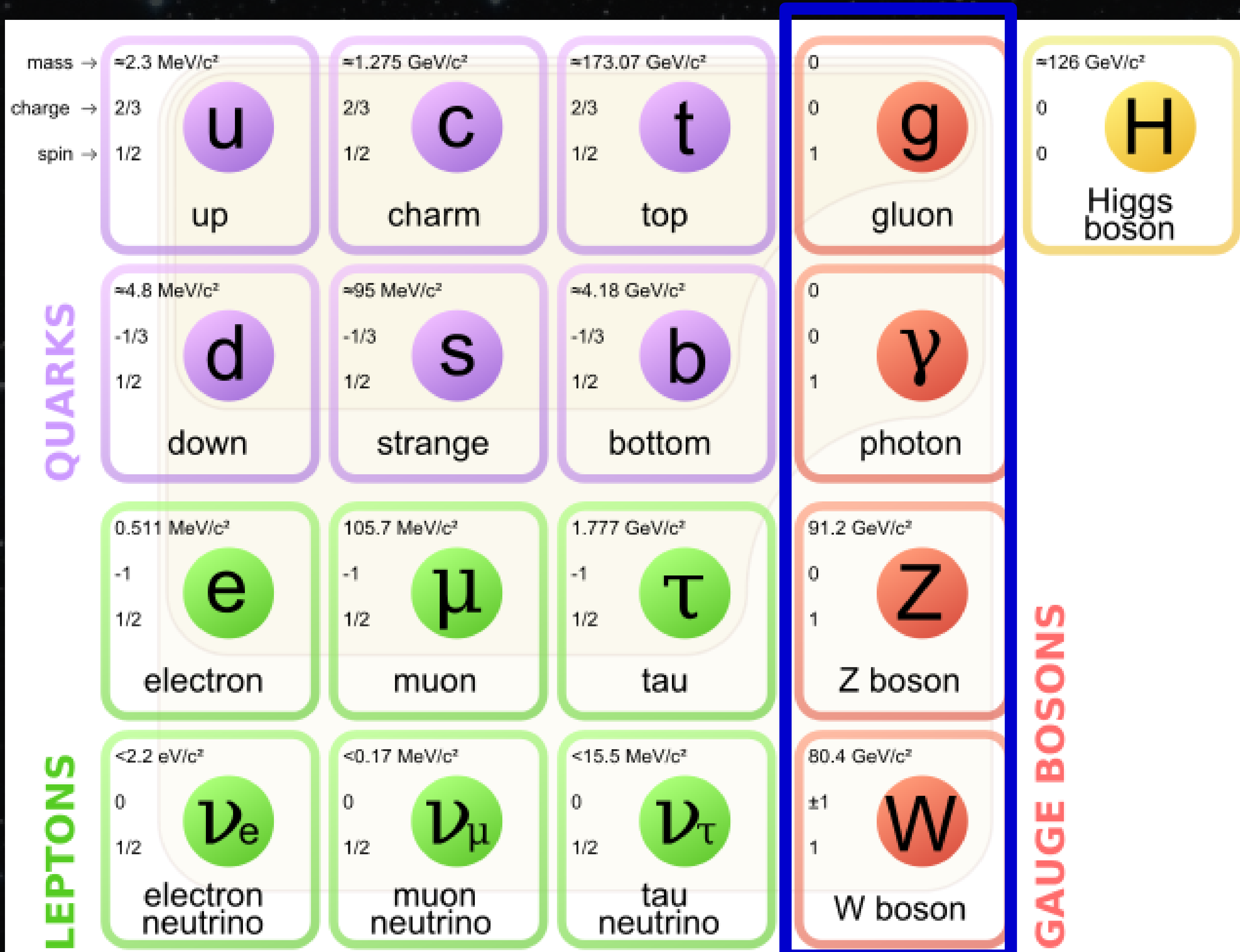

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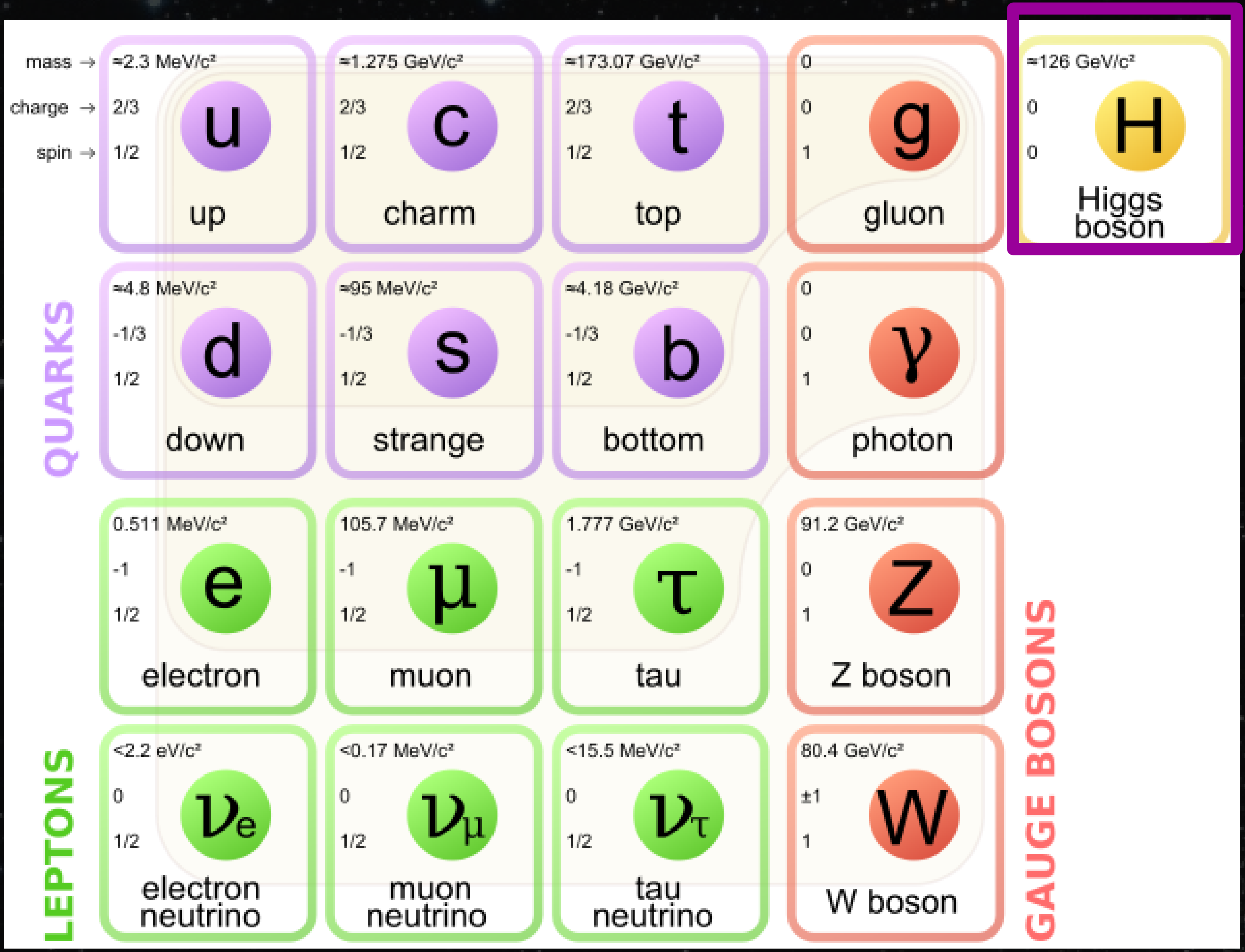
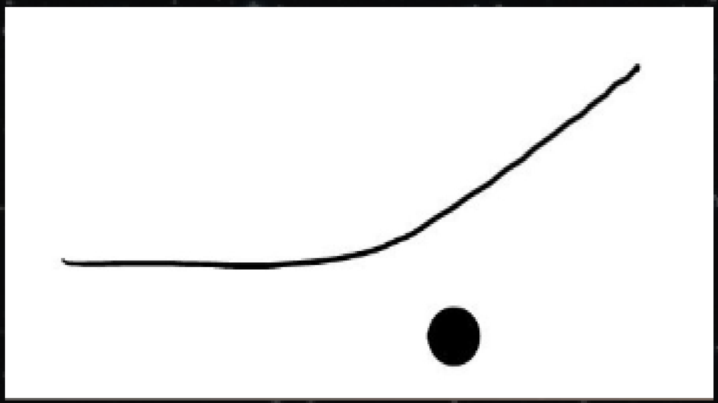


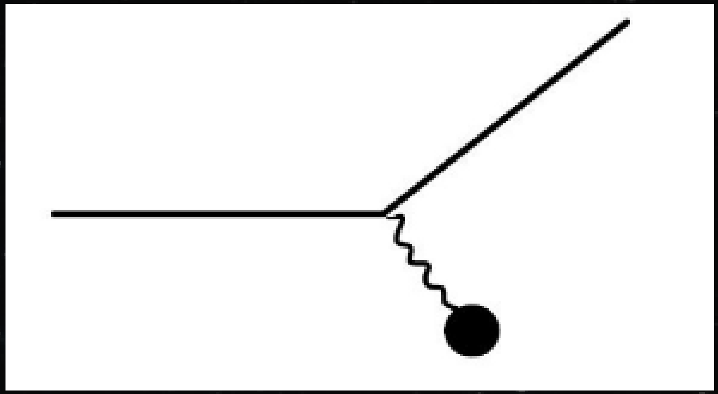
CRASH COURSE IN PARTICLE PHYSICS

Classical Physics



Video

Field theory



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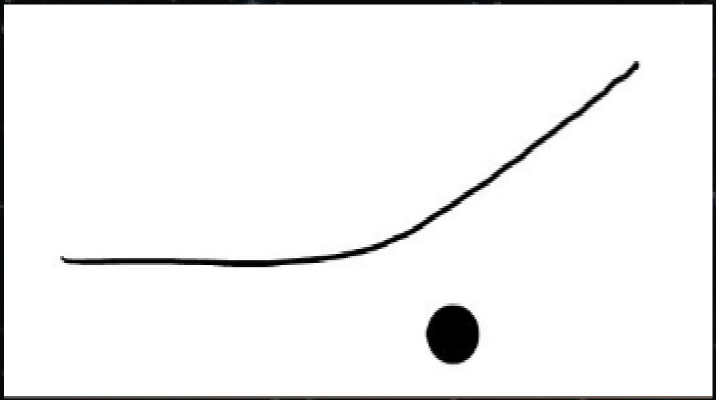

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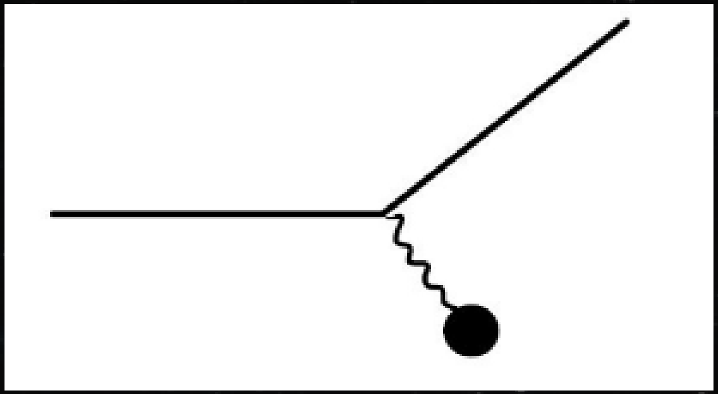

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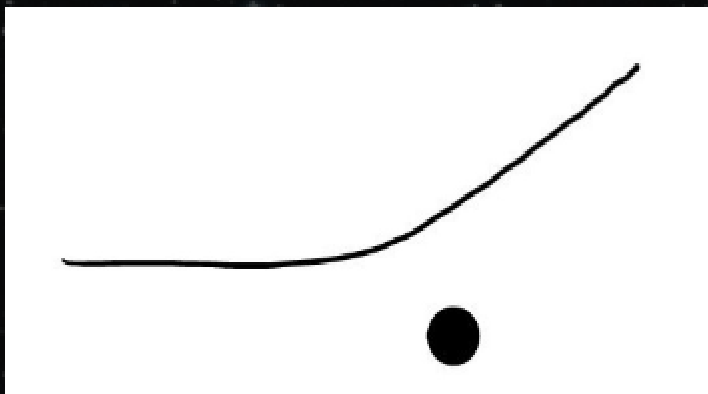

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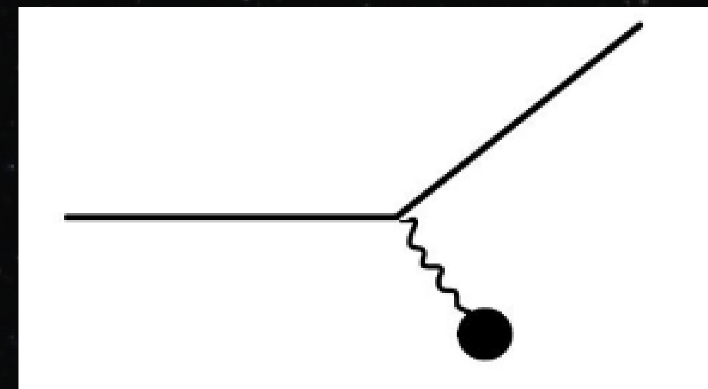

Strong force→ quarks

CRASH COURSE IN PARTICLE PHYSICS

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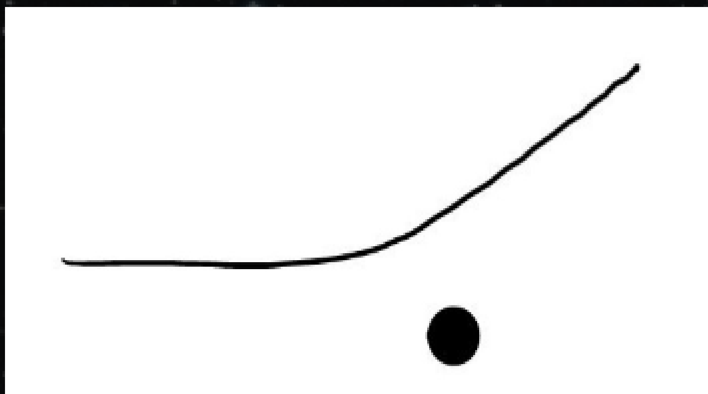

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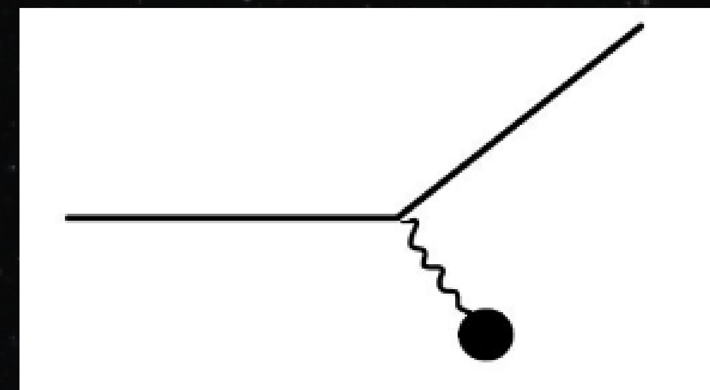

Strong force→ quarks

Electromagnetic force
→ particles with charge

CRASH COURSE IN PARTICLE PHYSICS

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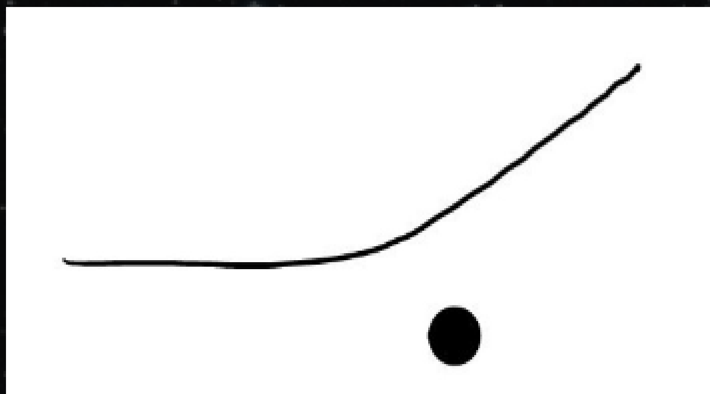

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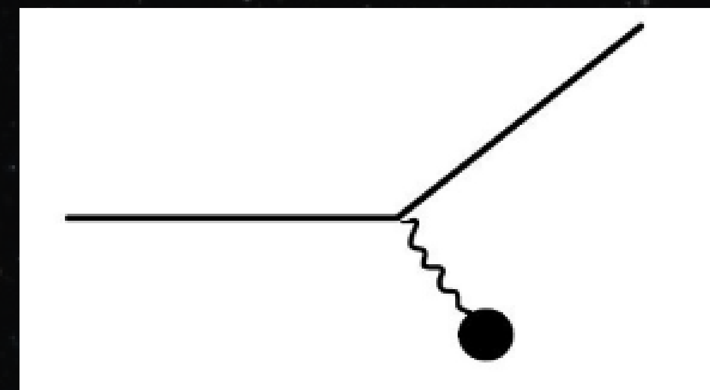

Strong force→ quarks

Electromagnetic force → particles with charge

Weak force→ every particle

CRASH COURSE IN PARTICLE PHYSICS

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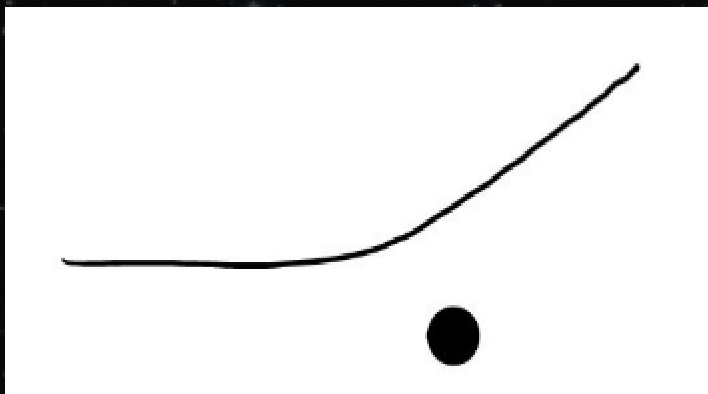

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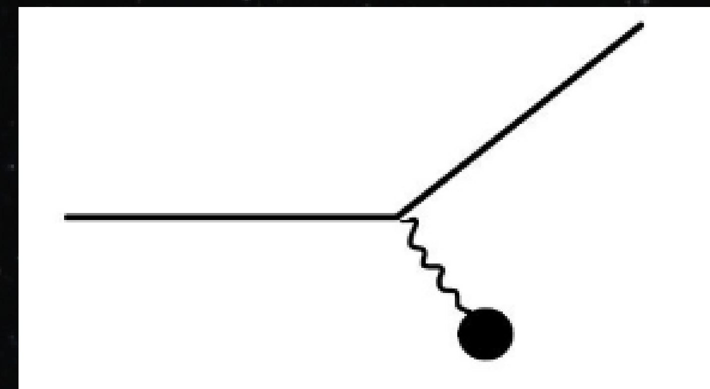
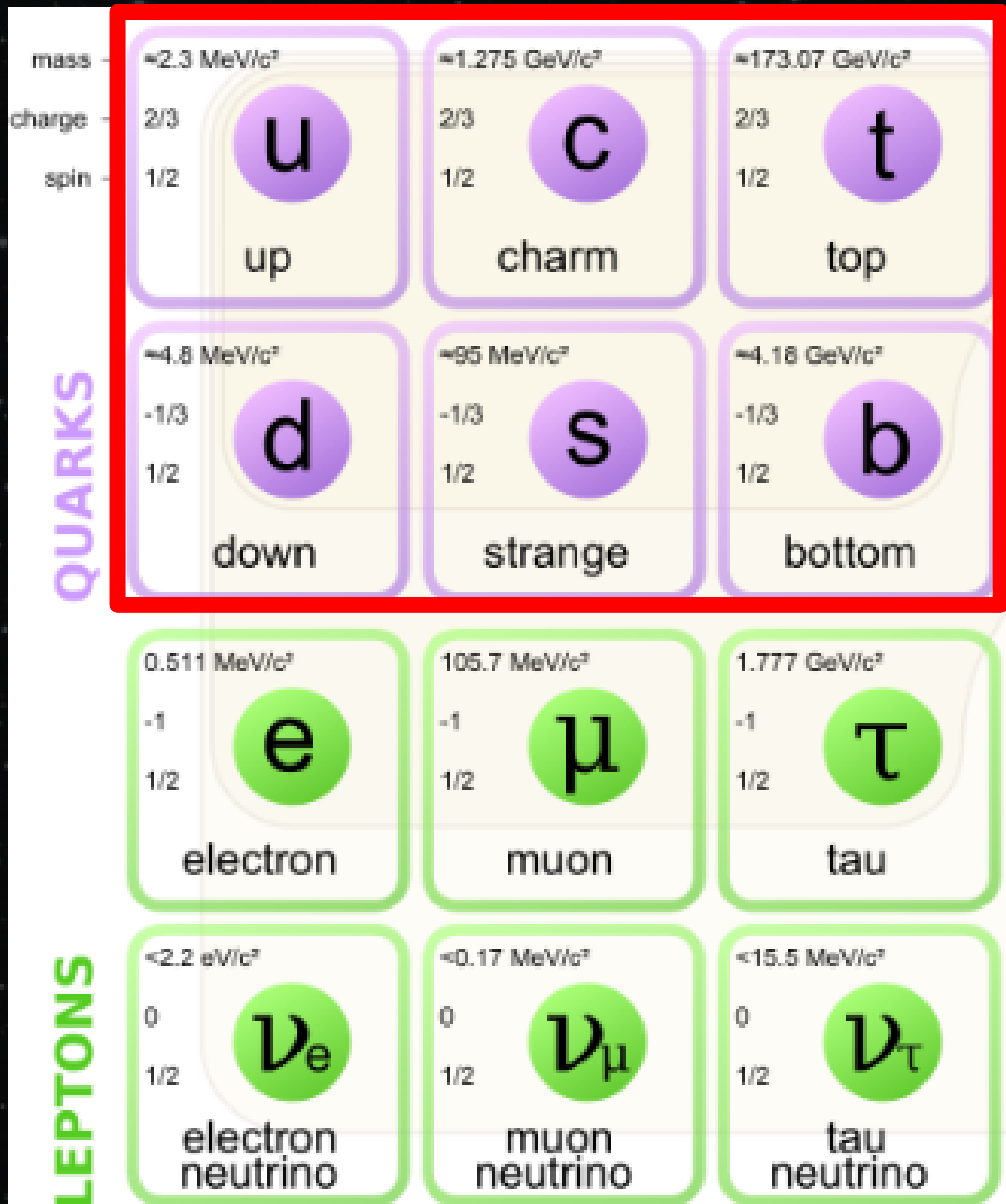


Gravity is not included in the Standard Model!

But any particle with mass interacts with gravity

CRASH COURSE IN PARTICLE PHYSICS



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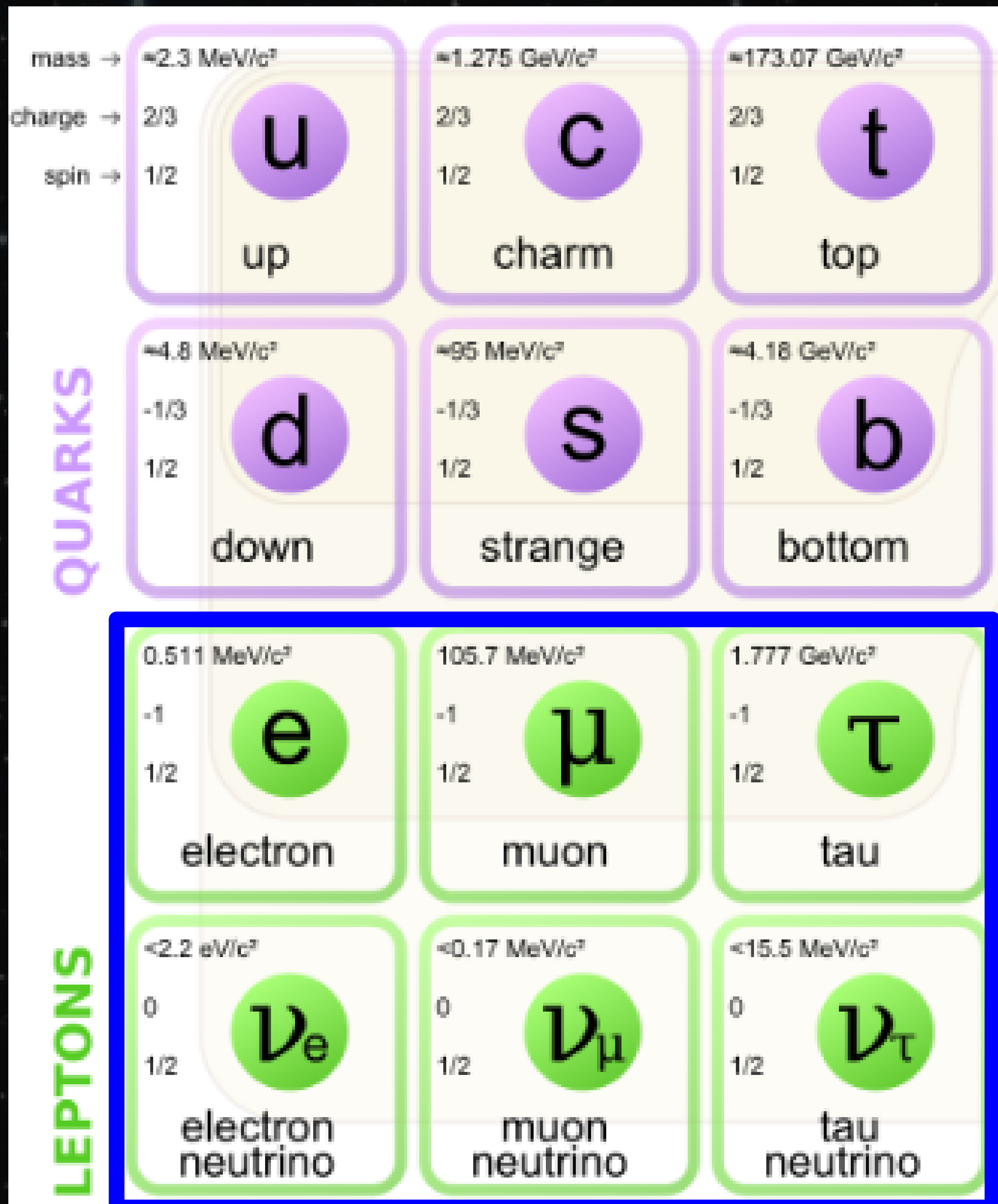

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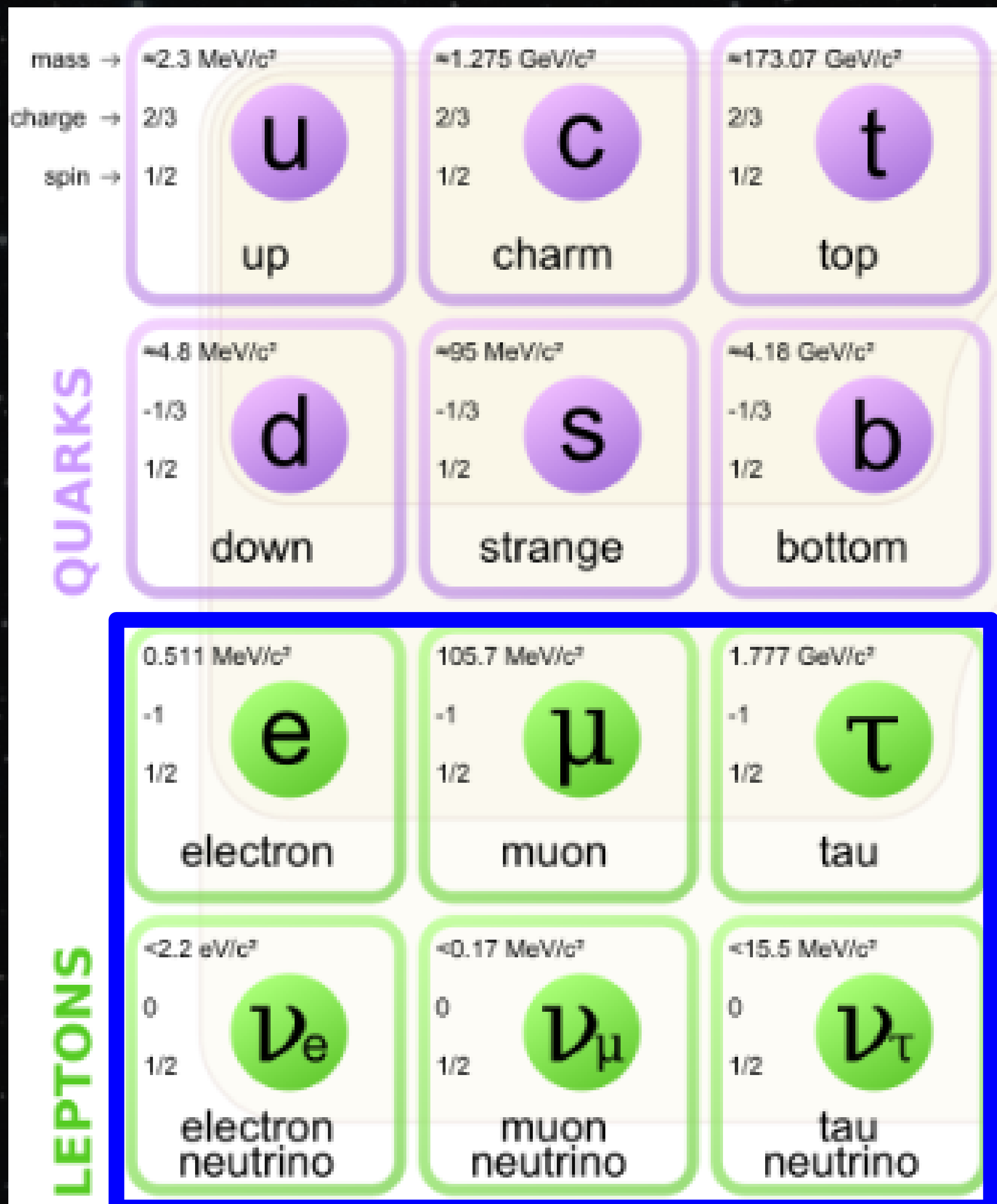

There are three generations of particles

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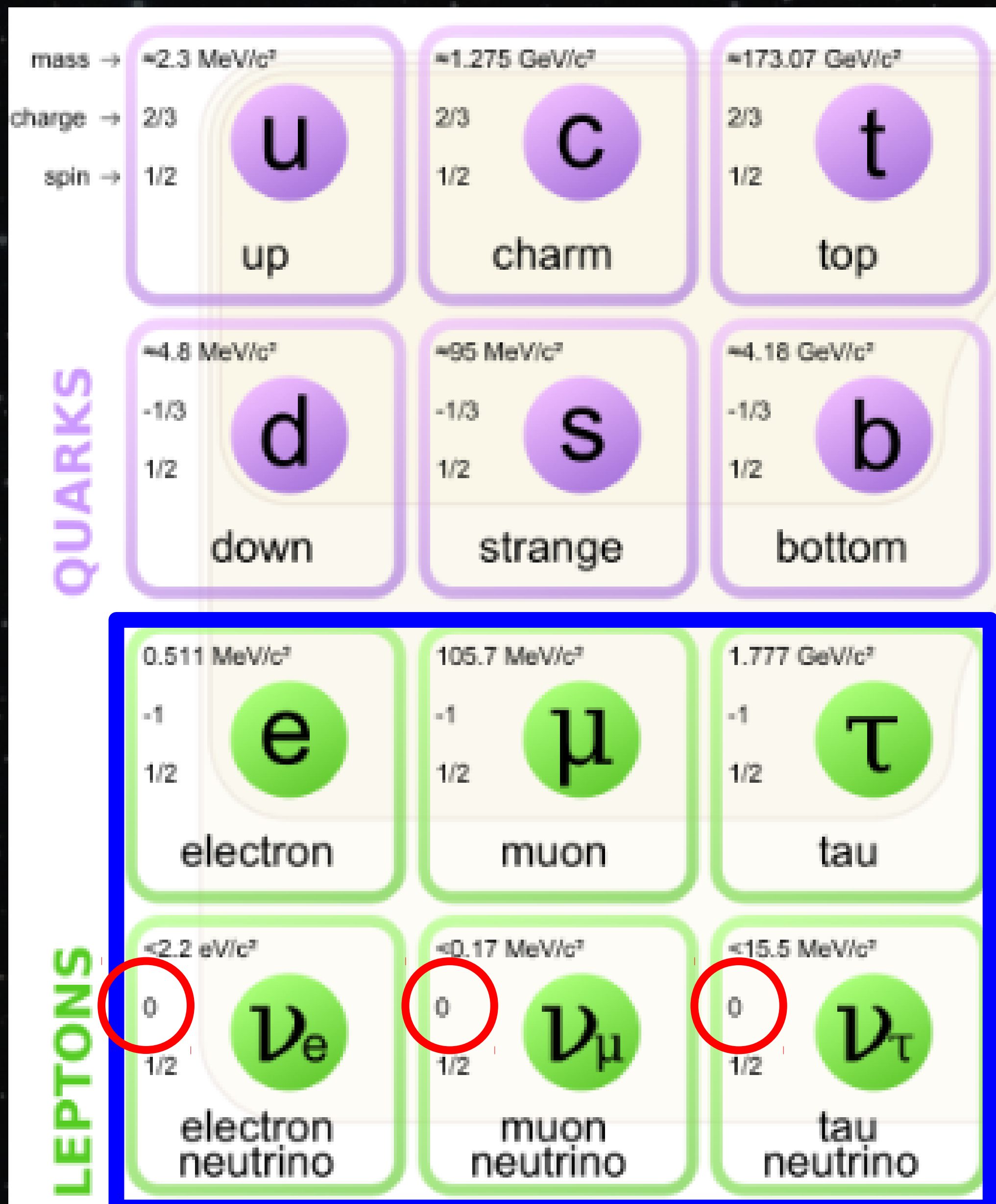
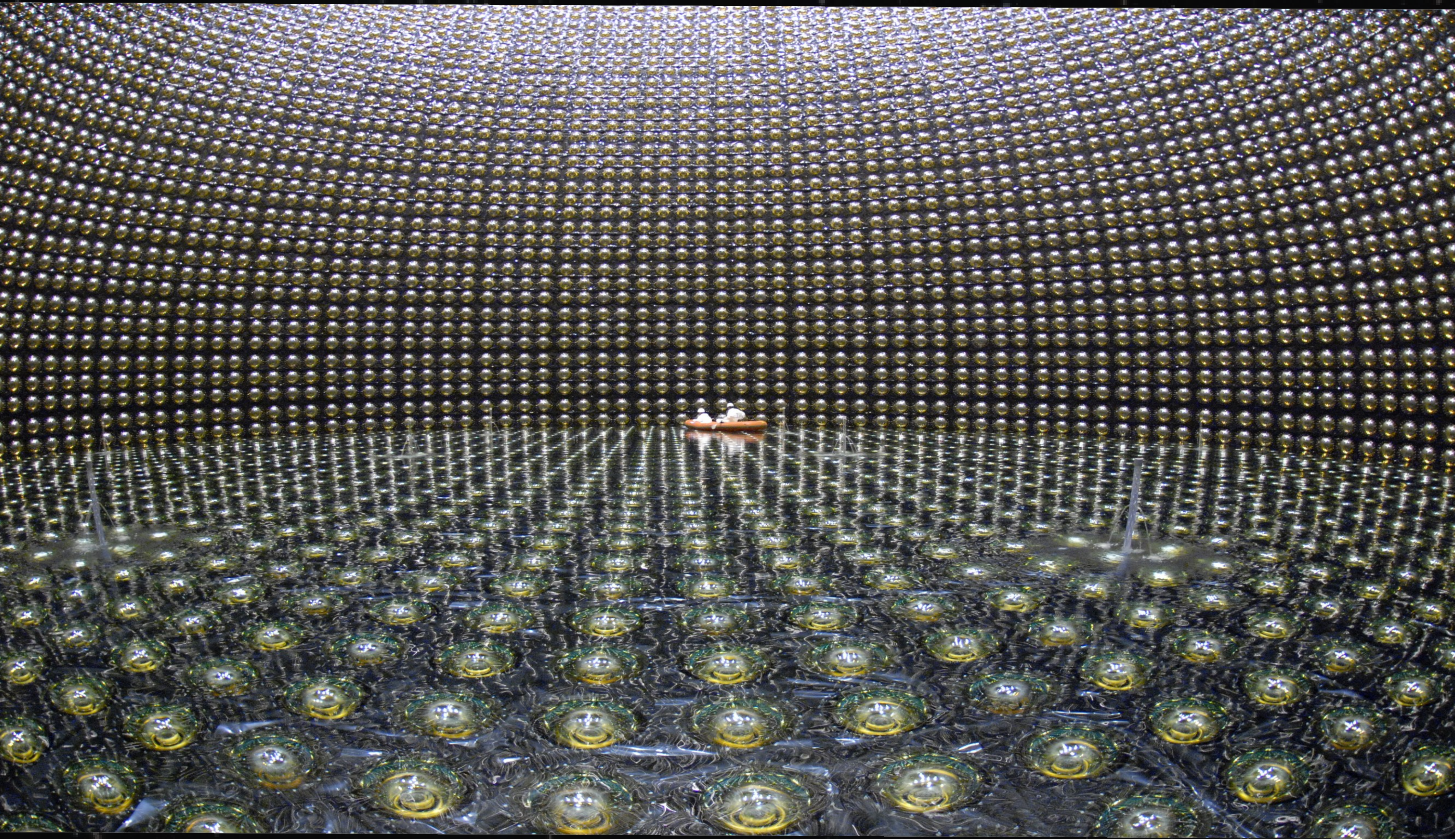


There are **three** generations of particles

Neutrinos are "invisible"

HOW ARE NEUTRINOS DETECTED?



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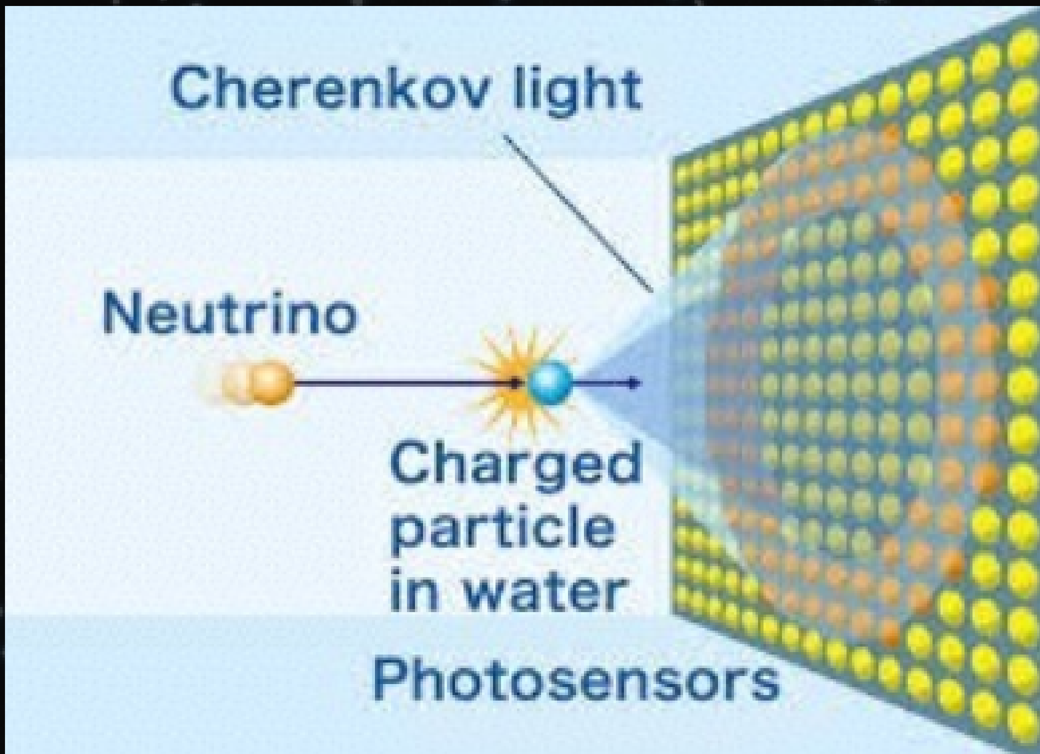

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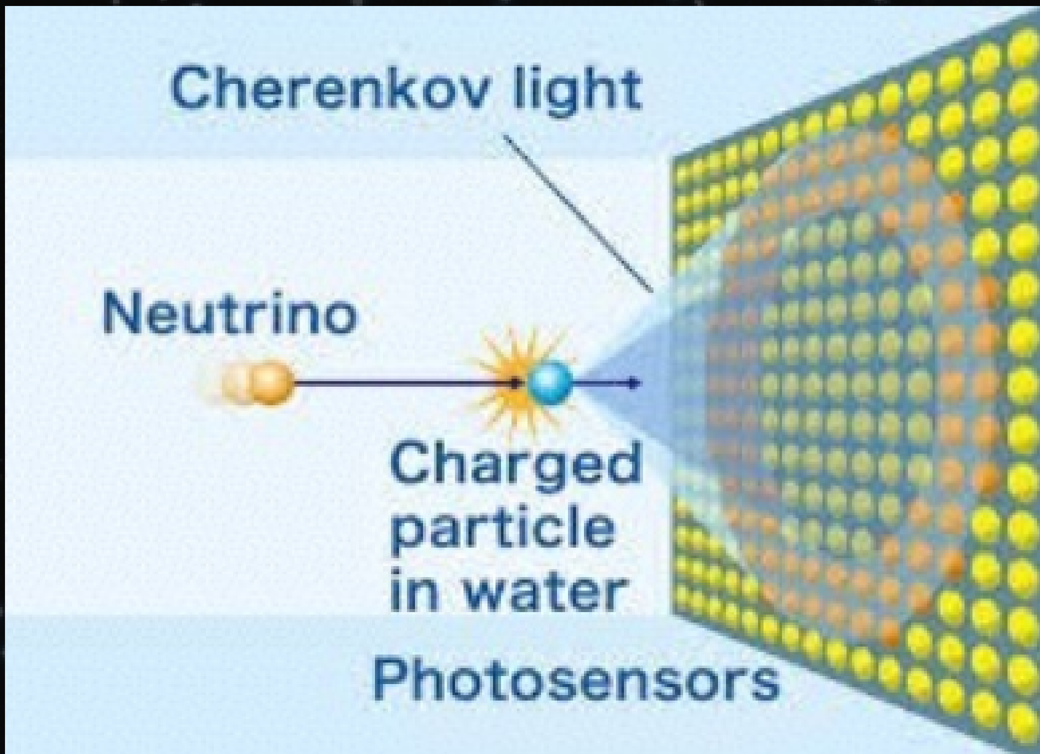

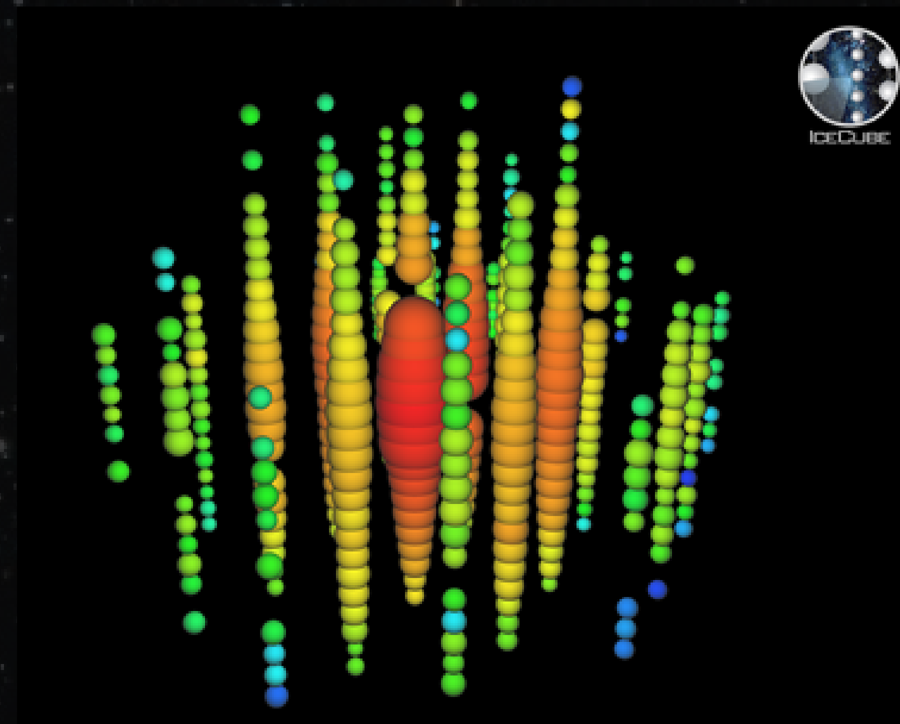

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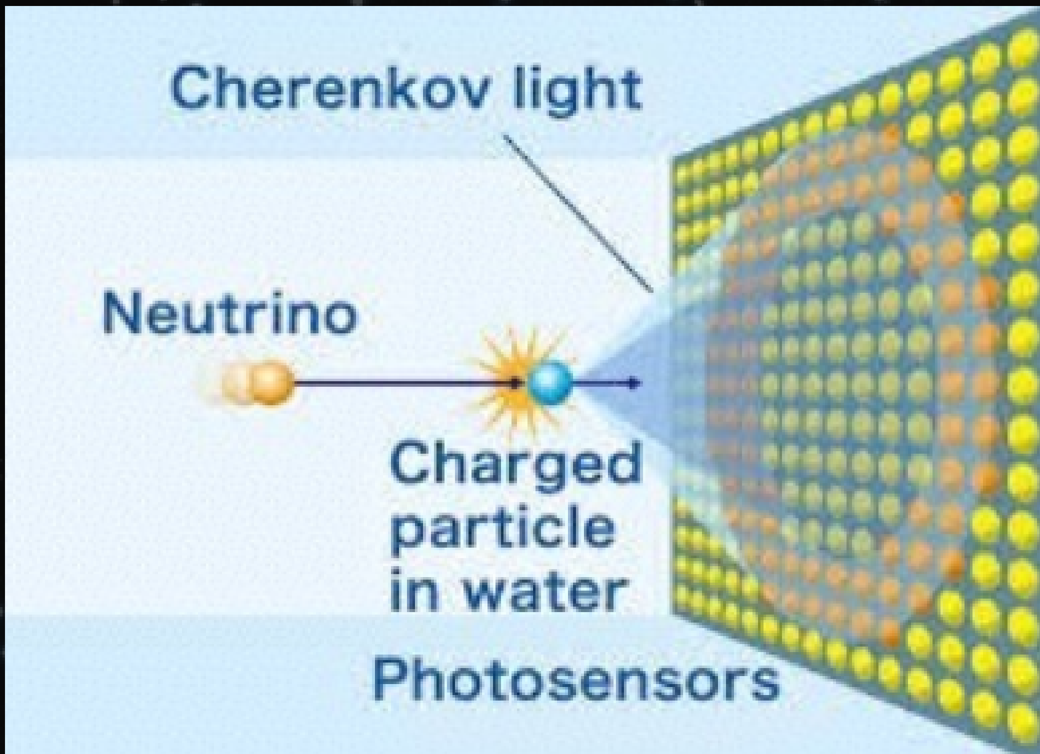
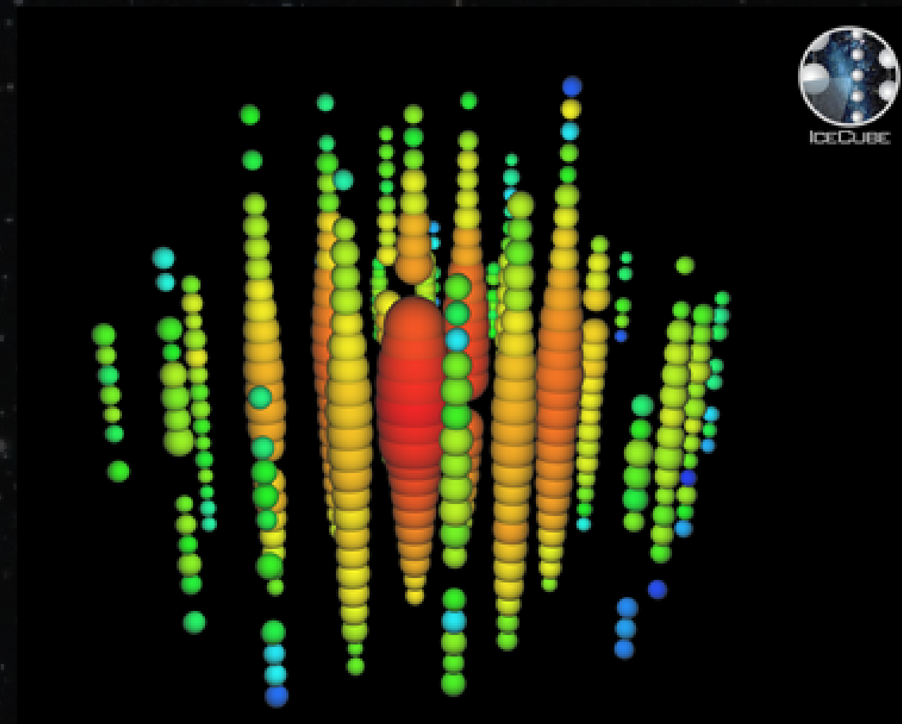
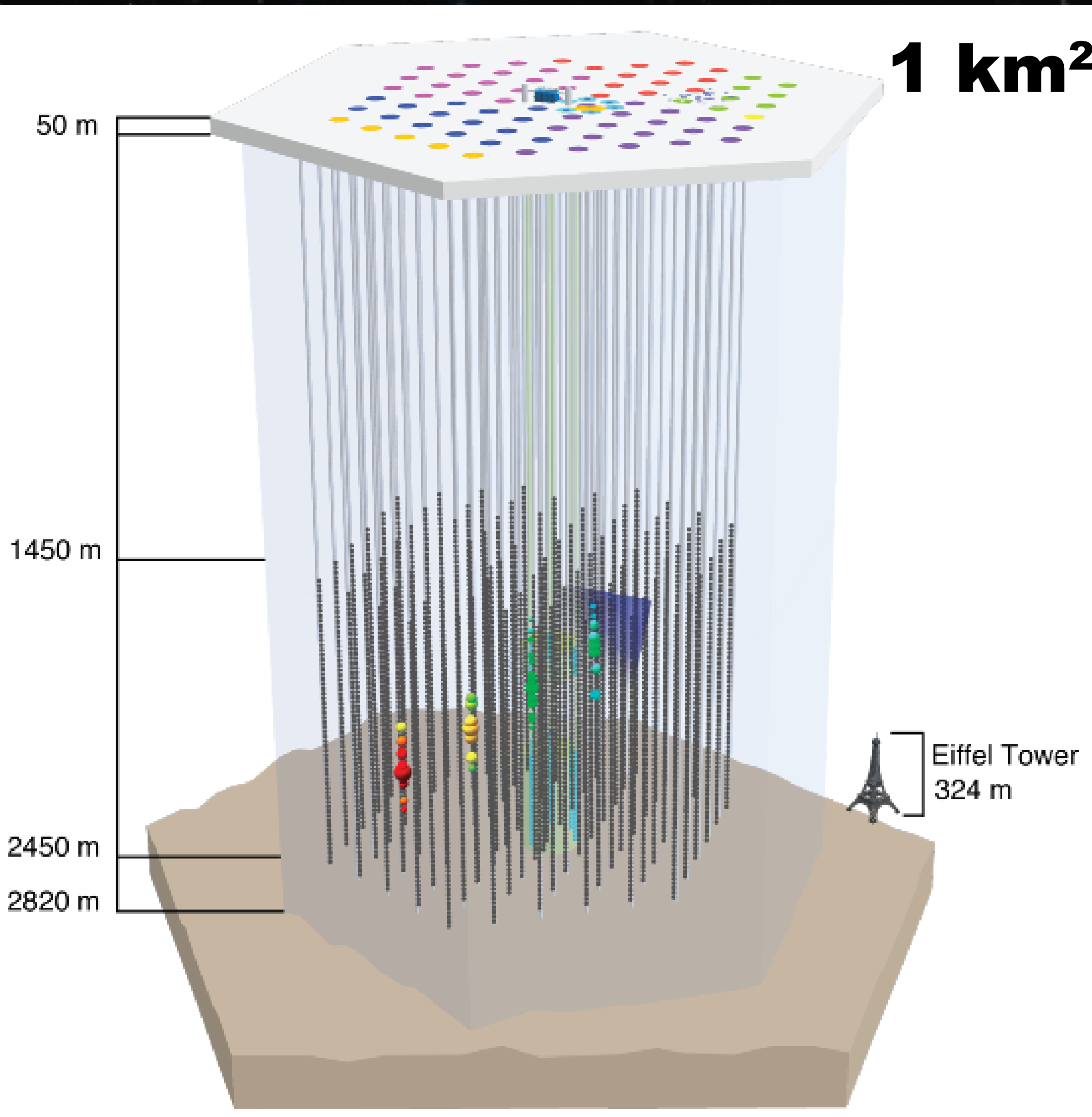




If we observe an electron, this means that the neutrino that hit the water was of electron type

THE ICECUBE DETECTOR



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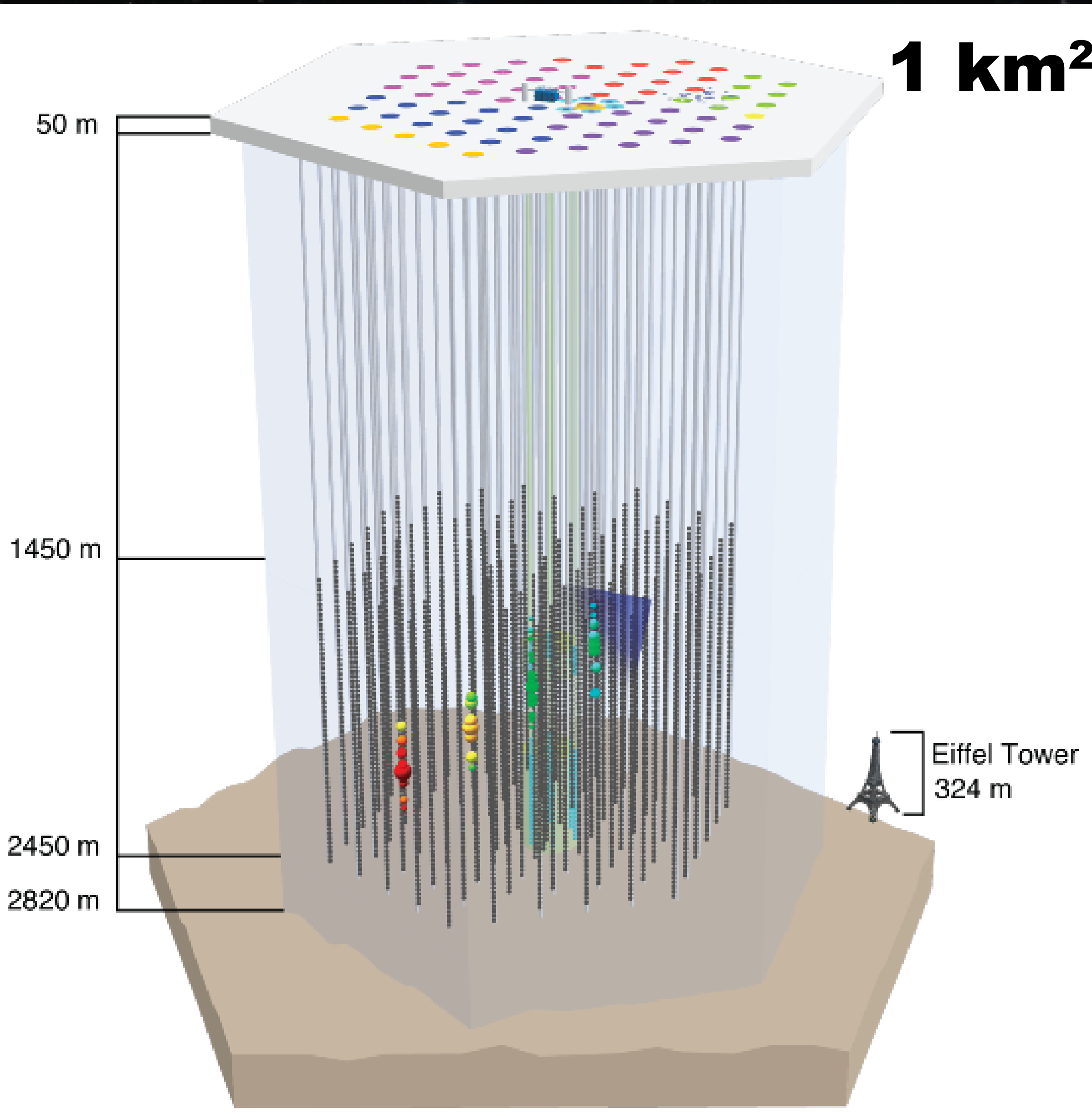

It uses 100 000 cameras!

10^{12}

por sec

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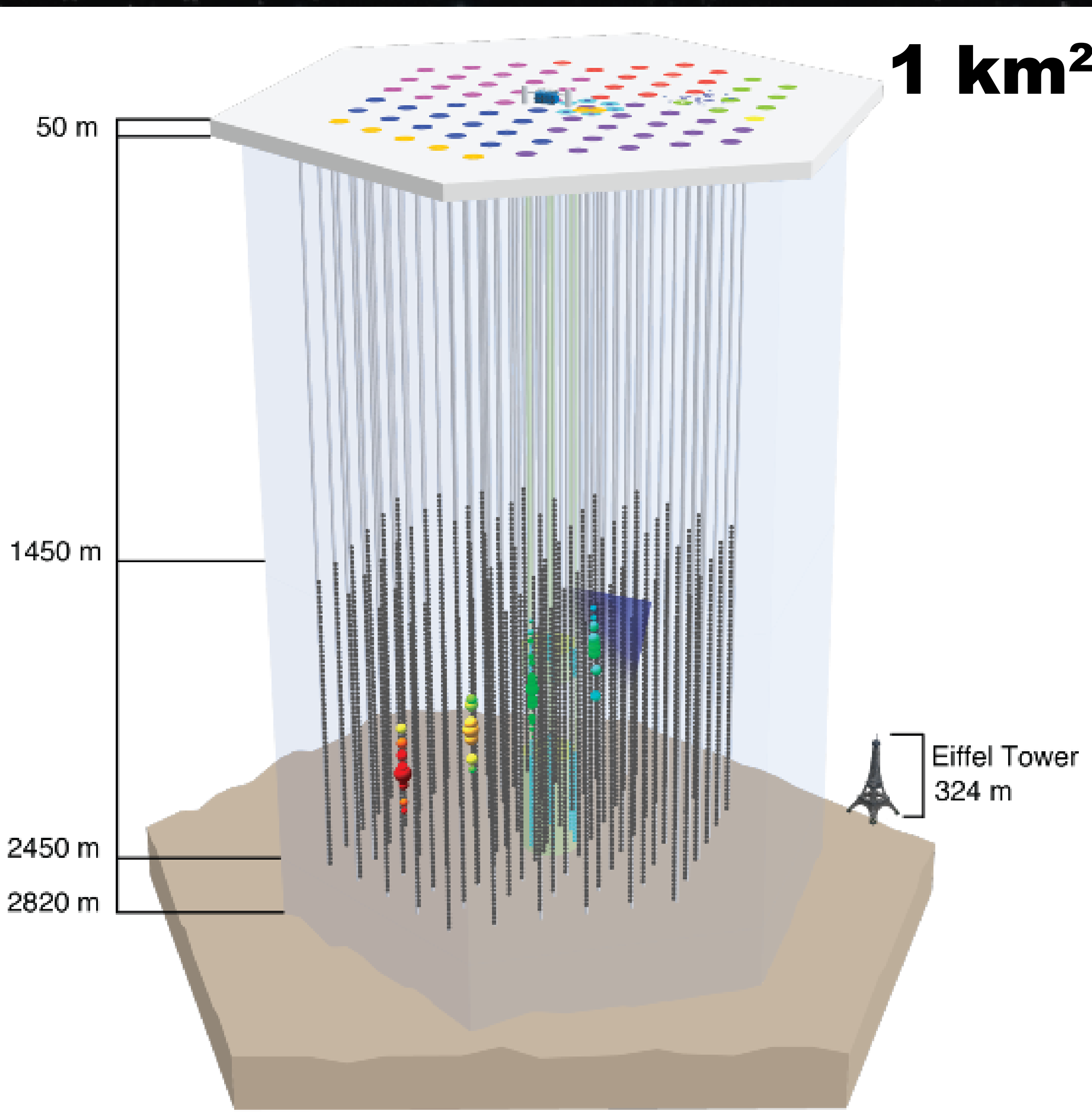

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A <u>minimum energy</u> of 1 TeV is needed for particles to emit light within the ice

THE ICECUBE DETECTOR

Electron neutrinos produce cascades

1 km^2

10^{12}

por sec

<u>THE ICECUBE DETECTOR</u>

$1\ km^2$

Electron neutrinos produce <u>cascades</u>

10^{12}
por sec

Muon neutrinos produce <u>tracks</u>

THE ICECUBE DETECTOR

1 km^2

Electron neutrinos produce cascades

10^{12}
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Tau neutrinos produce double-bangs

THE ICECUBE DETECTOR

1 km^2

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10^{12} por sec

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In order to distinguish a neutrino from a charged particle, the most important thing is to make sure the light starts inside the detector

THE ICECUBE DETECTOR

1 km^2

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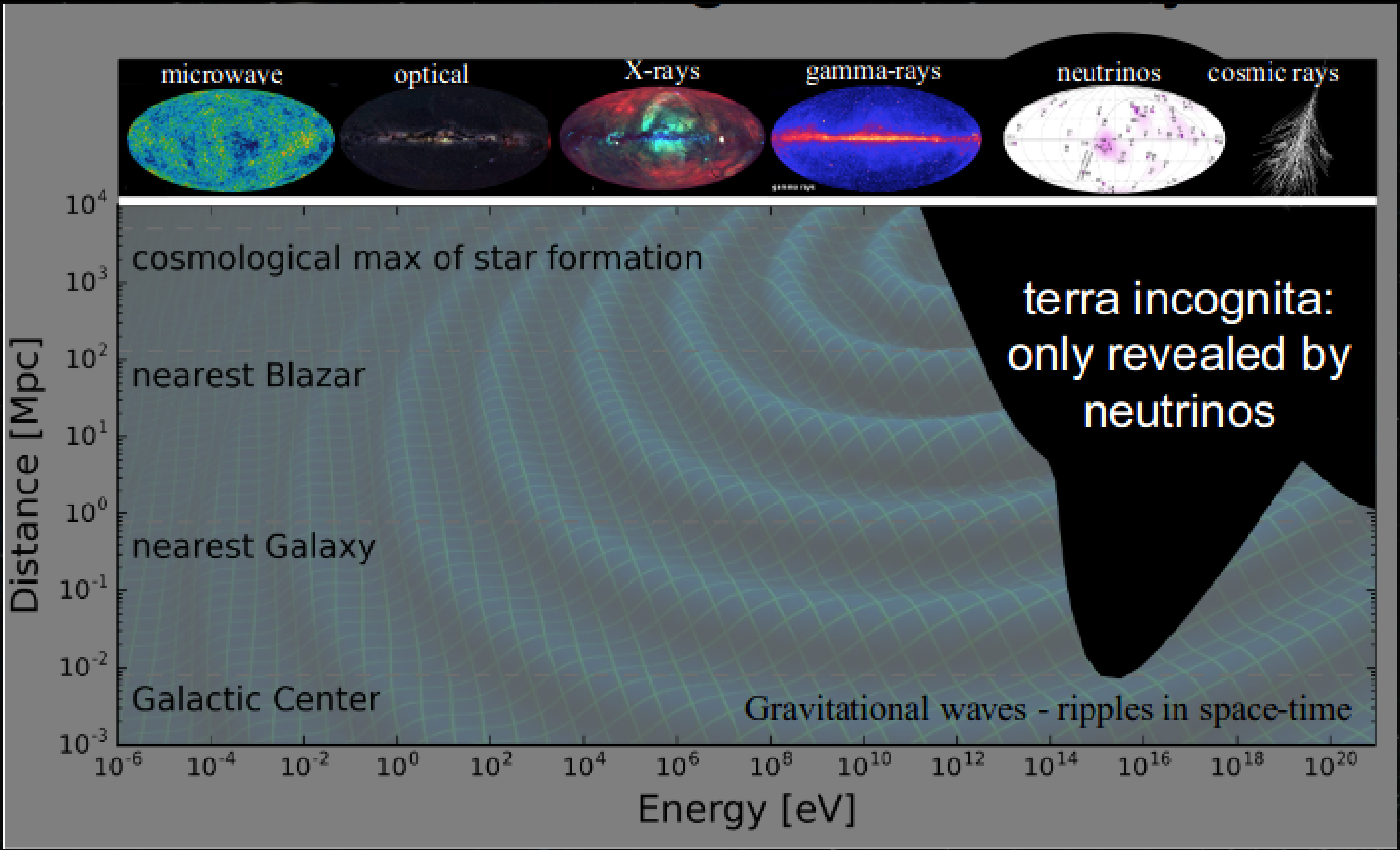
Muon neutrinos produce tracks

Tau neutrinos produce double-bangs

In order to distinguish a neutrino from a charged particle, the most important thing is to make sure the light starts inside the detector

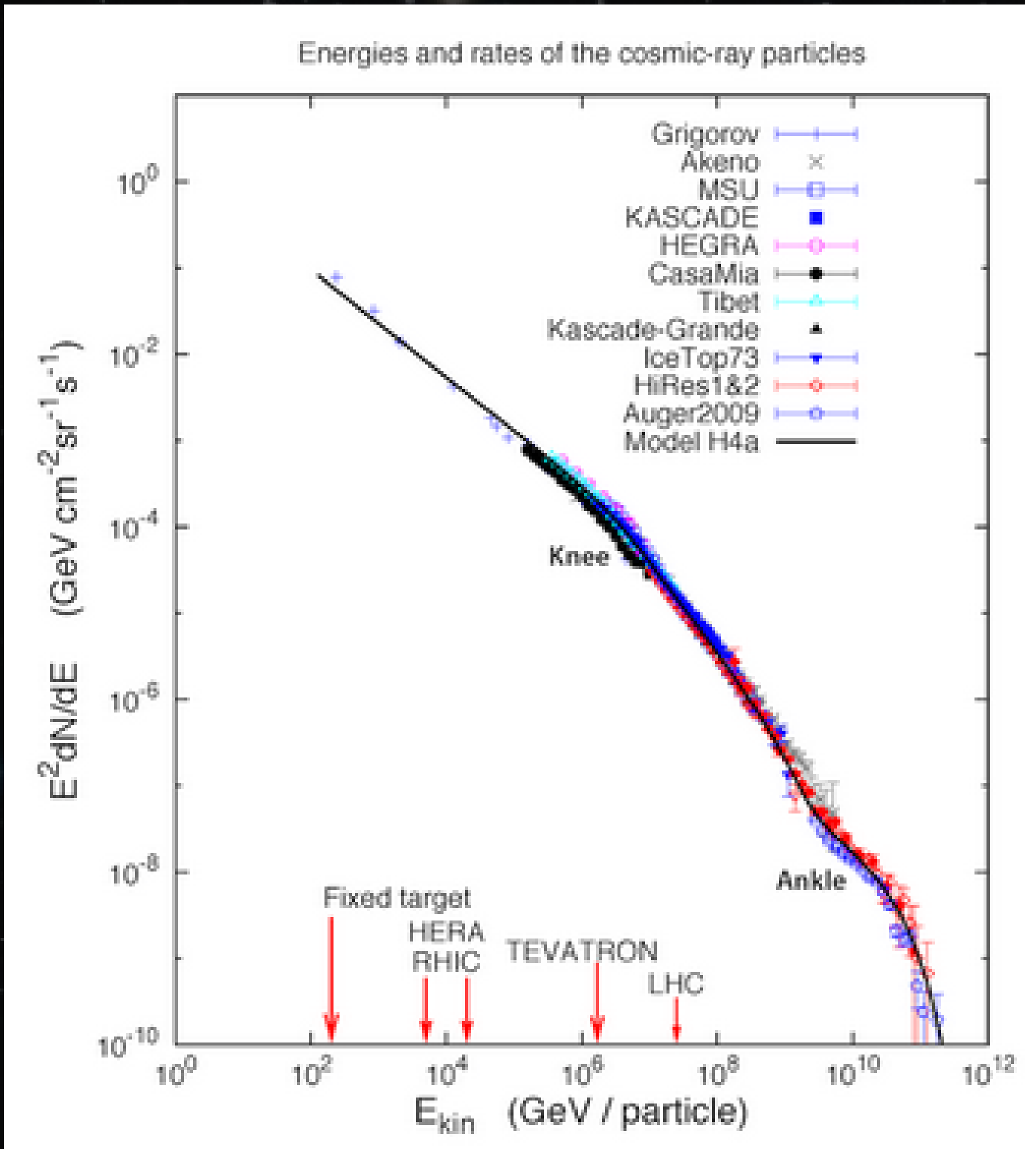
Quiz

WHERE DO NEUTRINOS COME FROM?



20% of our observable universe is not visible with light

WHERE DO NEUTRINOS COME FROM?



km²

10^{12}

por sec

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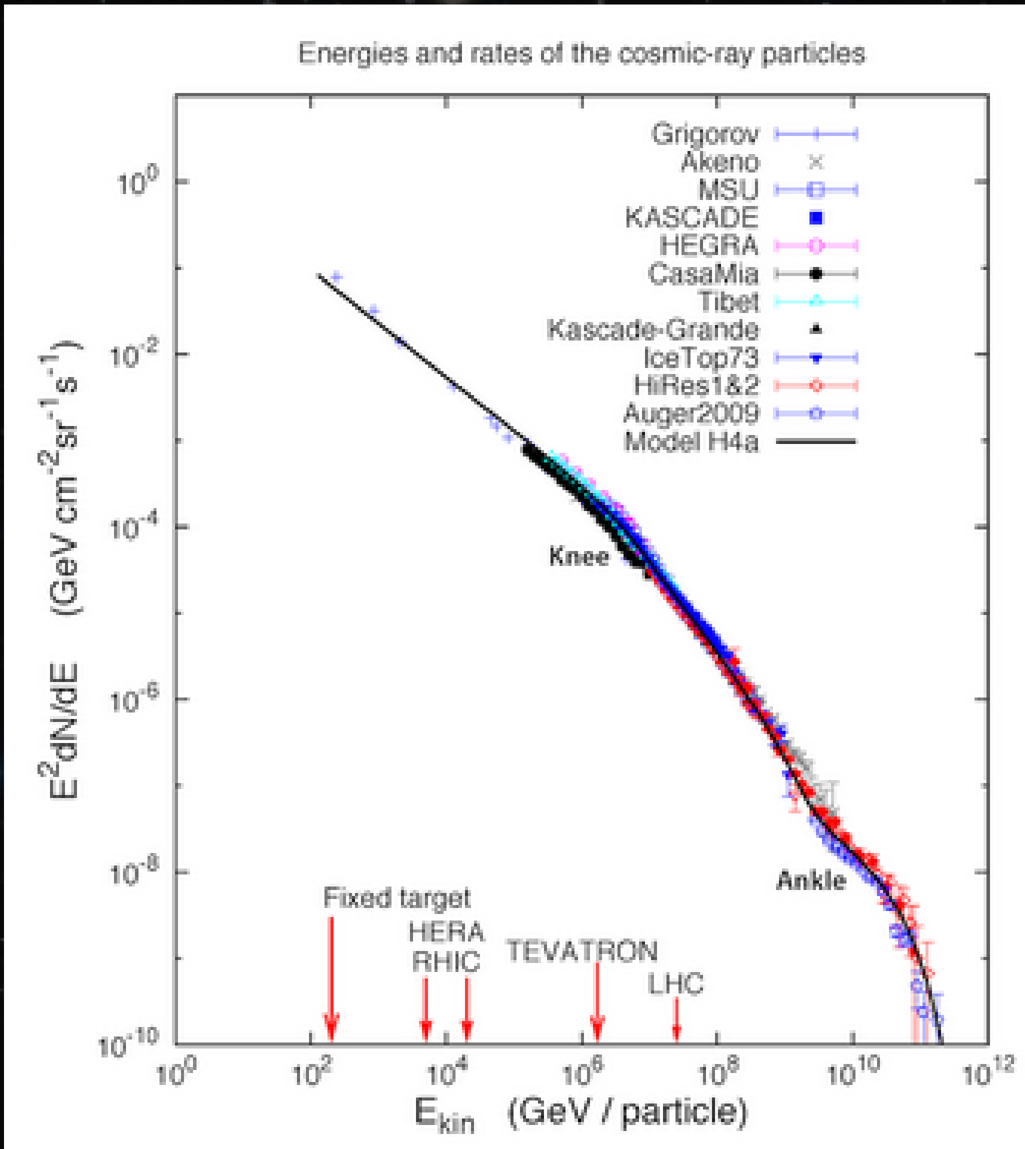

km²

10^{12}

por sec

We do not know how cosmic rays are created!

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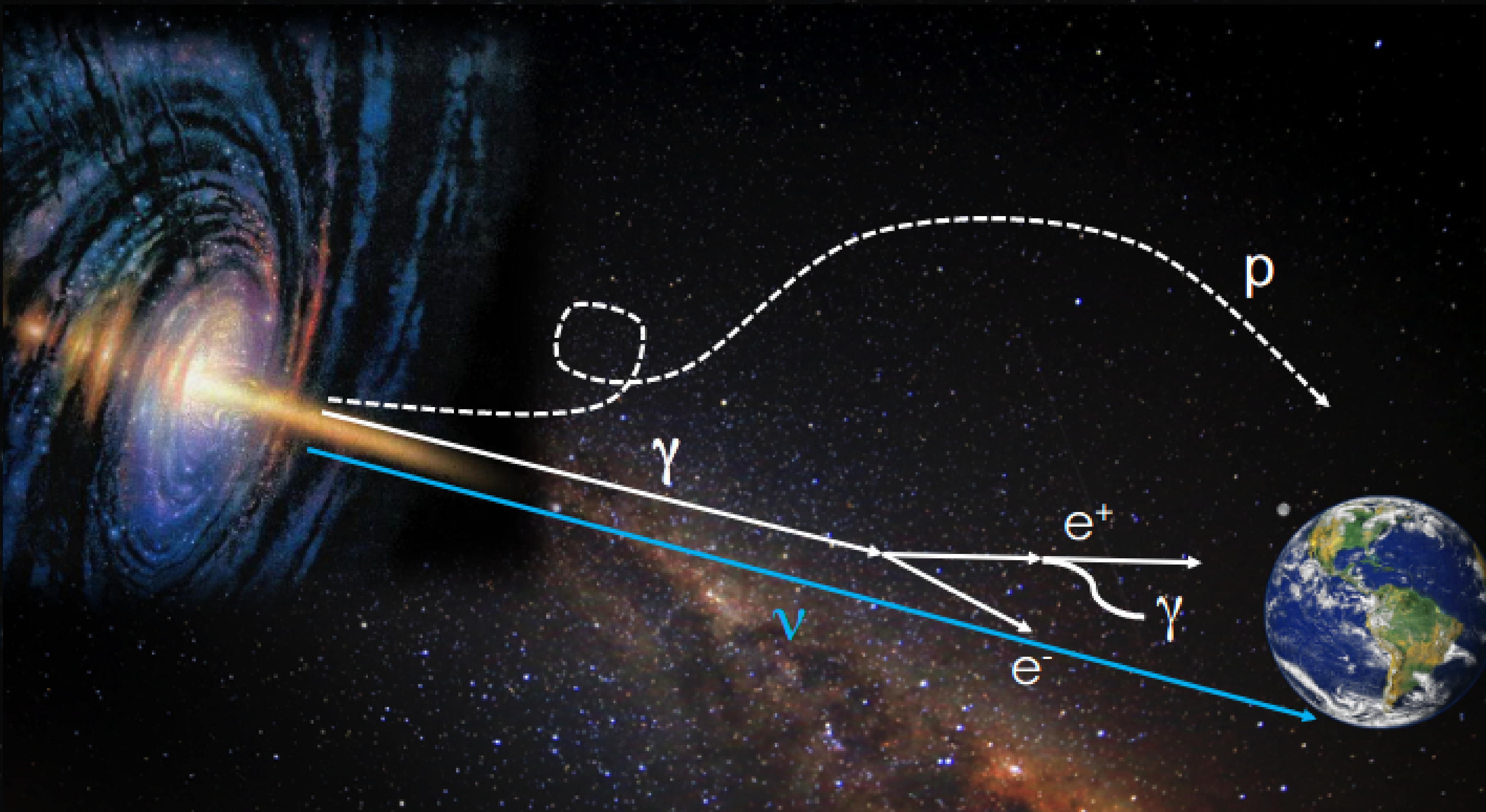

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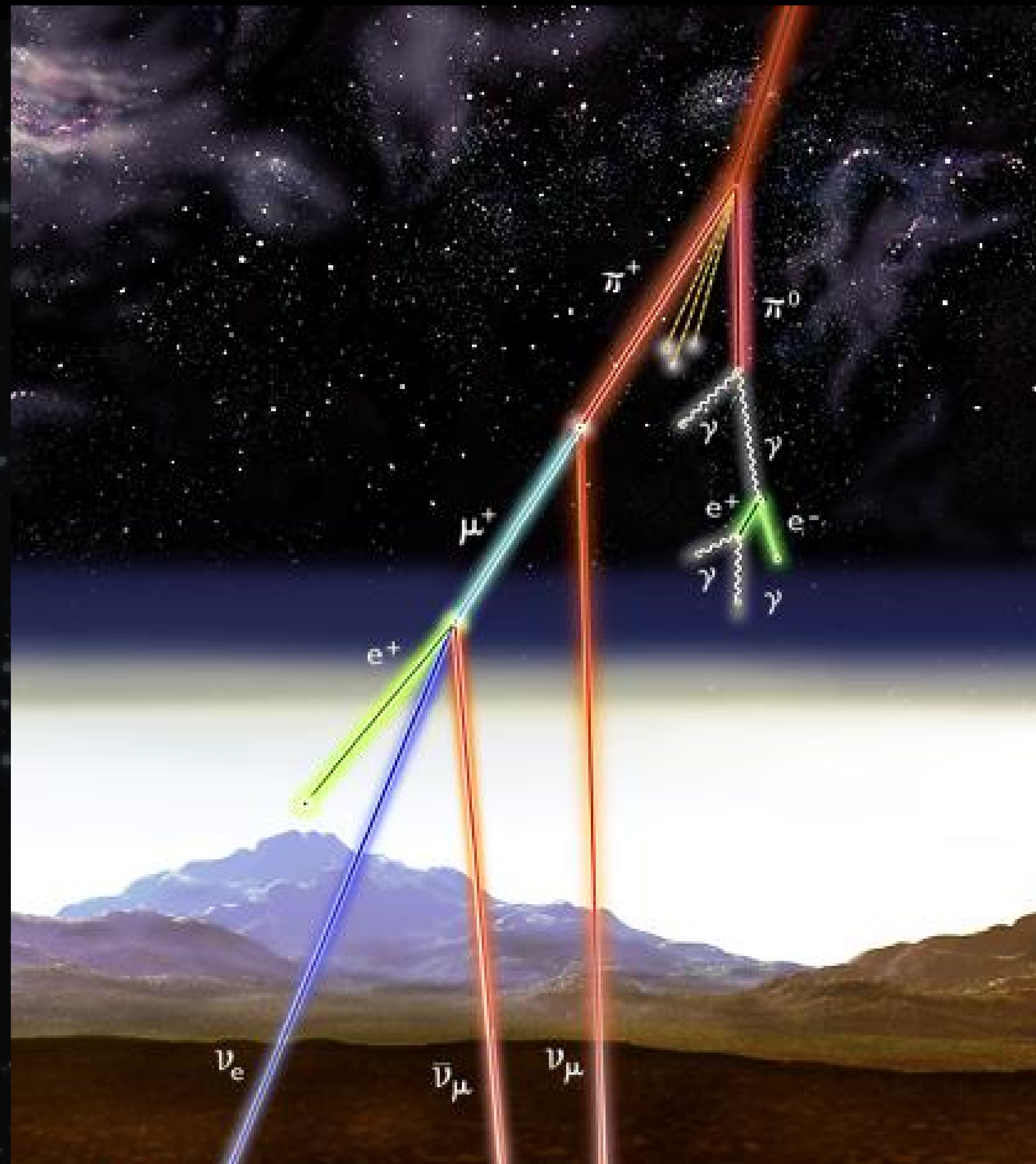

10^{12}
por sec

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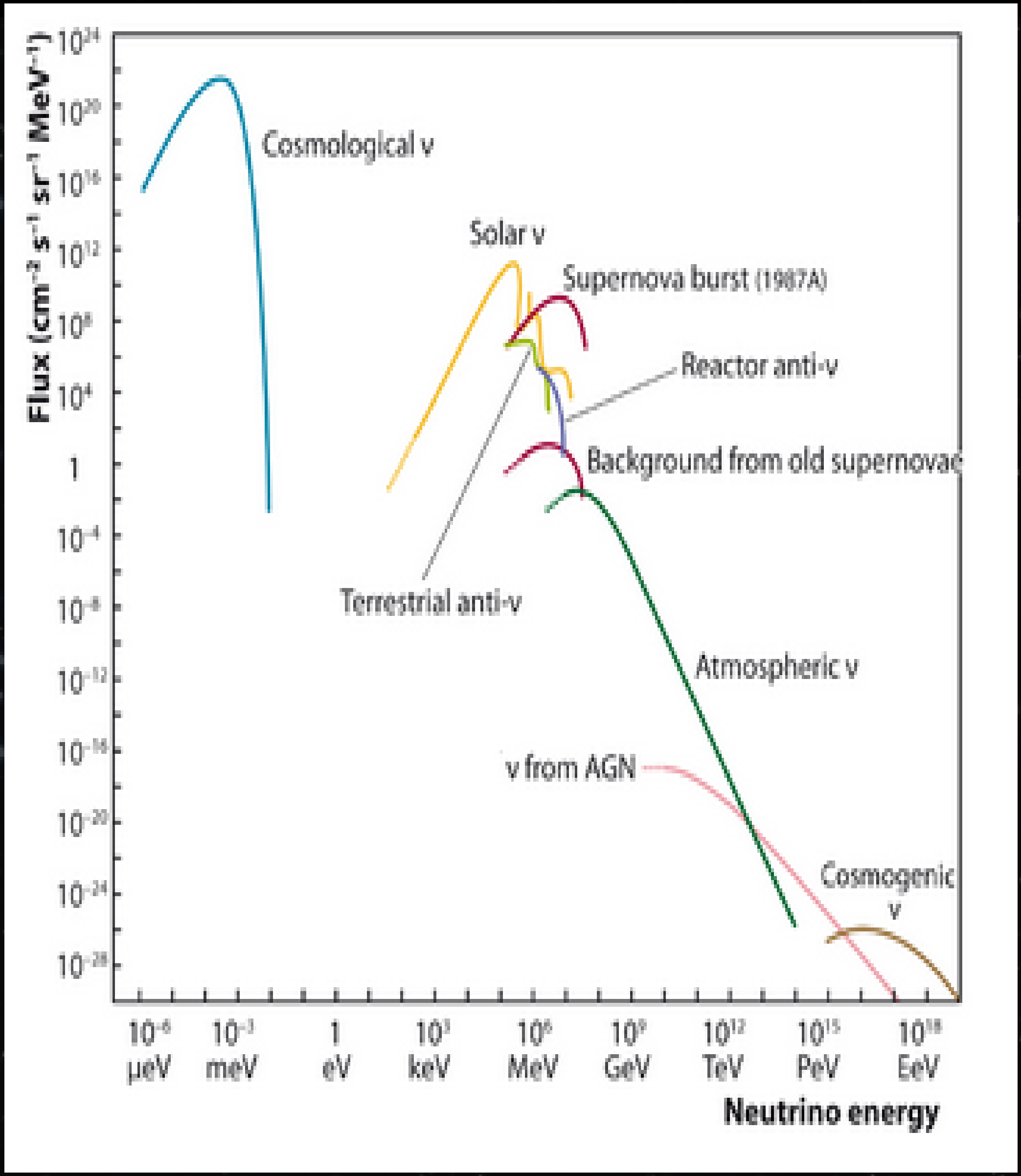

10^{12} por sec

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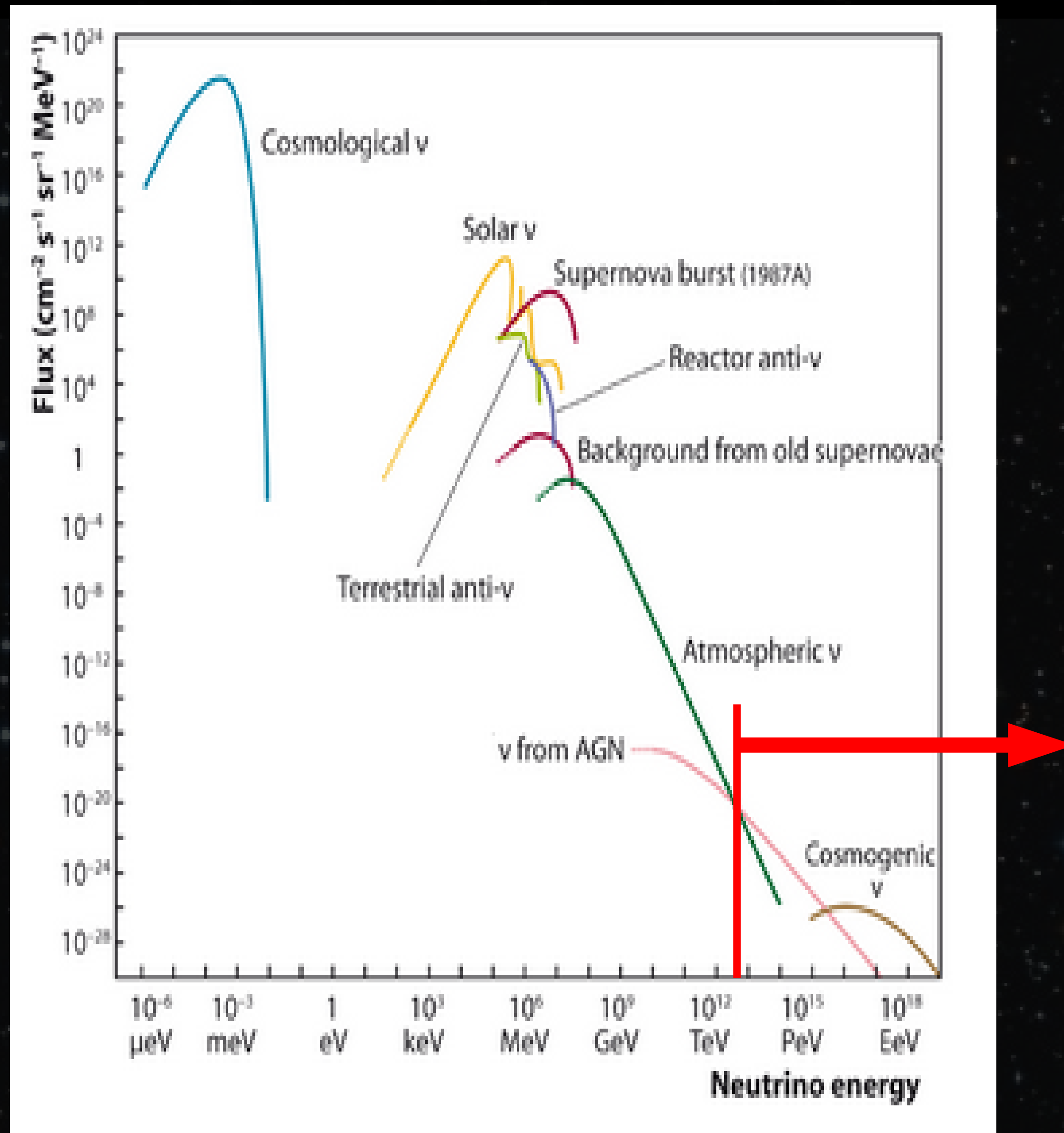
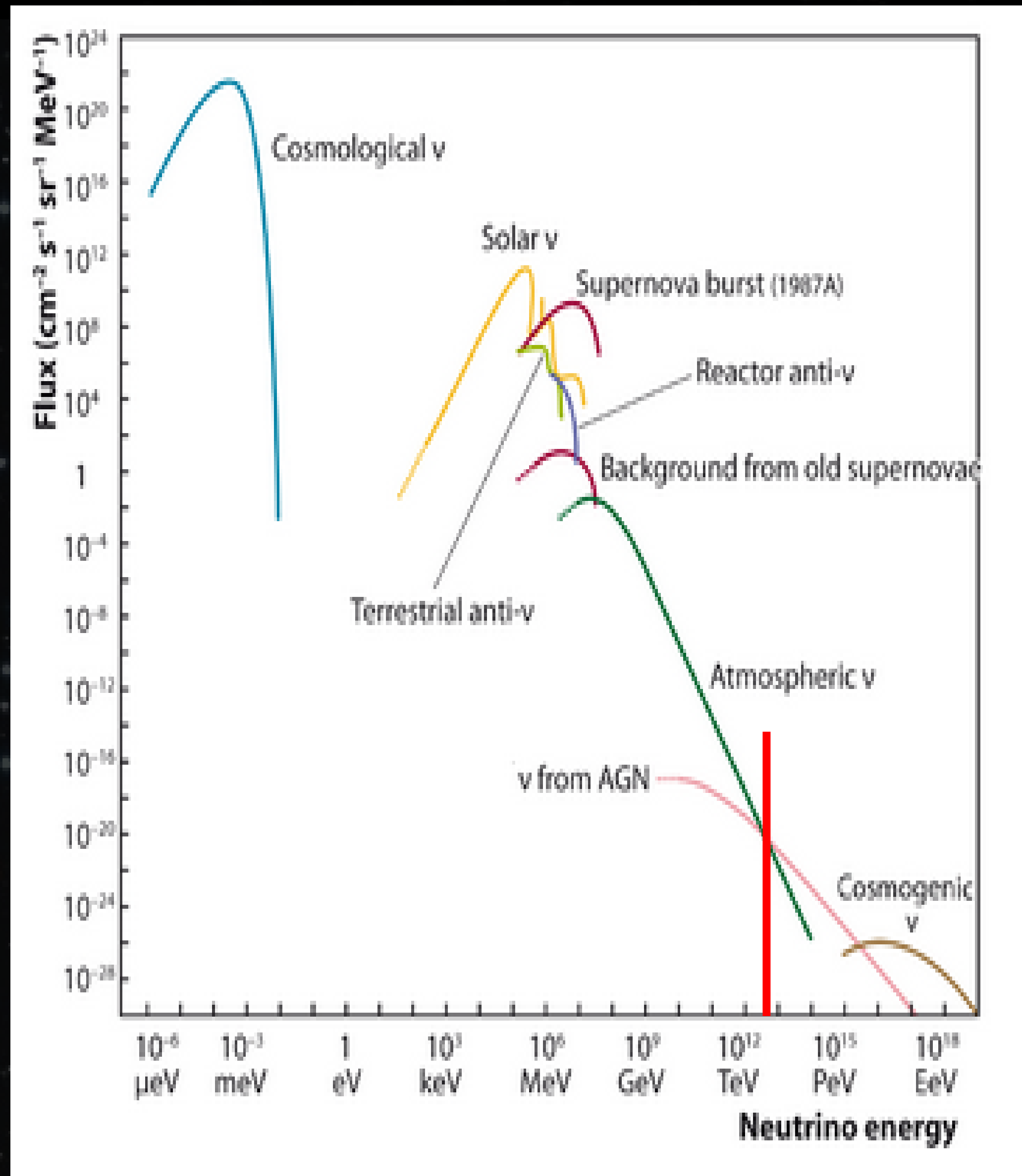


10^{12}
por sec

IceCube energies

WHERE DO NEUTRINOS COME FROM?



10^{12}
por sec

We have to distinguish the "signal" from the "background".
75 neutrinos per day vs 1 per month!

ACTIVITY

1 km^2

1) Go to http://nuclass.weebly.com/1

10^{12}
por sec

2) Open the questionnaire.

https://bit.ly/2Eqqwys

3) Read and complete the tasks, writing down the results in the questionnaire.

TASK 1

1 km²

Link

10^{12}
por sec

Which particles have been created inside the detector?

Is it possible to know whether they are atmospheric neutrinos (background) or extragalactic neutrinos (signal)?

TASK 2

1 km²

Link

10^{12}
por sec

In order to pass veto, a charged particle has to be created inside the detector.

In order to pass the charge cut, the charge deposited in the detector has to be larger than 6000 pe.

TASK 3

1 km^2

Link

10^{12} por sec

Look at the images and try to figure out which neutrinos have the largest energy.

Which features of the images make you think that the neutrino has a large energy?

TASK 4

$1\ km^2$

Link

Now you can look at each event in more detail.

10^{12} por sec

What are the most important characteristics of each event?

Link

TASK 5

Here you can look at the differences between simulations (in gray) and real data (in black).

1 km^2

10^{12} por sec

Change the energy cut until the simulations match the data and there is a large difference between the signal and the background.

What information about the neutrinos can you learn using the declination?


Time to
Analyse!