Neutrinos: a peek into the origin of the Universe?

Jaafar Chakrani
Lawrence Berkeley National Laboratory
<jchakrani@lbl.gov>

QuarkNet - Physics in and through Cosmology
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BERKELEY LAB

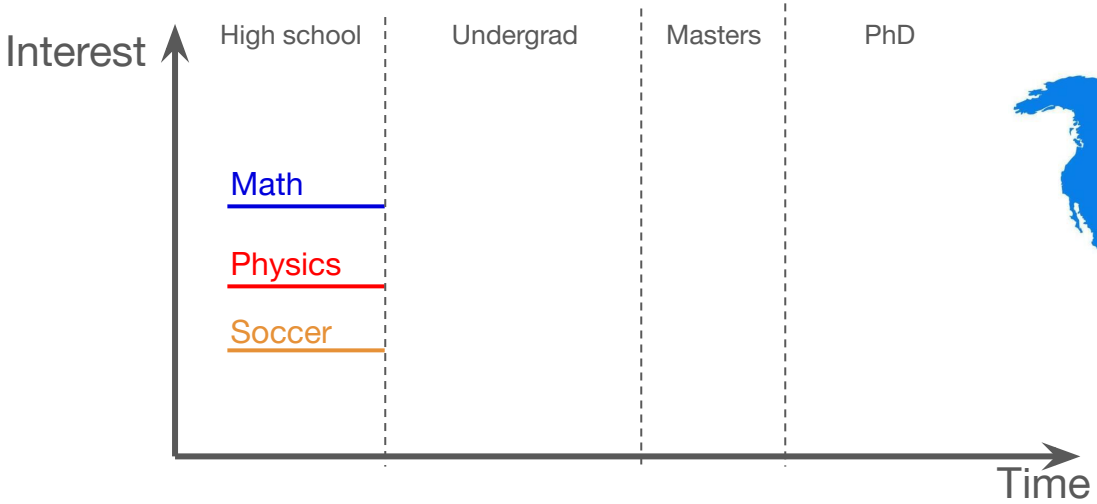
U.S. DEPARTMENT OF ENERGY

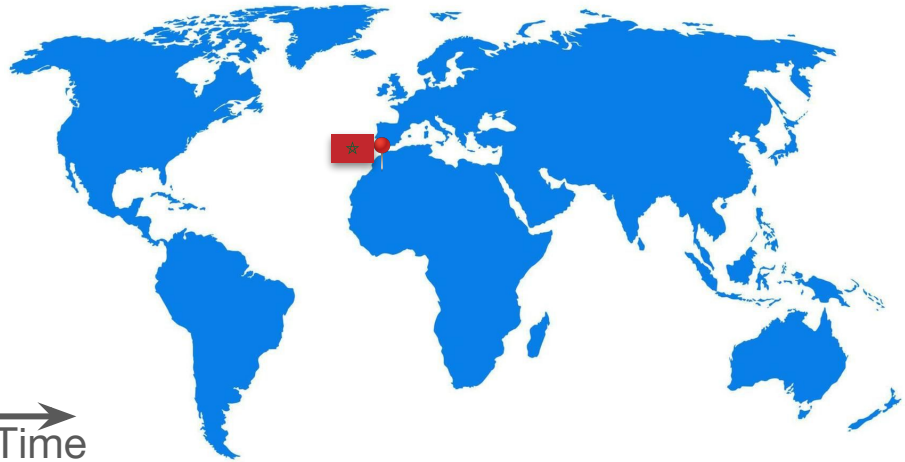
Outline

- About me
- Neutrinos in particle physics
- Neutrino oscillations

About me

- Grew up in Morocco until high school





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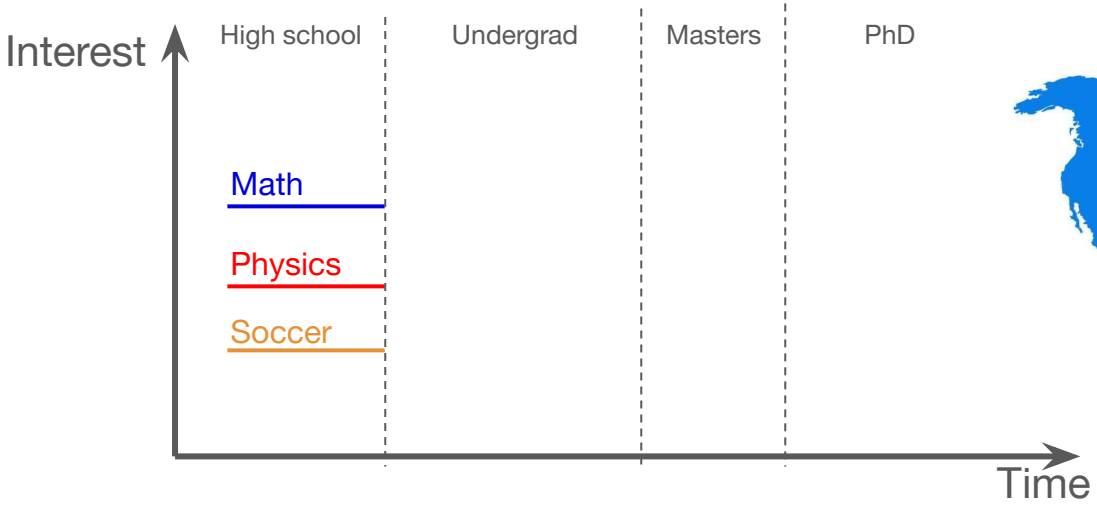
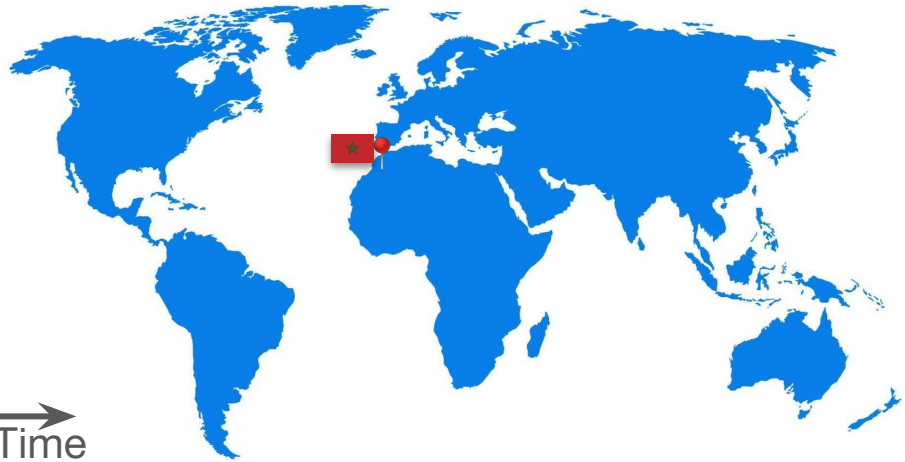
First African team to make it to the semi-finals!





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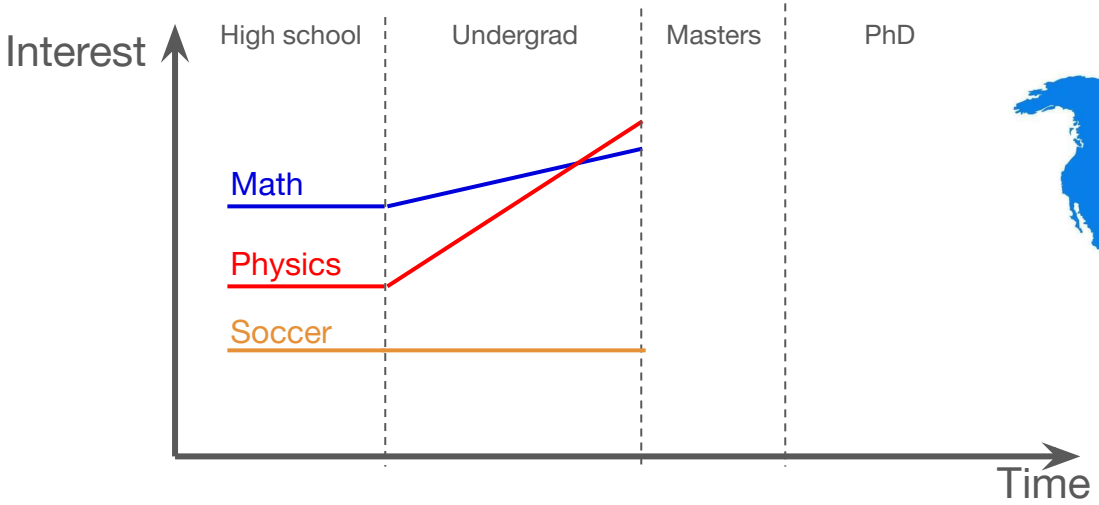

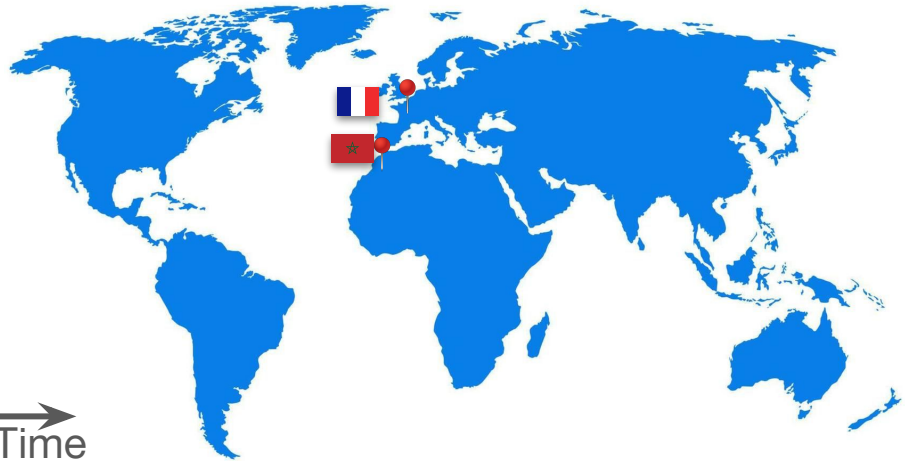

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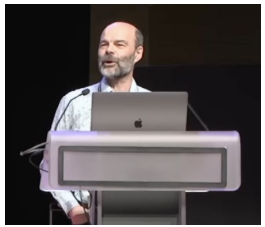
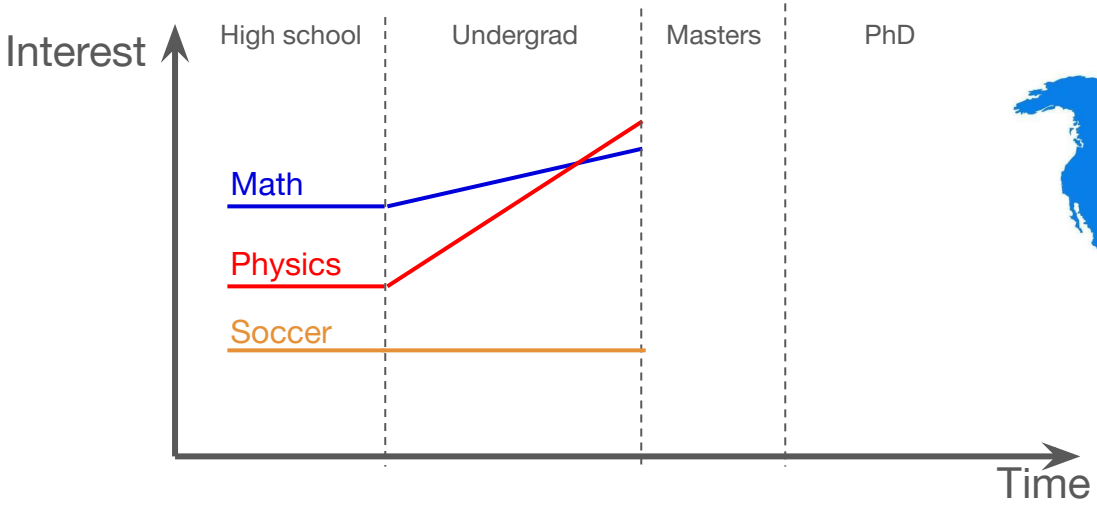
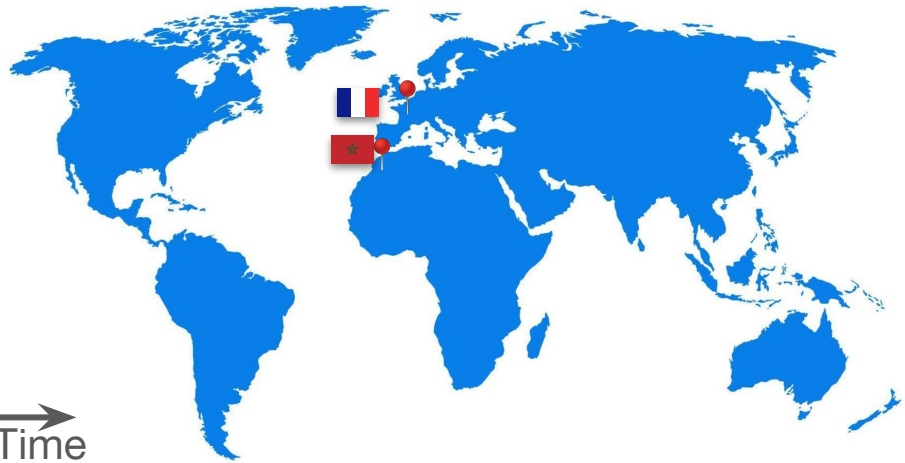
Prof. R. Lehoucq



Translation: "In Hollywood, even black holes put on makeup!"





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CITA ICAT
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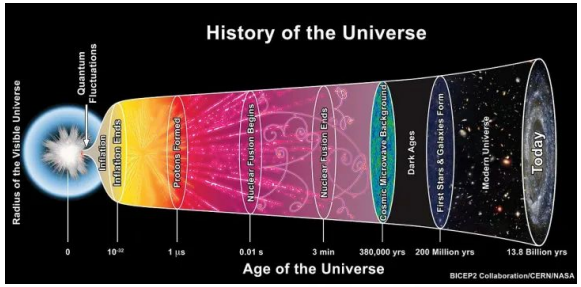

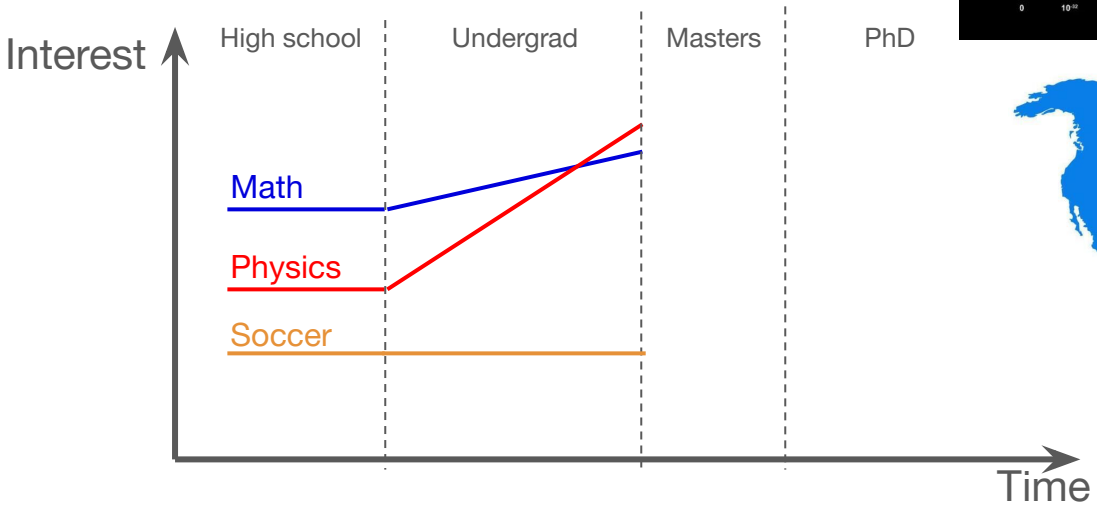

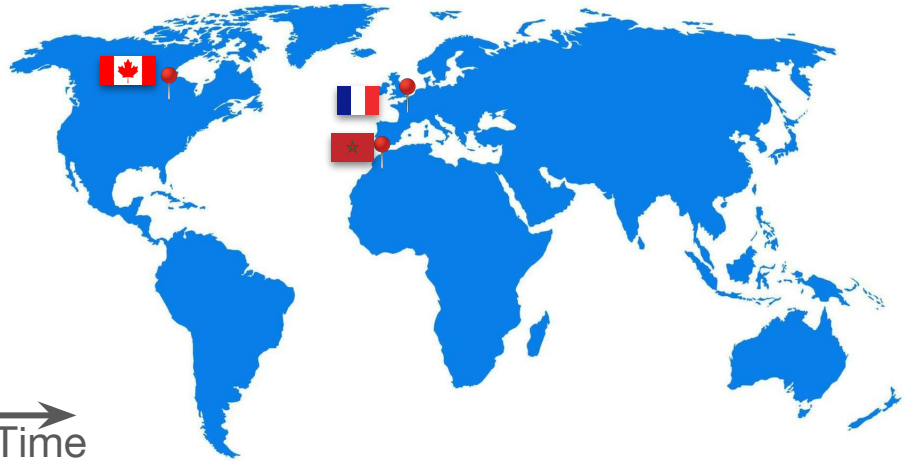

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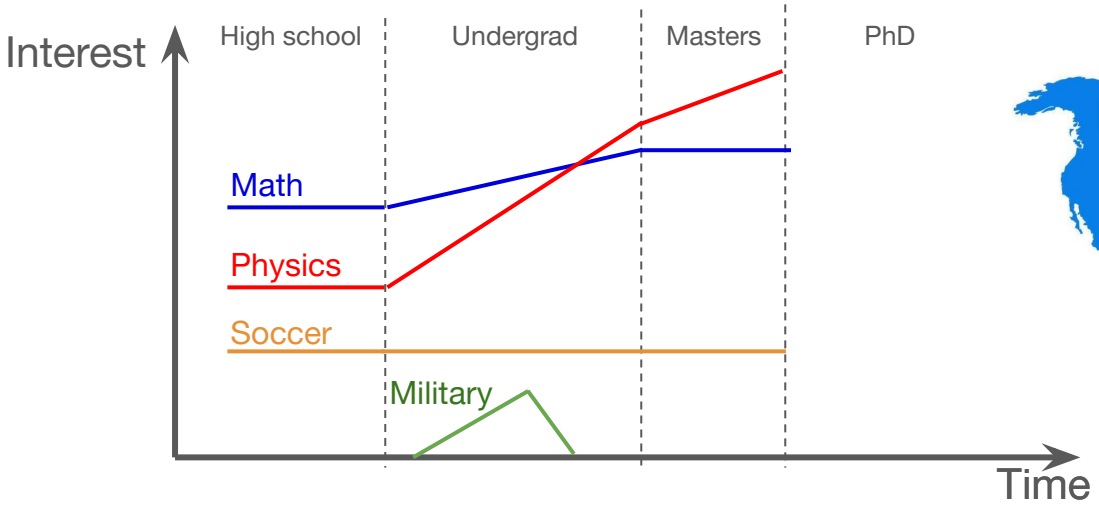

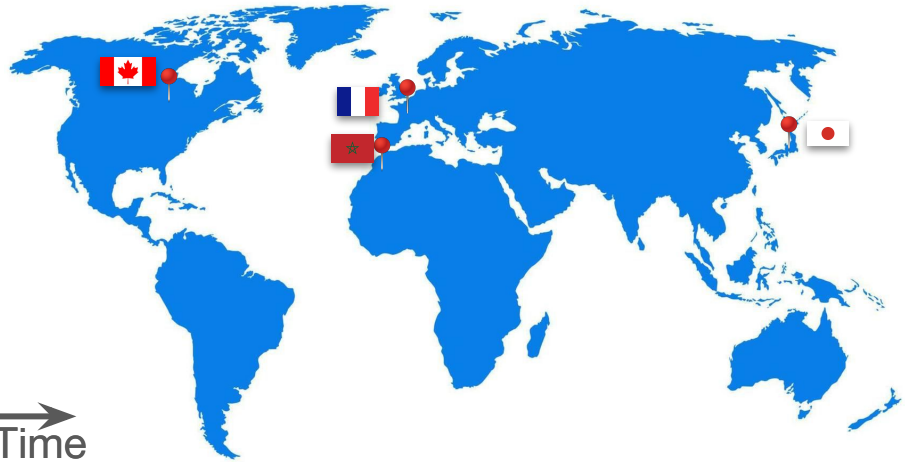

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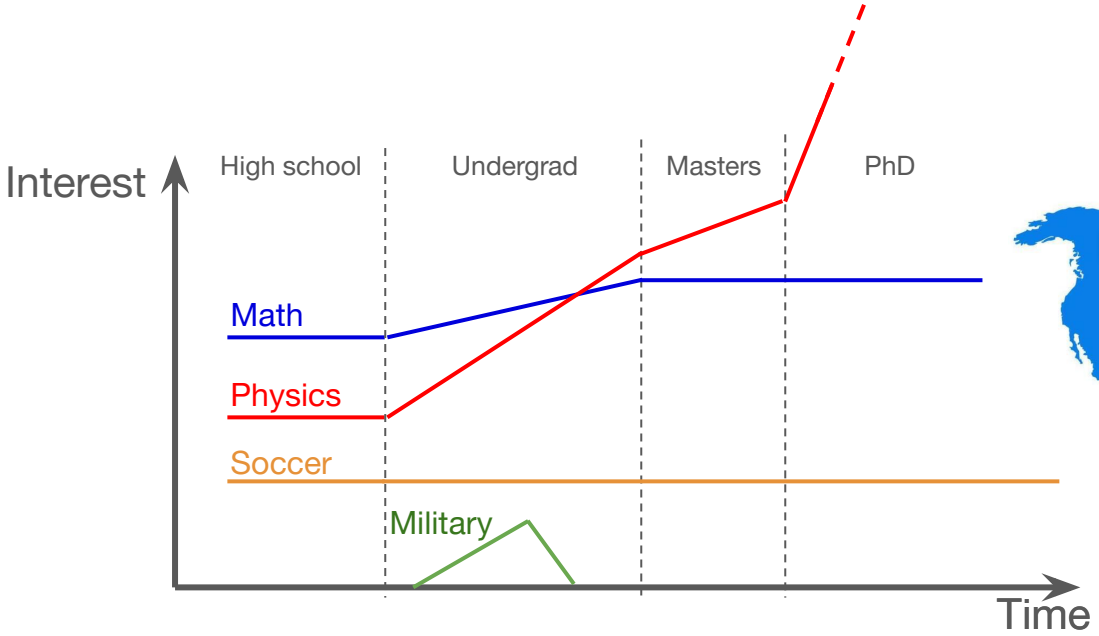

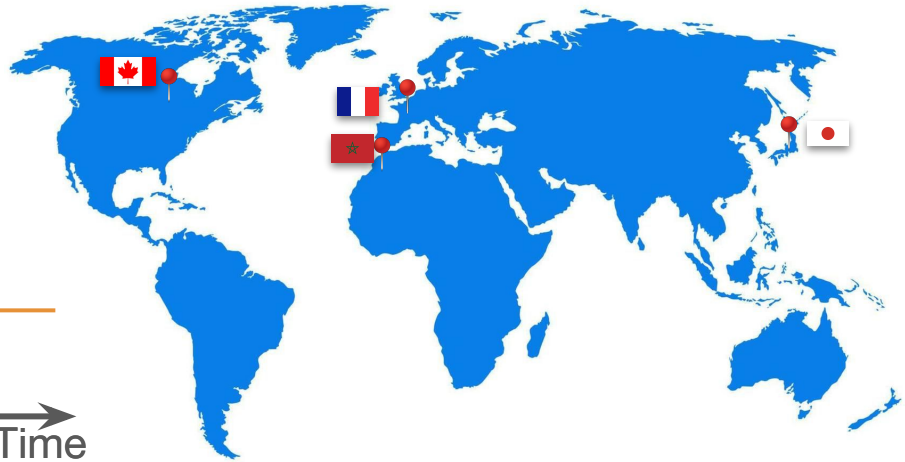

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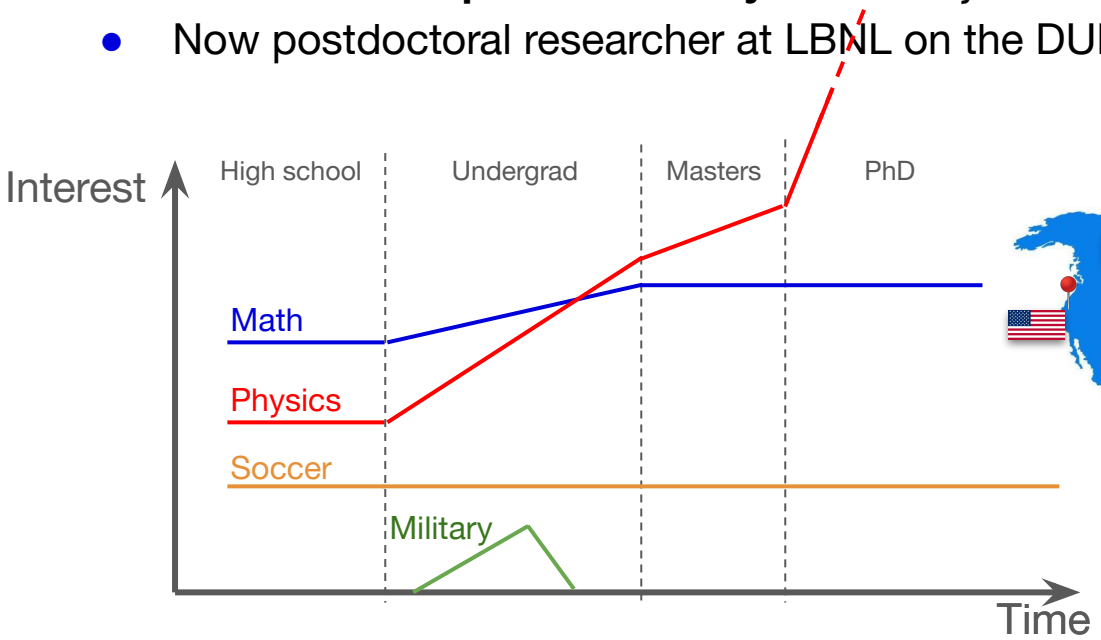
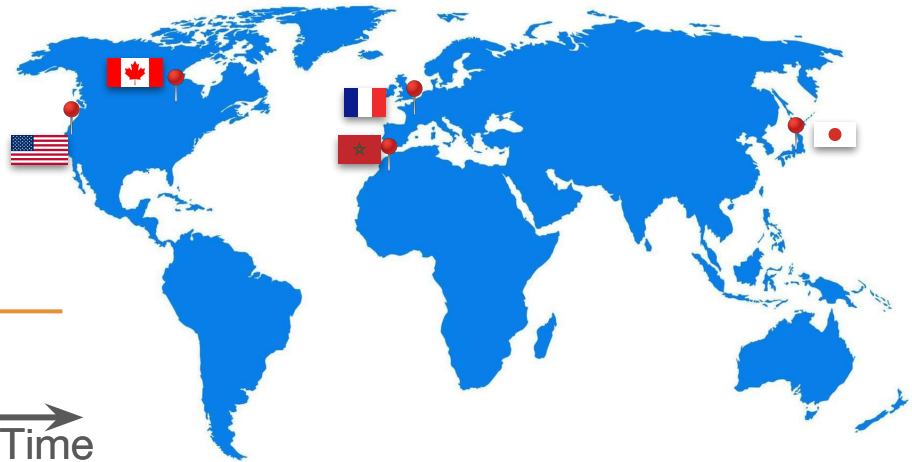
- Now postdoctoral researcher at LBNL on the DUNE experiment

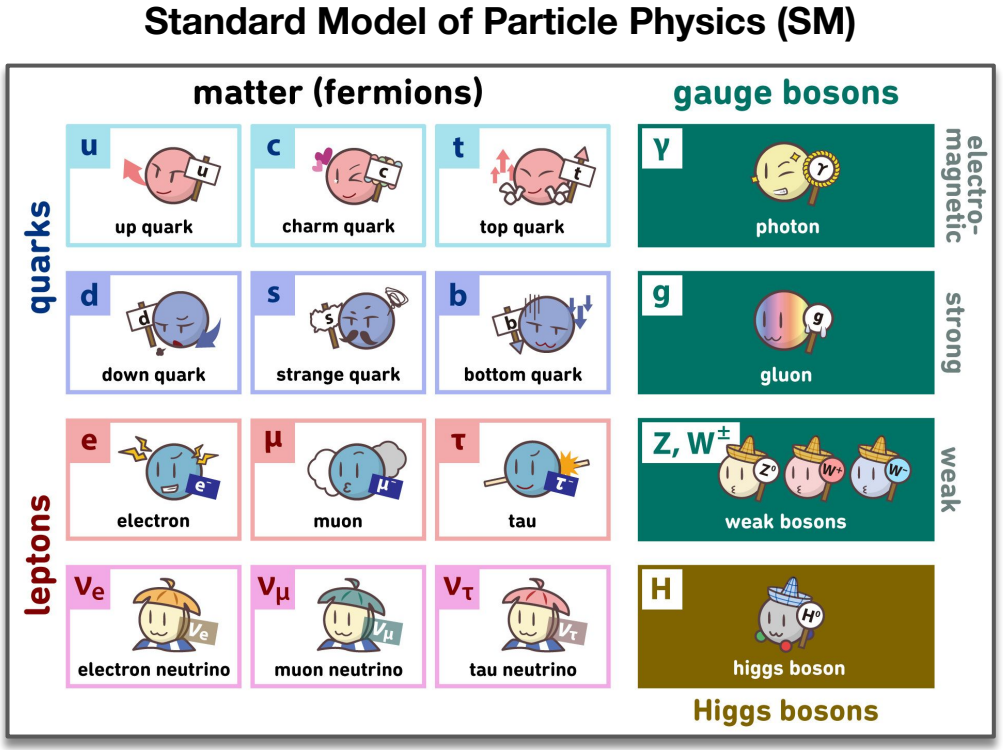




Neutrinos in particle physics

The Standard Model of Particle Physics

- The **Standard Model** describes our best understanding of the **elementary constituents of matter** and **how they interact with each other**



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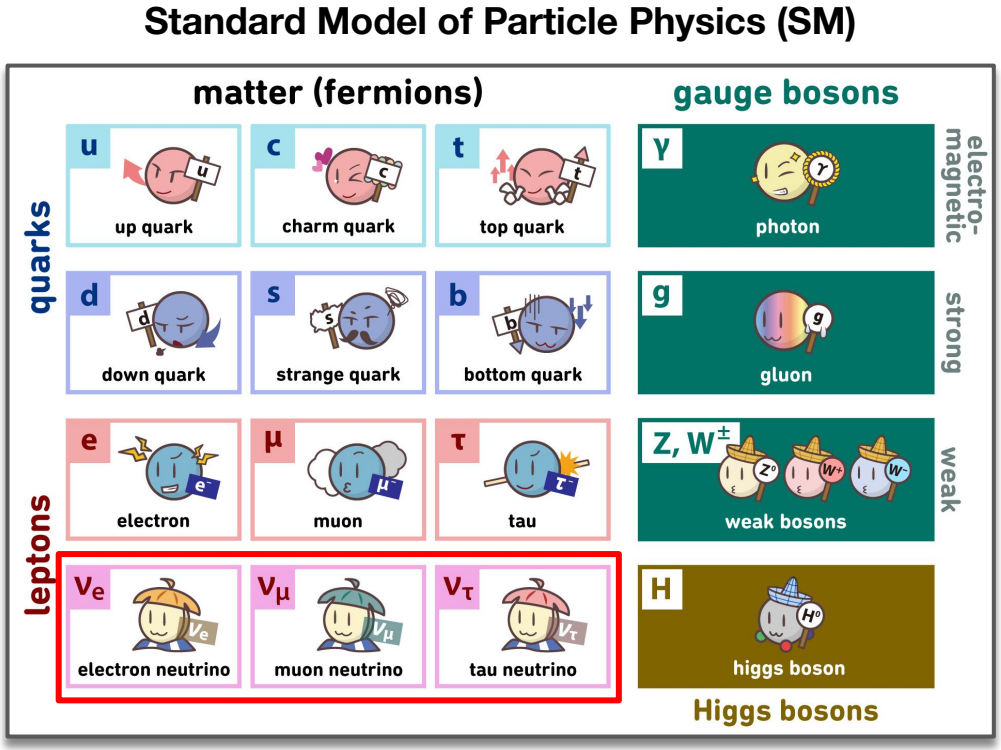
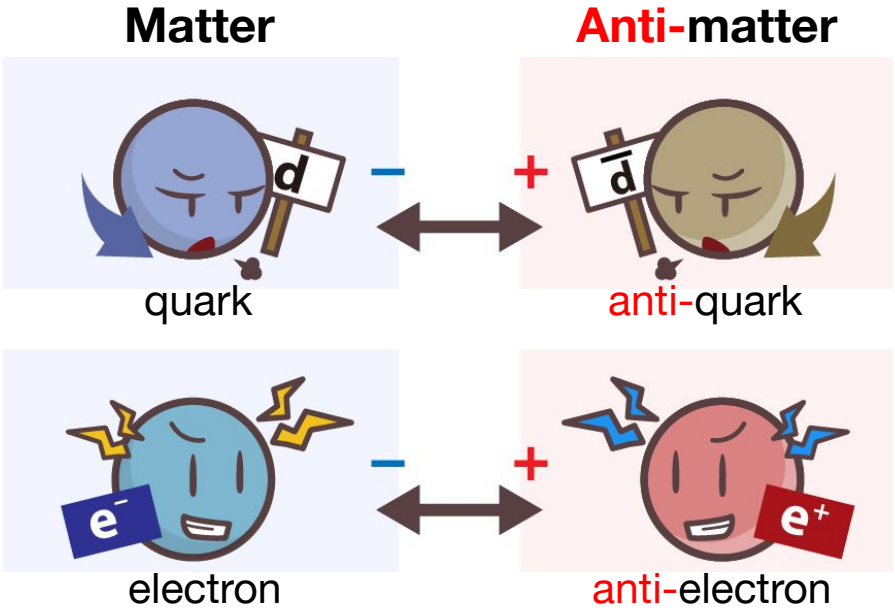
- Neutrinos are:
  - Massless in the Standard Model
  - Electromagnetically neutral
  - Mainly interact via the weak interaction



Matter vs. antimatter

- The **Standard Model** tells us that:
  - Every particle has a **look-alike** with the same properties but **opposite charge**



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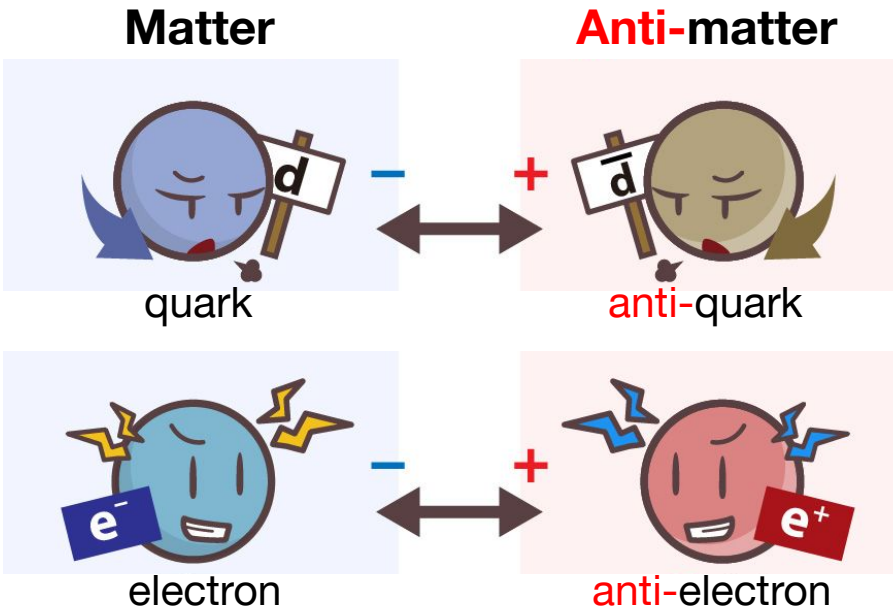
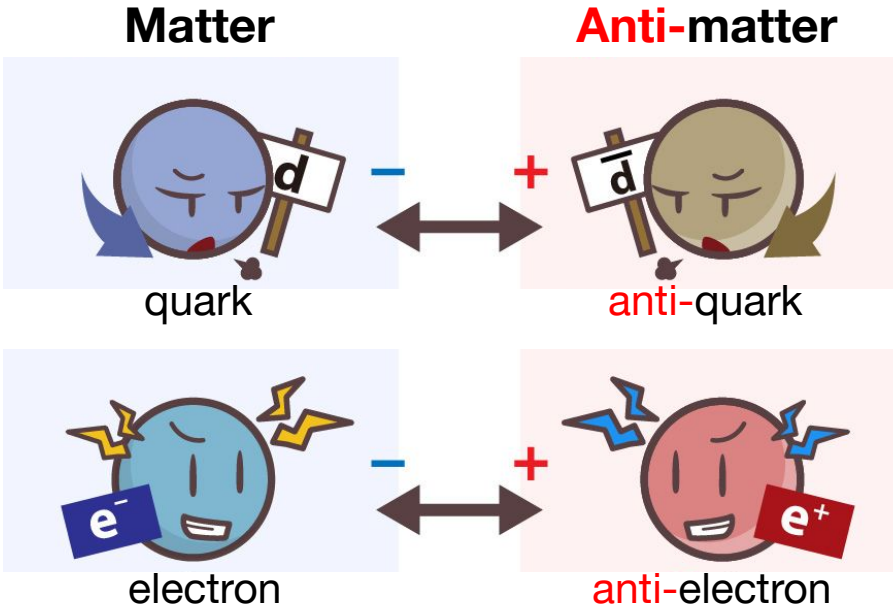


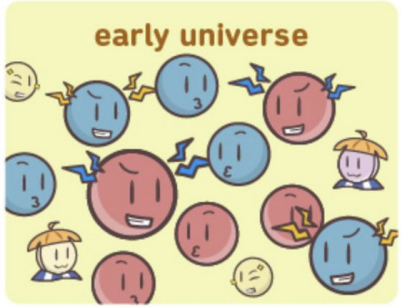
Matter vs. antimatter

- The **Standard Model** tells us that:
  - Every particle has a **look-alike** with the same properties but **opposite charge**
  - Matter and antimatter **annihilate each other**
- Pretty much **everything** in the Universe is made of **matter**



Where is antimatter?

- Scientists believe that at the Big Bang, both **matter and antimatter** were created in **equal amounts**

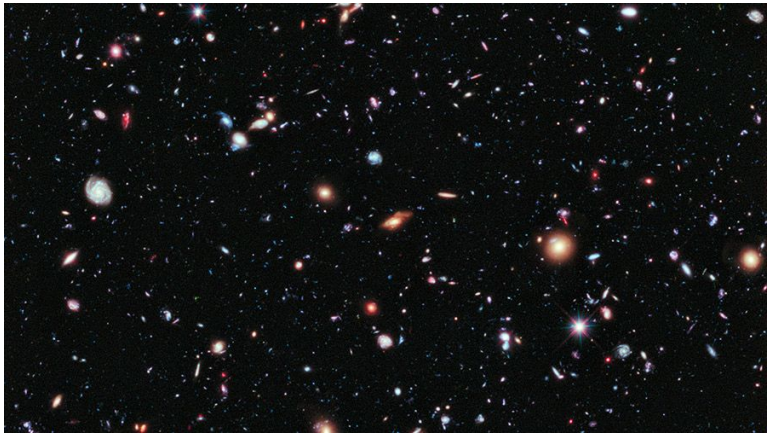


Matter + antimatter

Almost only matter

- Why didn't matter and antimatter destroy each other? Why is today's Universe made almost only of matter? … Why do we even exist?

- Neutrinos may help us understand!

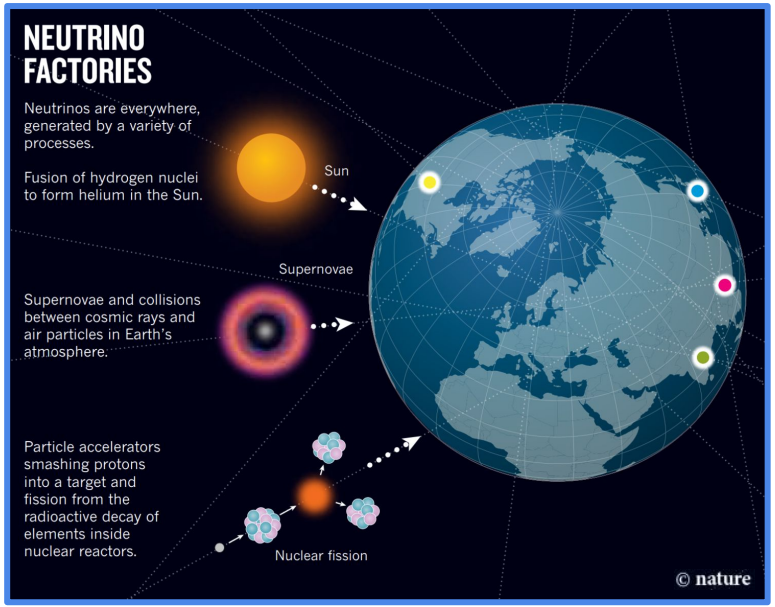


Neutrino oscillations

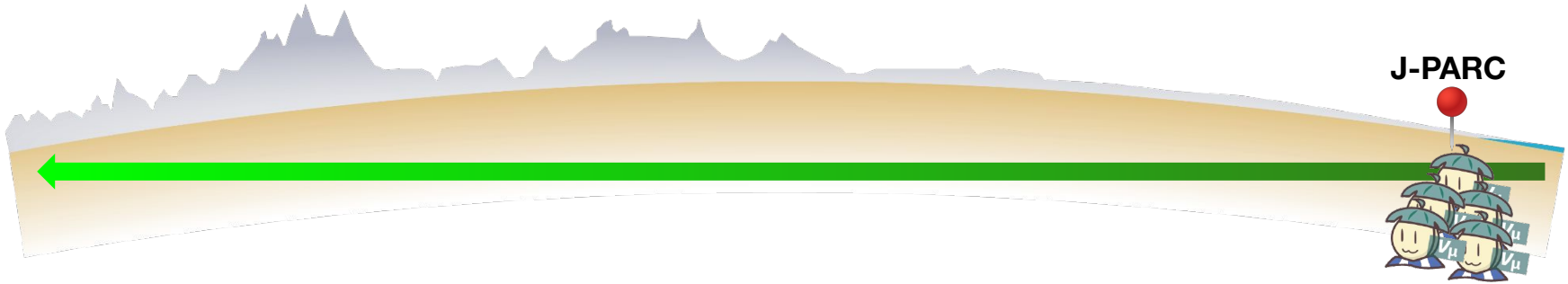
Neutrino oscillations

- Neutrinos are produced everywhere in various ways

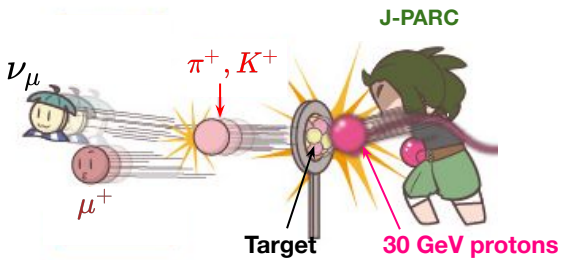
- A recent discovery showed that neutrinos can **change their identity** as they travel: **neutrino oscillations**
(2015 Nobel Prize in physics)

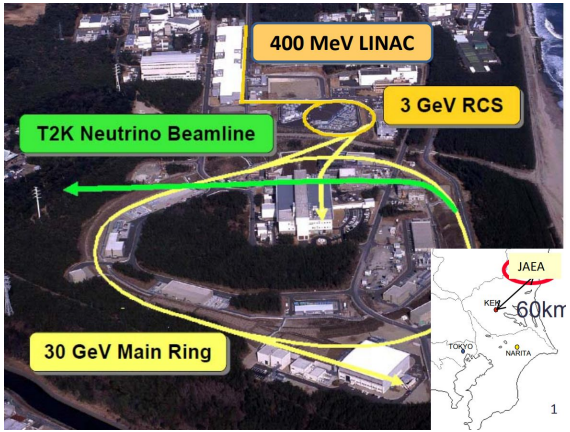


Measuring neutrino oscillations



- Proton beam on graphite target
- Produced *hadrons* decay into muon (anti-)neutrinos





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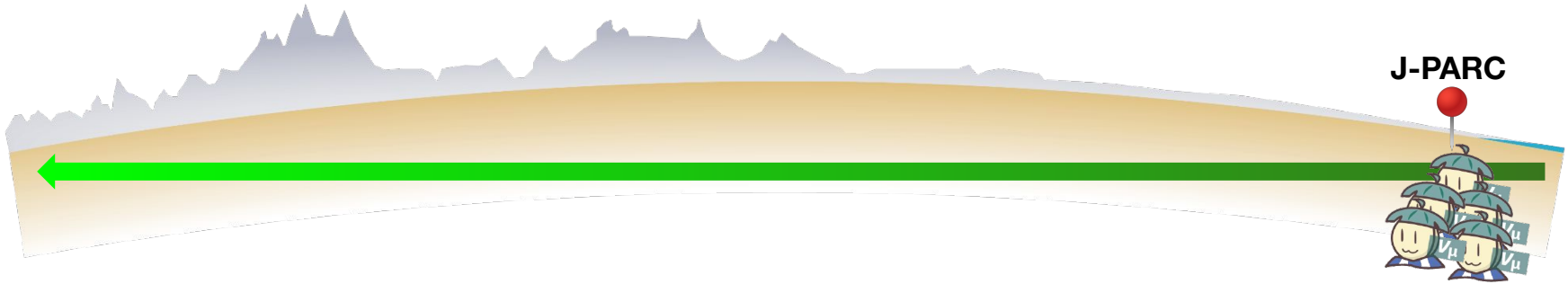

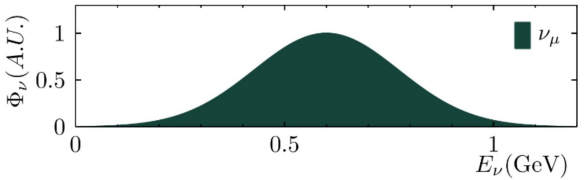

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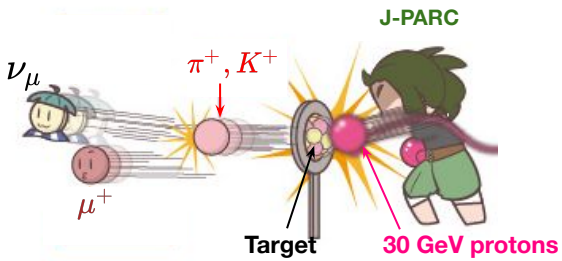

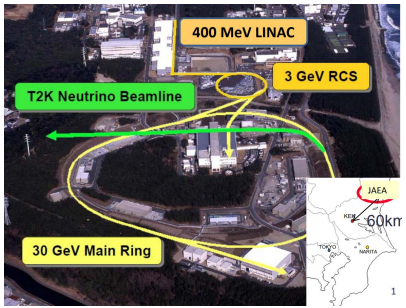

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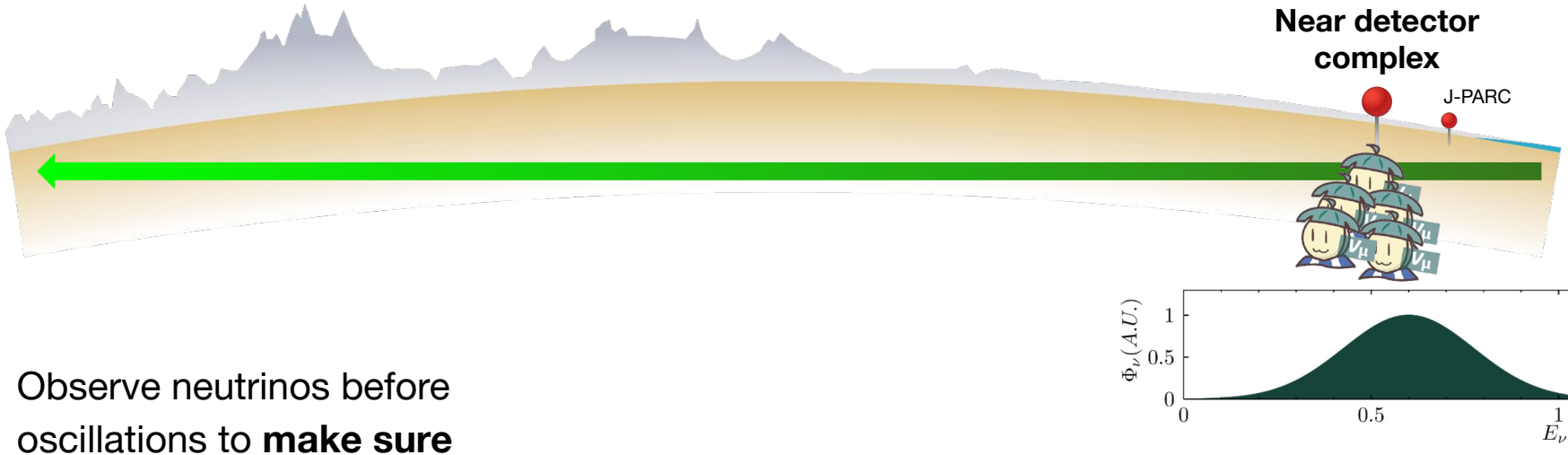

Observe neutrinos before oscillations to **make sure only muon neutrinos are there** (among other things)

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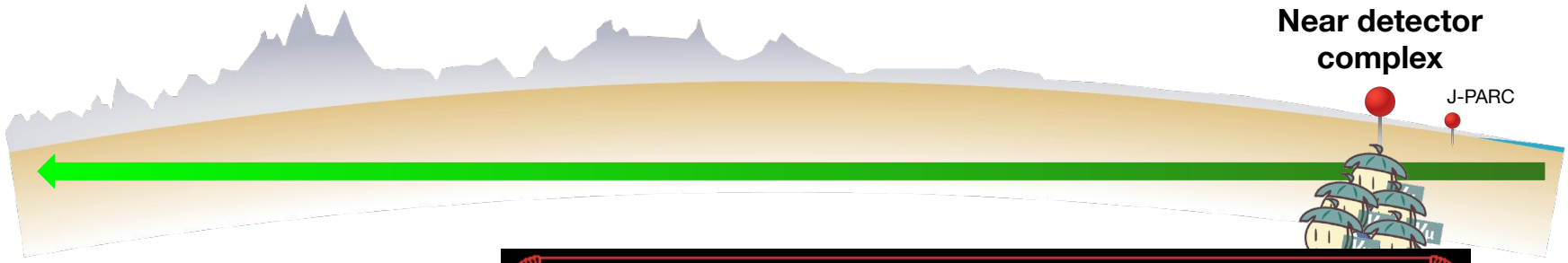

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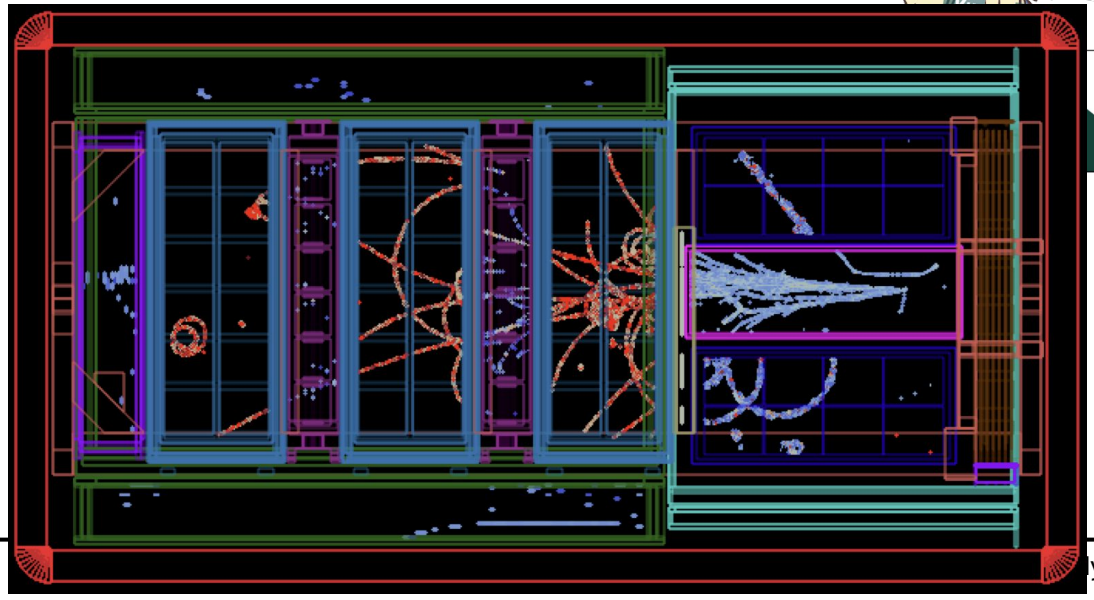

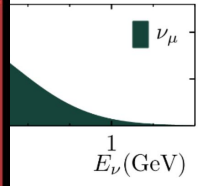

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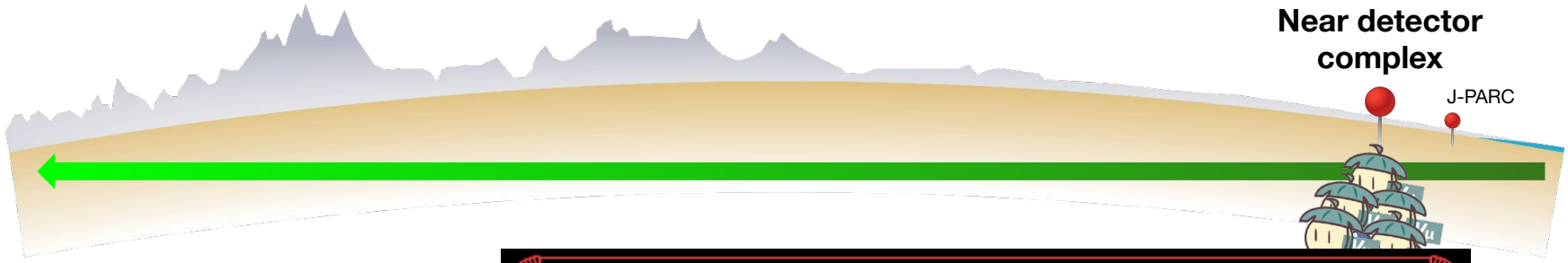

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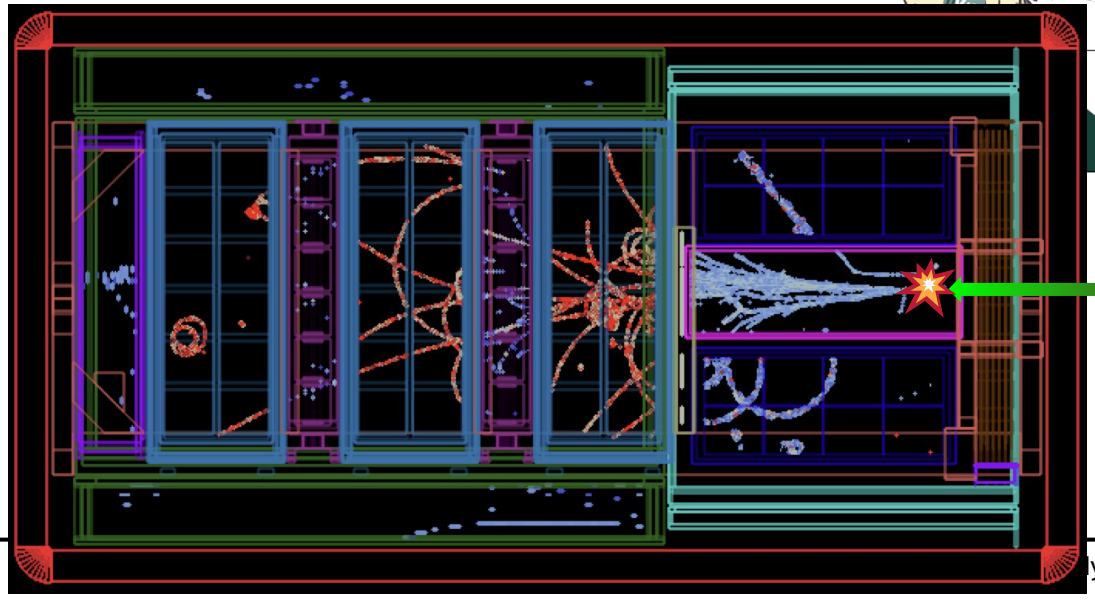

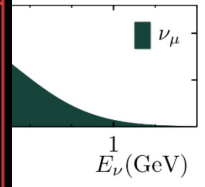

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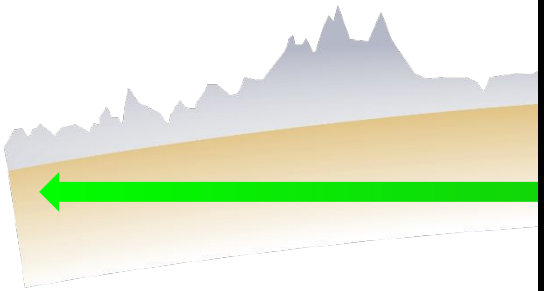

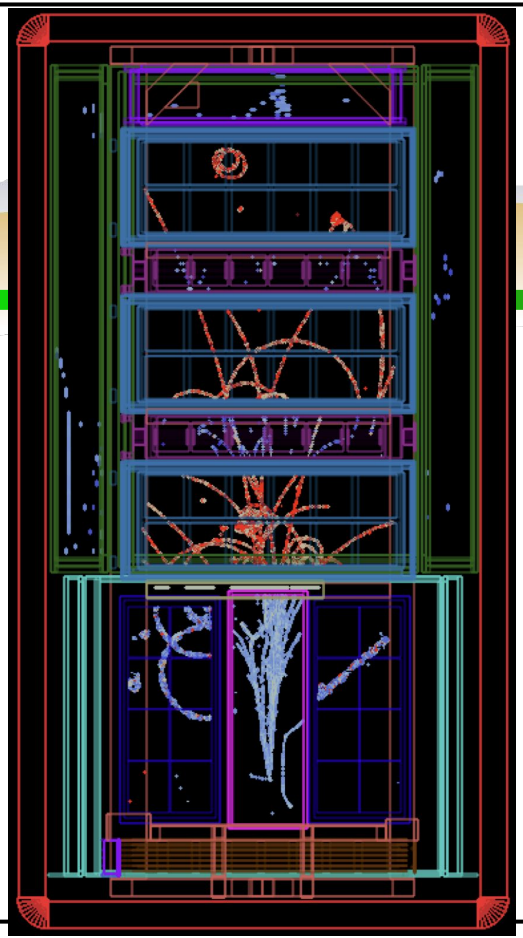

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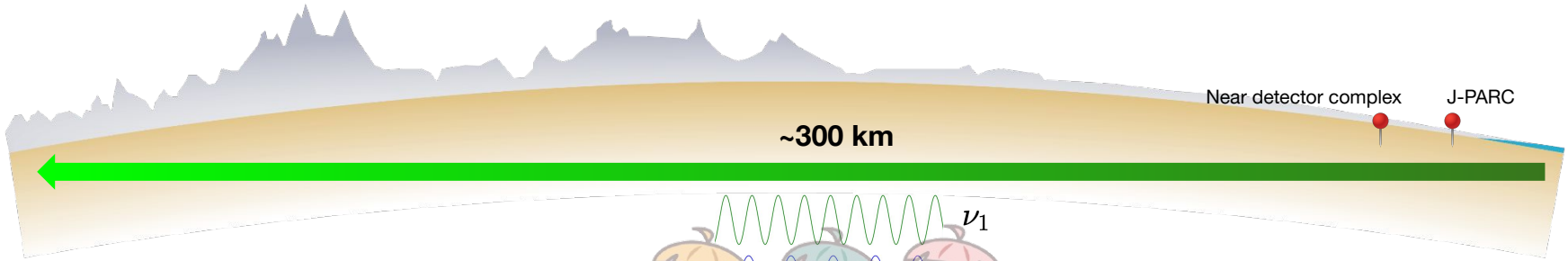
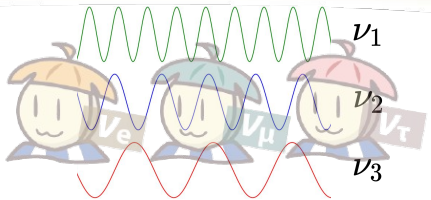
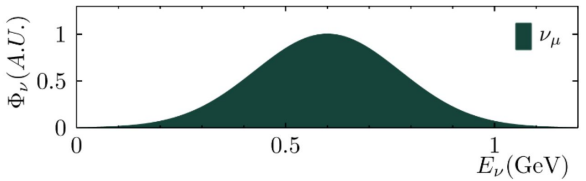


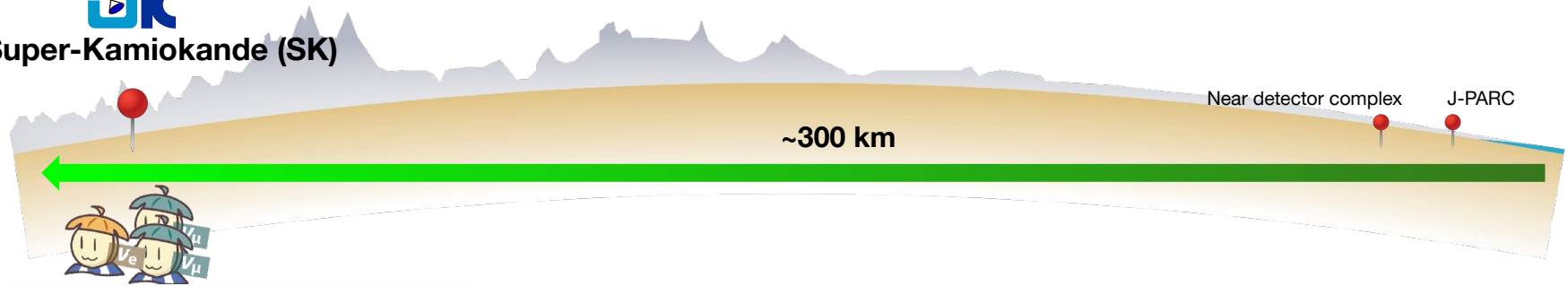


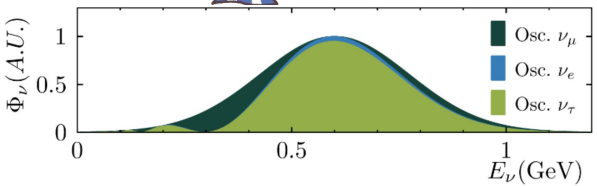
$$|\nu_i\rangle = \sum_{\alpha=e,\mu,\tau} U_{\alpha i} |\nu_\alpha\rangle$$

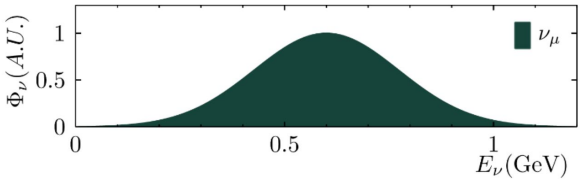


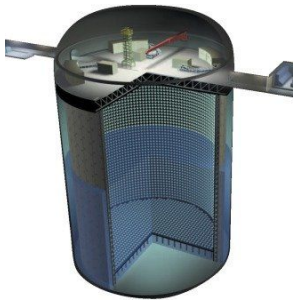
Measuring neutrino oscillations

Super-Kamiokande (SK)









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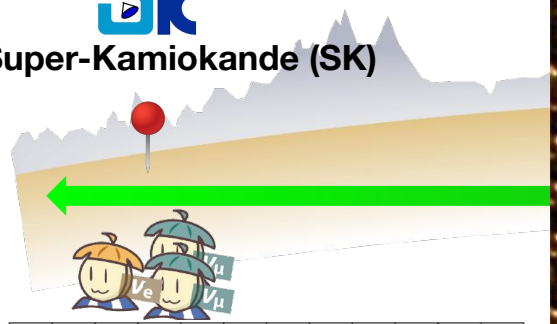

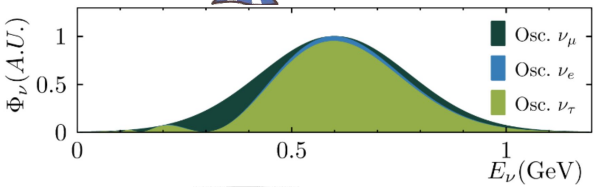

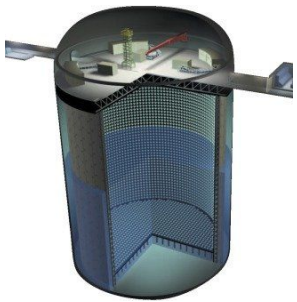

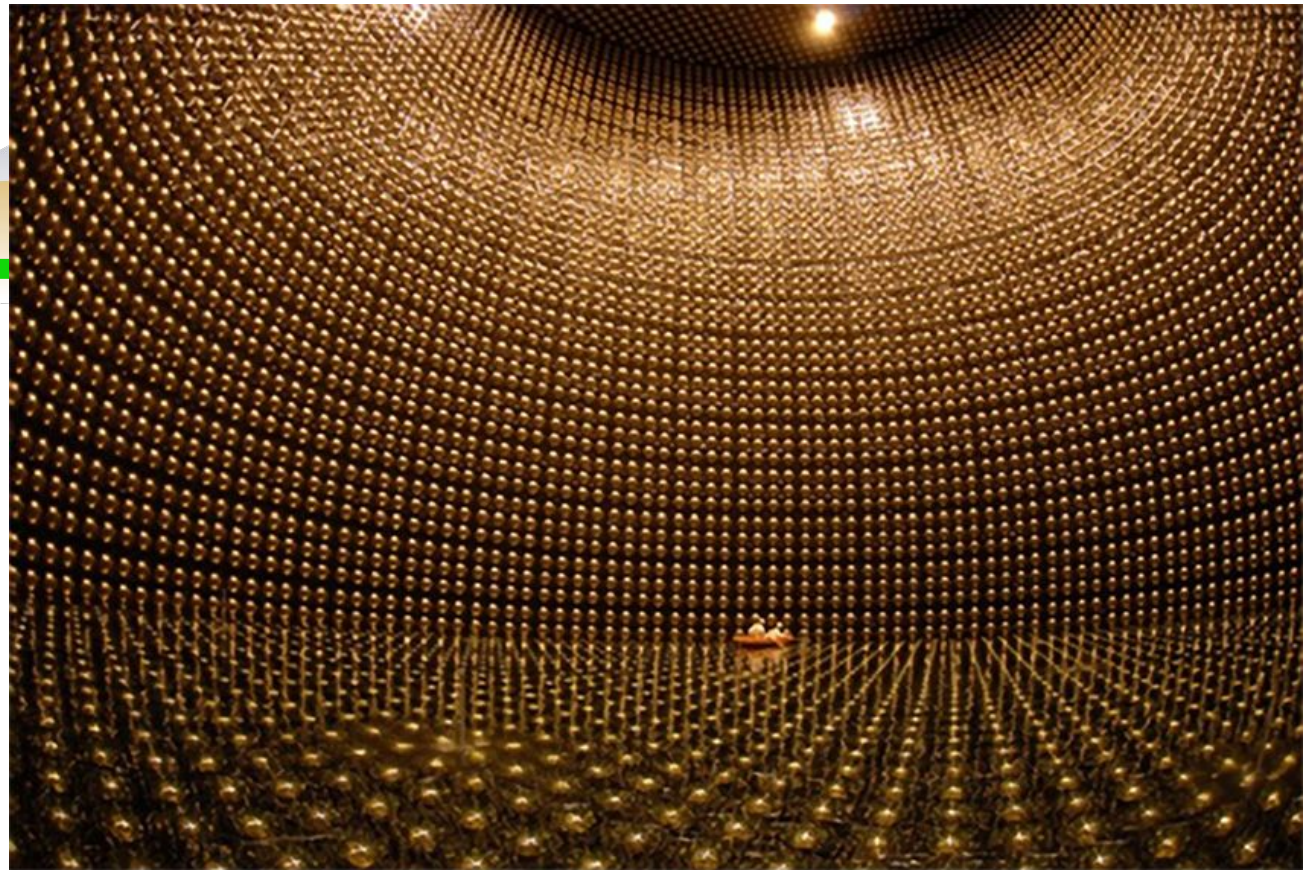

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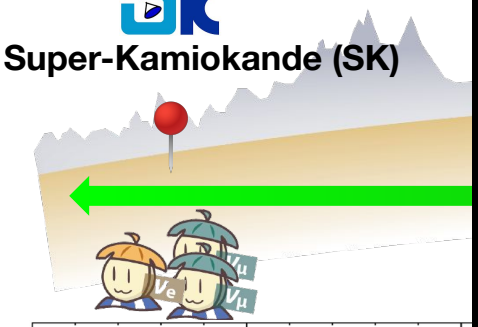
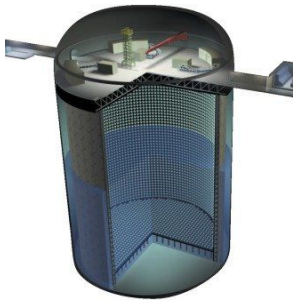
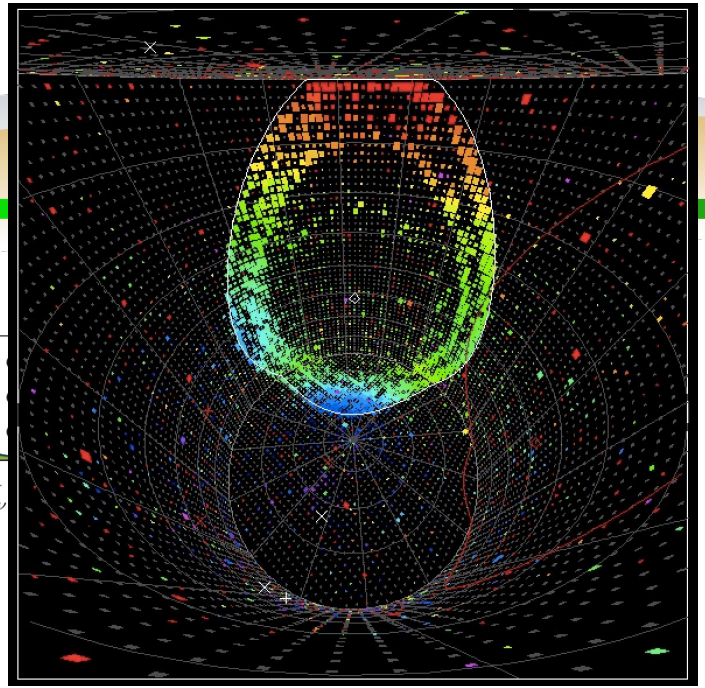
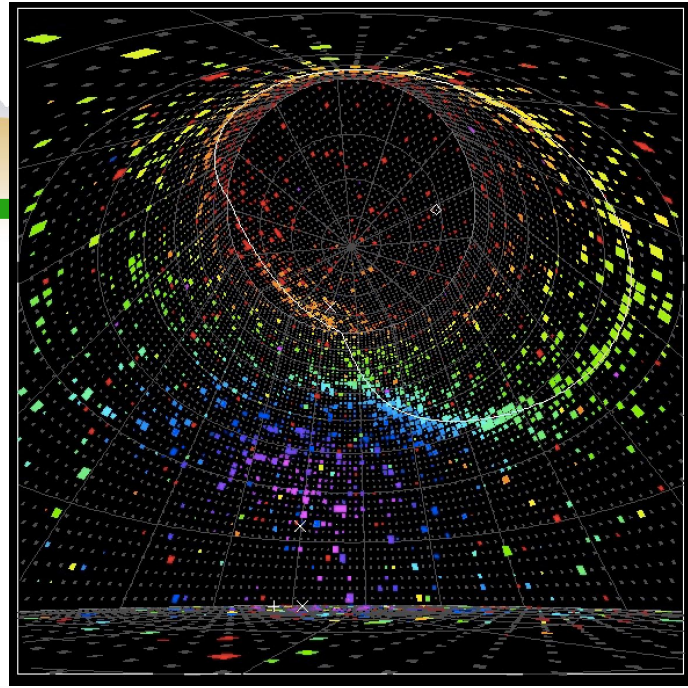
Super-Kamiokande (SK)

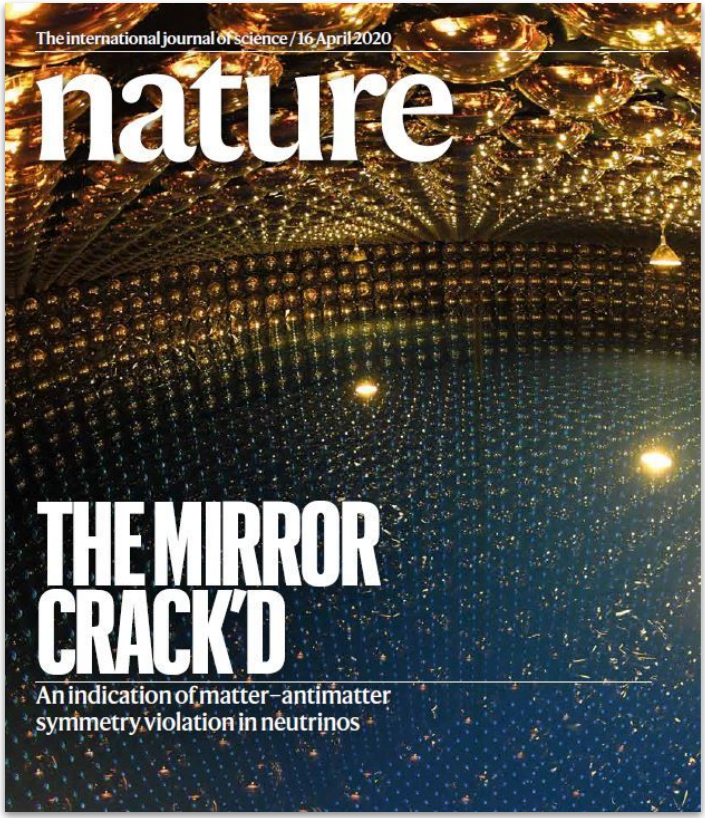








Measuring neutrino oscillations



April 2020

“Our universe is dominated by matter: it makes up everything around us. But physicists have long puzzled over the absence of antimatter. Theories say that antimatter should have been produced by the Big Bang just as matter was and in equal amounts. Now a huge experiment in Japan may have found a subtle imbalance which could help explain why our universe is the way it is.”

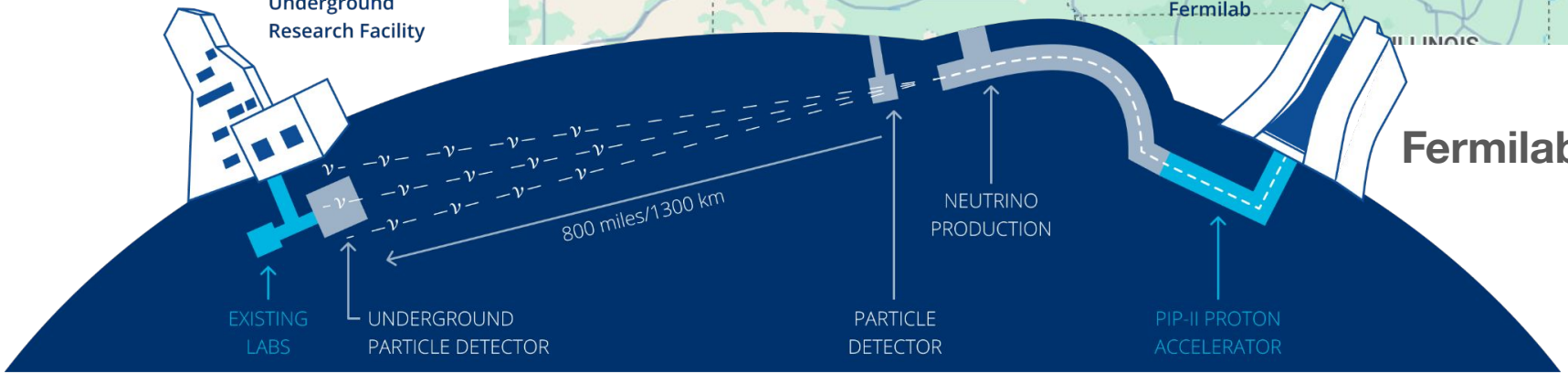
https://www.nature.com/articles/d41586-020-01117-x

T2K has found **indications of a difference between oscillations for neutrinos and antineutrinos…**

Still a **very long way** to go to make a definite statement!

Future of neutrino oscillations

Similar idea as T2K, but **much larger** and with **new particle detection technologies**

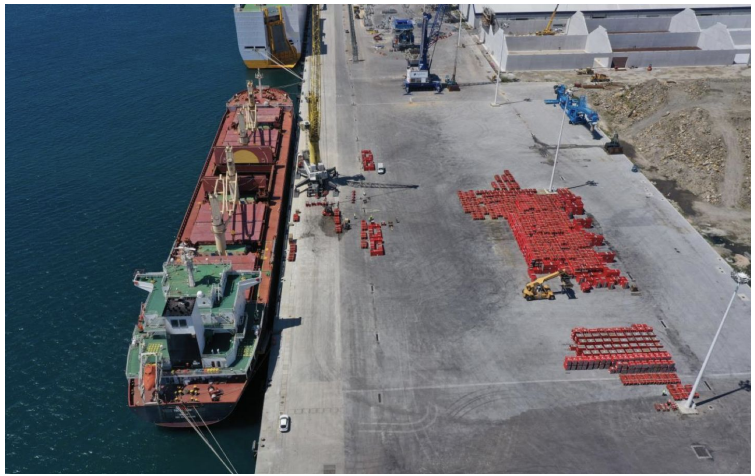


DUNE under construction

Excavation of the South Dakota site is complete

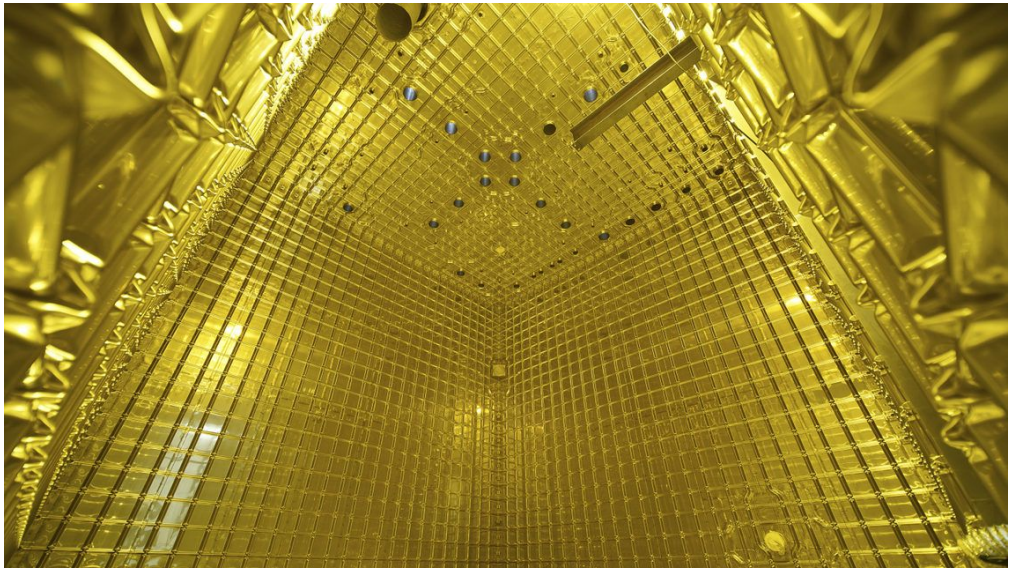
DUNE under construction

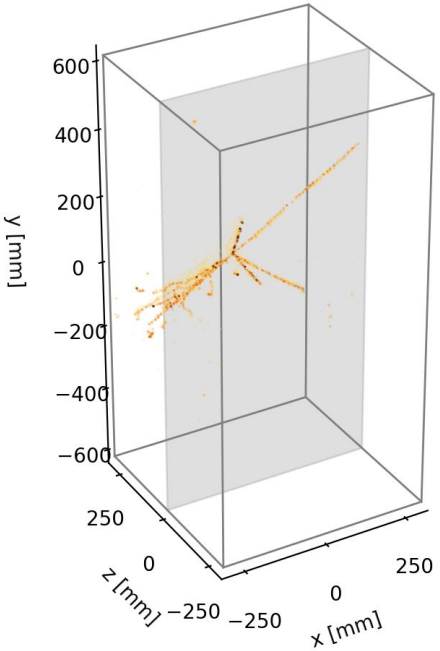
Excavation of the South Dakota site is complete



Detectors are on their way on a ship across the Atlantic

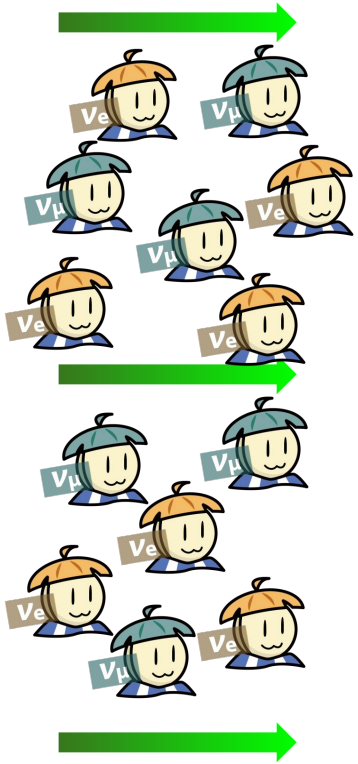
New detectors!

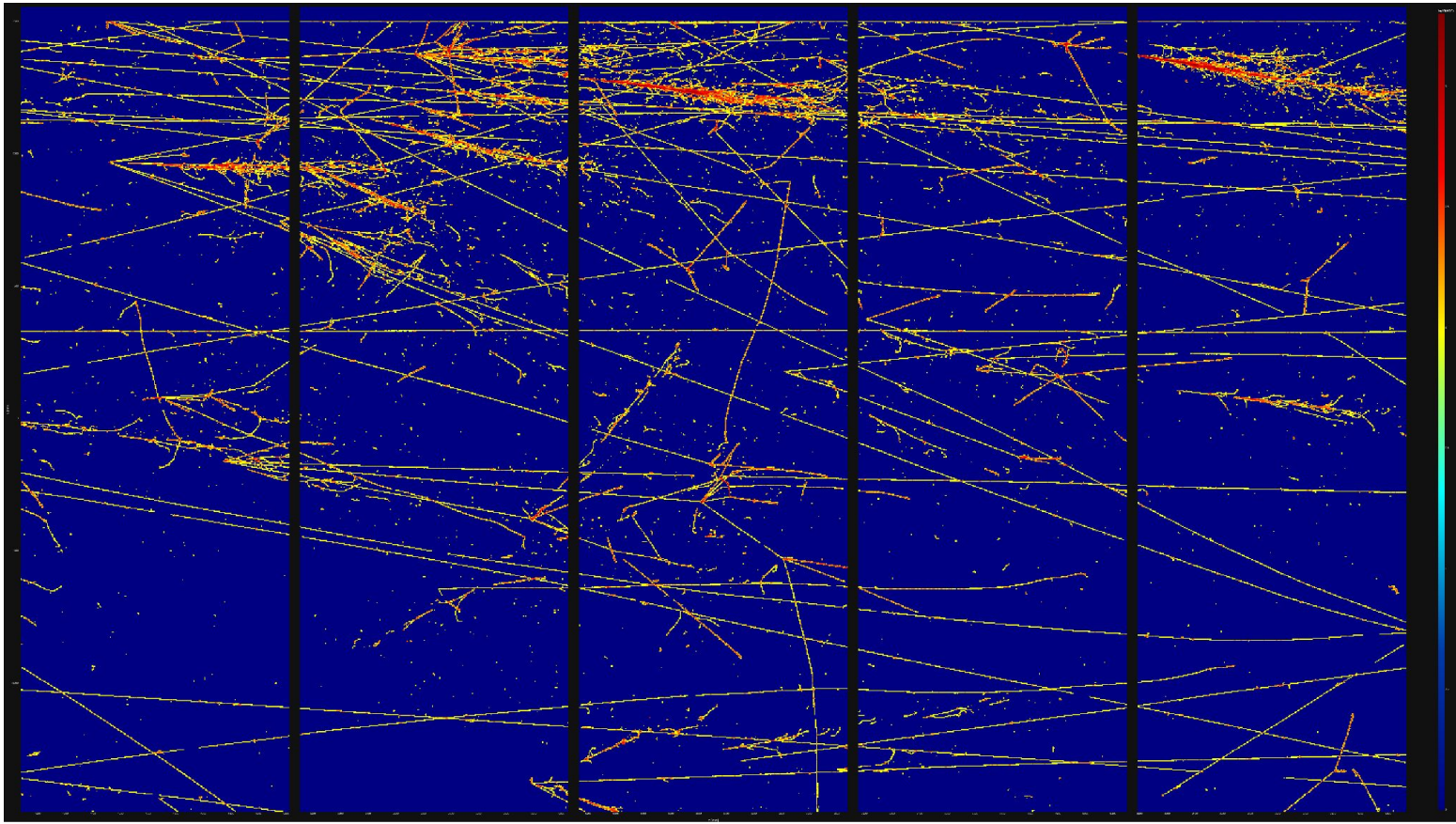




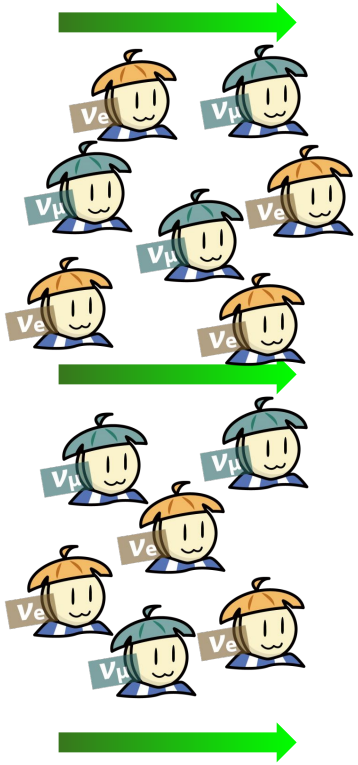
- New detectors using novel **liquid argon** technology, with new challenges:
  - Very high purity
  - Very low temperature (-190 degrees Celsius)
  - Too many neutrinos!

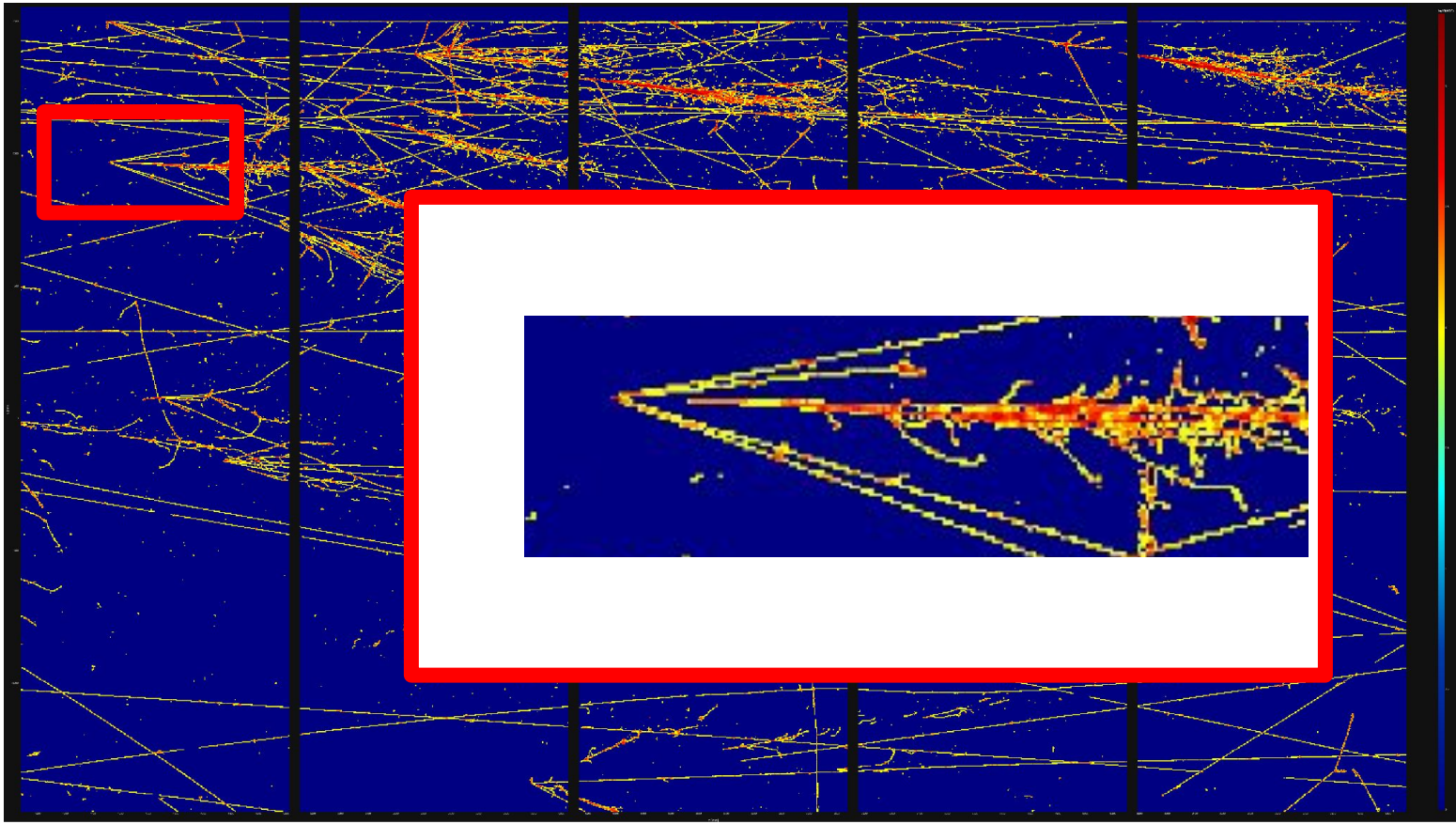
New detectors!





New detectors!





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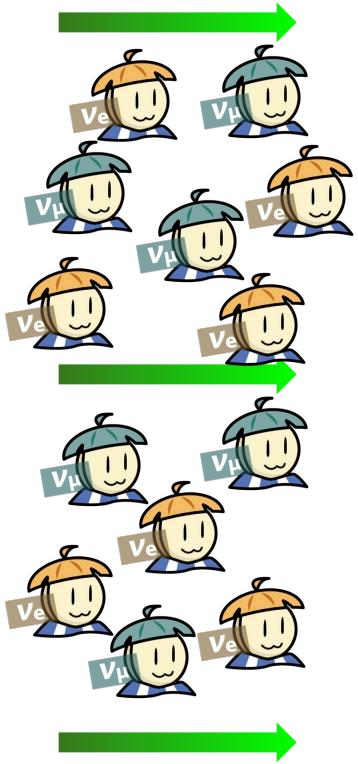

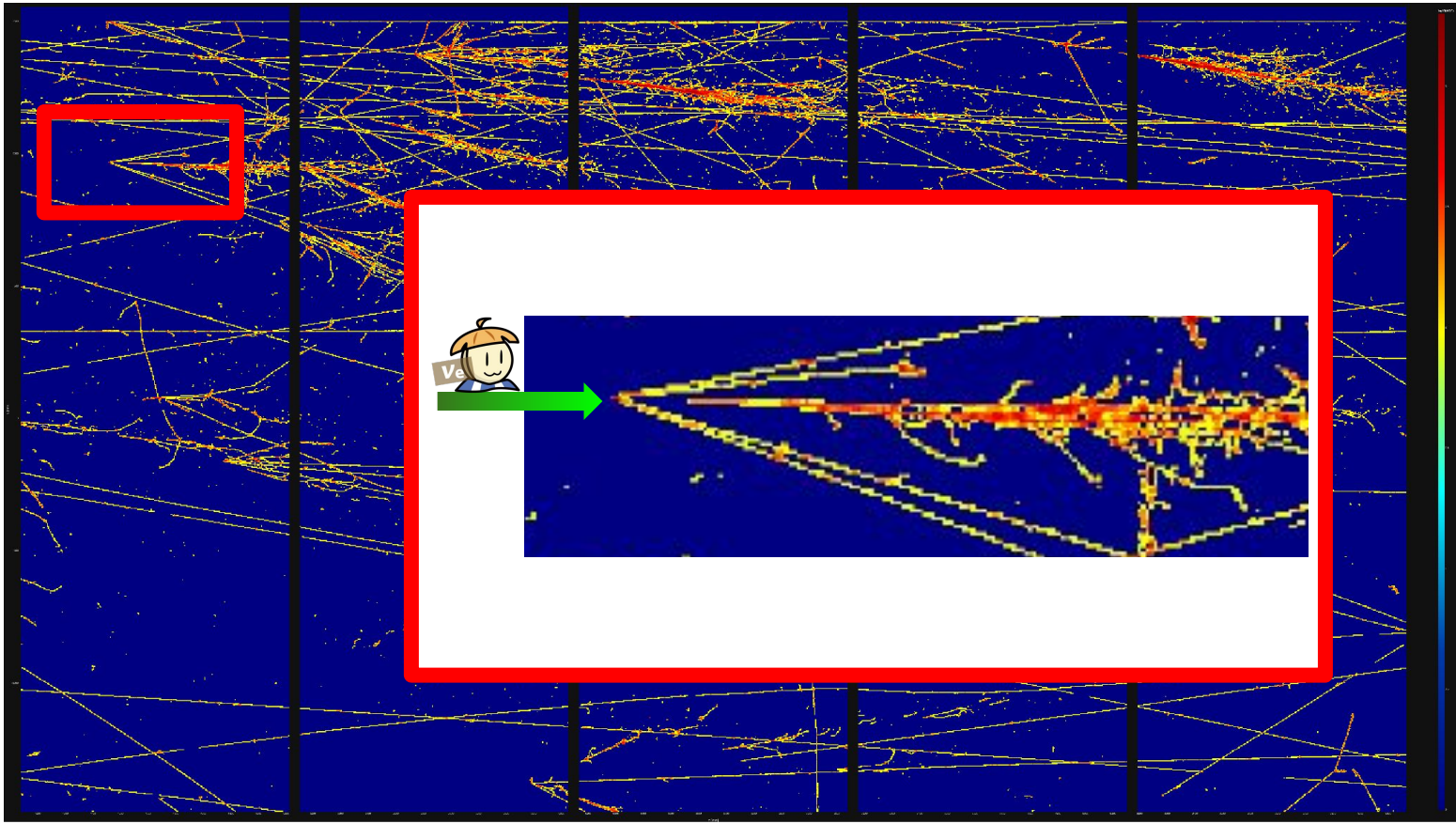

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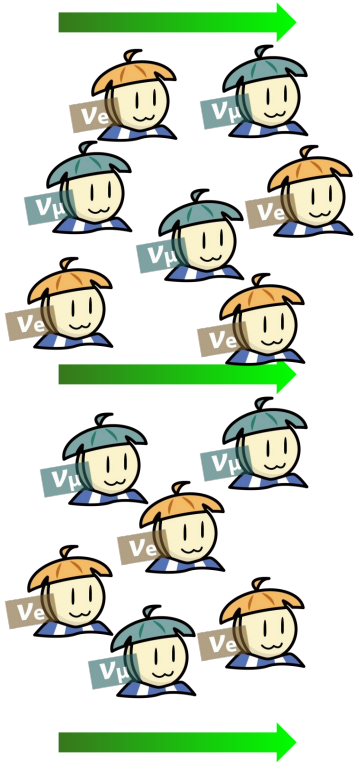
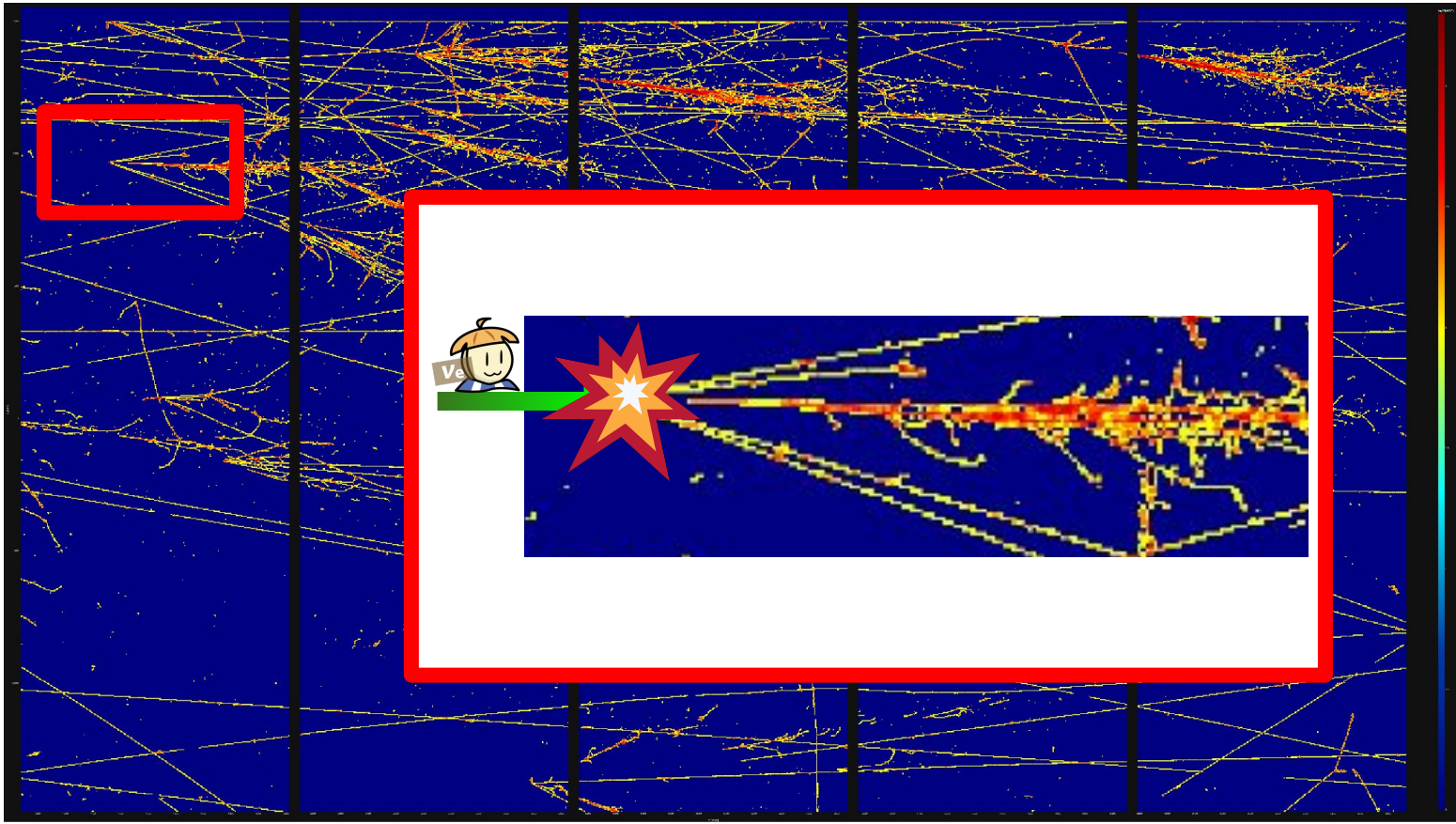
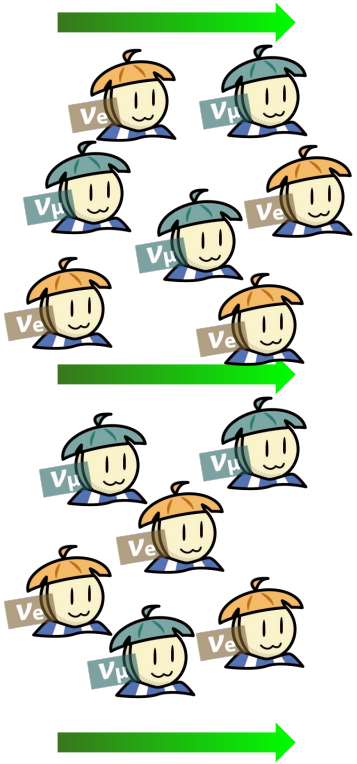
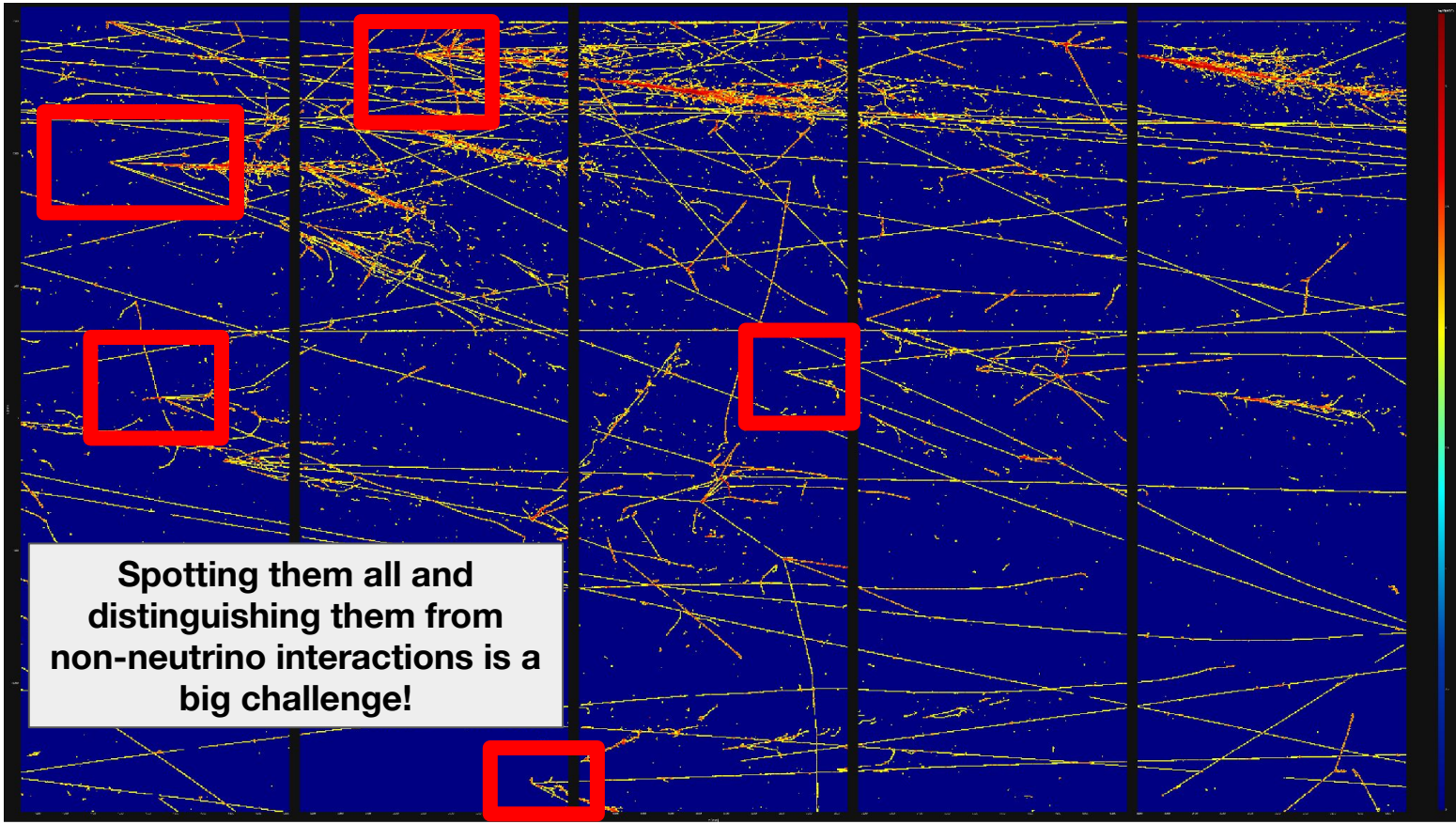




New detectors!





Conclusion

Conclusion

- Neutrinos could hold the key of explaining why the Universe is dominated by matter through the phenomenon of **neutrino oscillations**
- **First indications** that support this has been shown by the T2K experiment in Japan
- We won't be able to make a definitive conclusion until the **new generation of detectors starts taking data**
- By the time these new detectors are installed, **you** could actually be working on this to help physicists **reach these conclusions**!