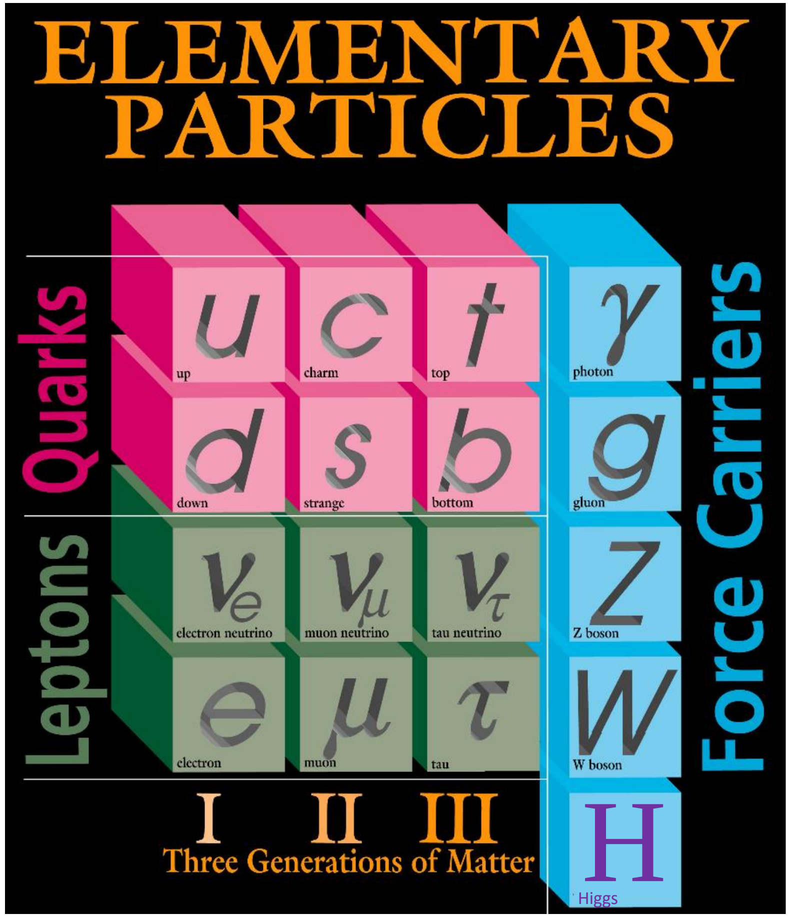
NOvA Experiment

Neutrino Oscillation Activity

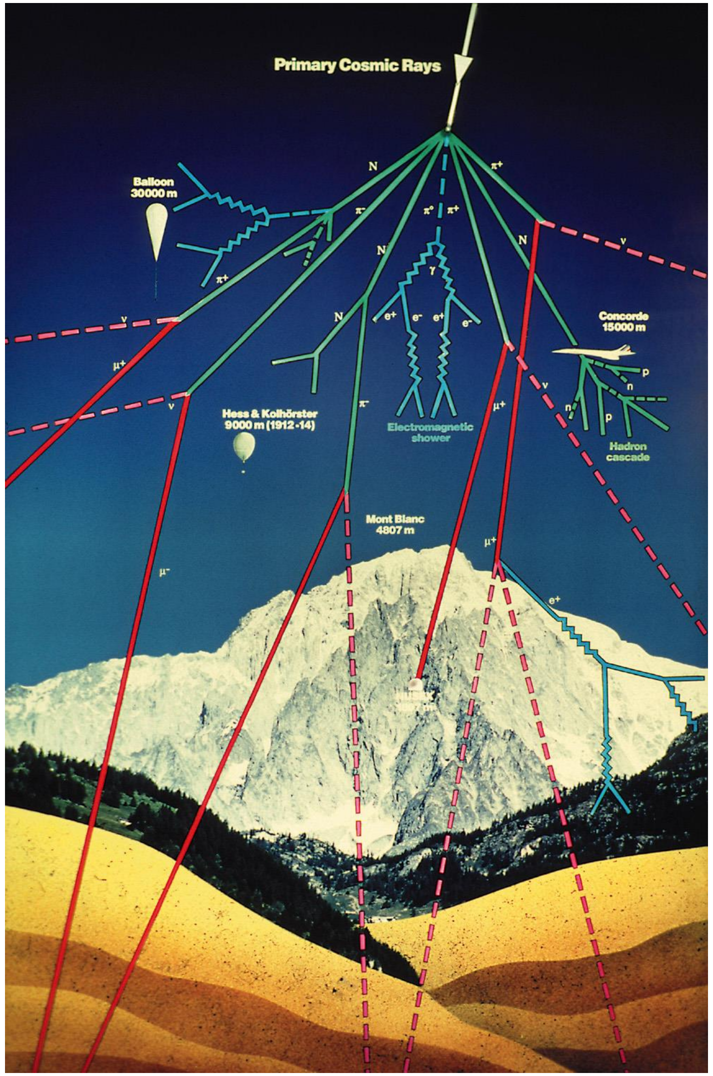
Building Blocks of the universe



Standard Model of Particle Physics

- Forcing carrying bosons
- Three generations of fermions
  - Quarks
    - 3 positively charged quarks
    - 3 negatively charged quarks
    - Make up protons, neutrons, etc
  - Leptons
    - 3 charged leptons
    - 3 neutral leptons

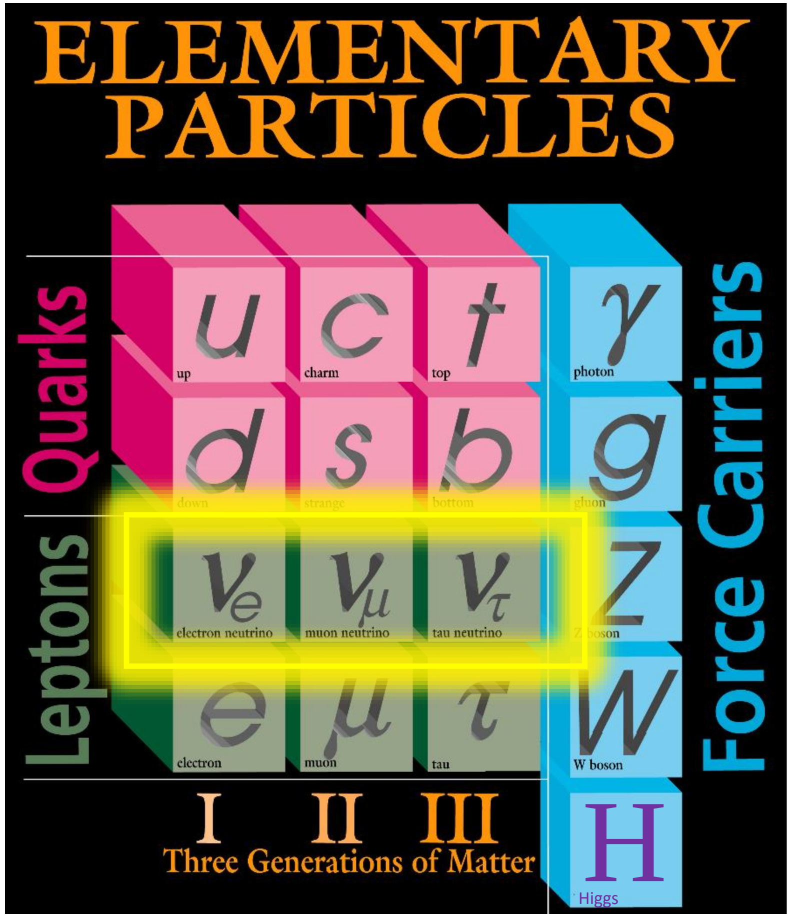
Heavy cousins of the electron



Heavier versions of the electron

- **Muon – μ**
  - 200 times the electron mass
  - Lifetime of 2 μs
  - Interact with us as cosmic rays
  - Θ(1) through hand each second
  - Θ(10%) daily radiation exposure
- **Tau – τ**
  - 3,500 times the electron mass
  - Lifetime of 0.3 ps

What about the neutrinos



Neutrinos are probably the least understood Standard Model particle

We've known about them for ~100 years

2nd most abundant particle in universe

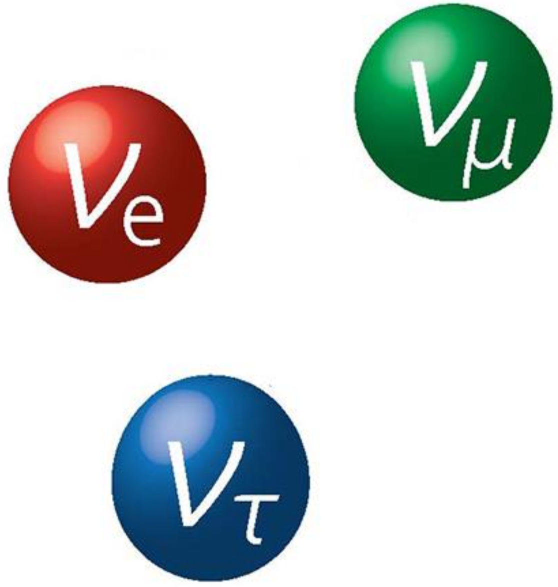
Θ(100 million) per cubic meter

100 billion solar neutrinos pass through your finger nail each second

Why do we know so little …

… because they're weird!

What about the neutrinos

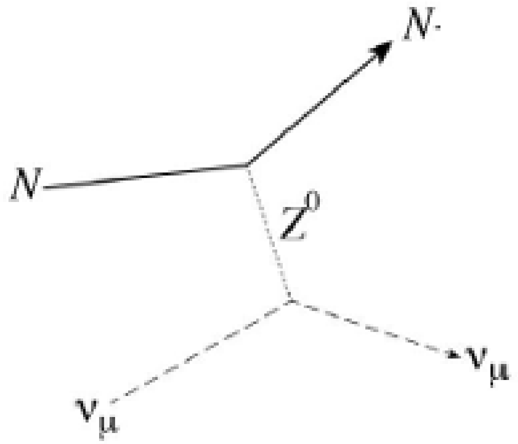


Why they're weird

- No electric or color charge
  - No EM or strong interactions
- Extremely tiny mass
  - At least a million times less massive than an electron

Only interact through weak force and gravity

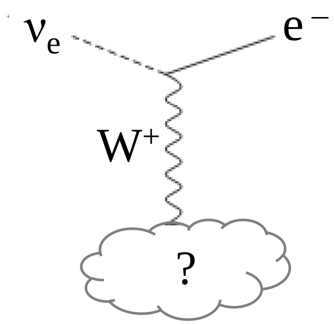
- Gravity is so weak
  - Only observed in cosmology
  - Completely ignorable at particle level
- Weak interaction important at particle level
  - Mediated by W & Z bosons with mass
    - $M_{Z,W}$ typically greater than ν energy



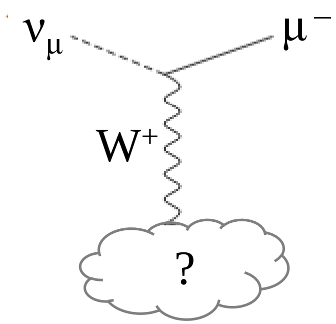
Neutrino Flavor

Identify neutrino flavor through charged-current (CC) interaction

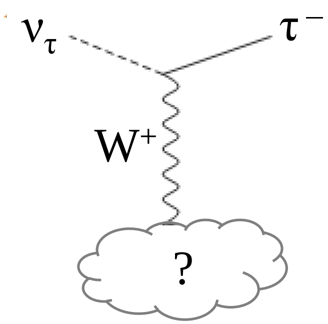
Electron Neutrino



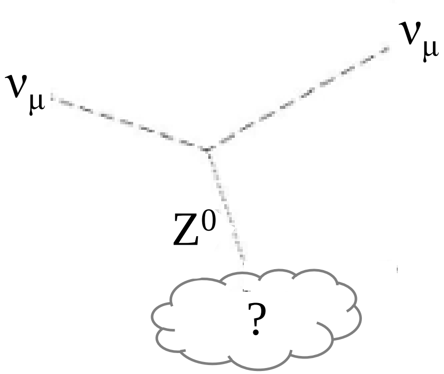
Muon Neutrino



Tau Neutrino



Neutral Current Interaction

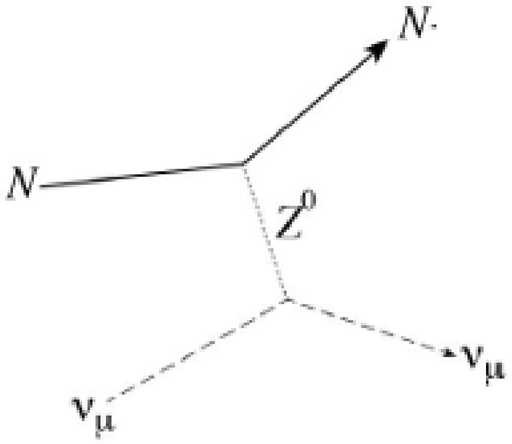


Neutrinos Rarely Interact

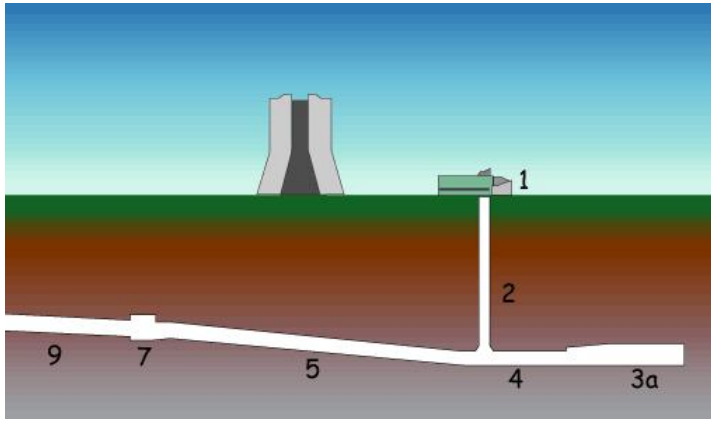
Shoot a neutrino through a infinite long slab of lead
It most likely won't interact until it has spent
over 1 year traveling through the material

ν ⟶

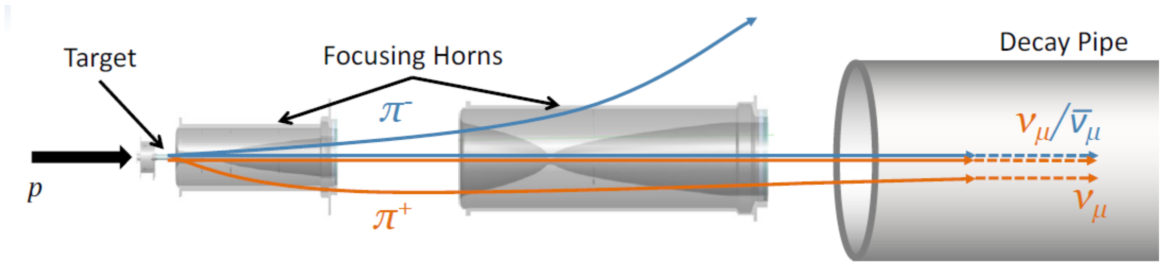
ν at typical energies

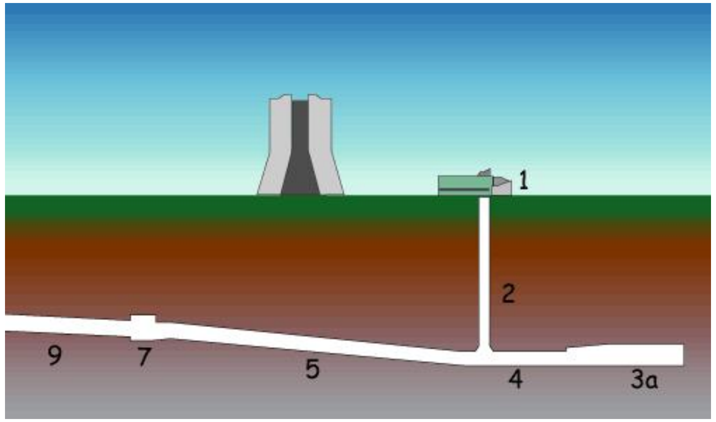


NOvA Experiment



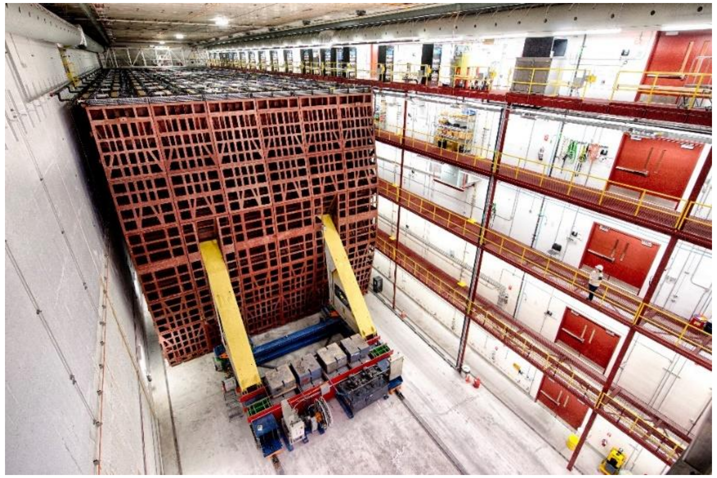
NOvA Neutrino Beam

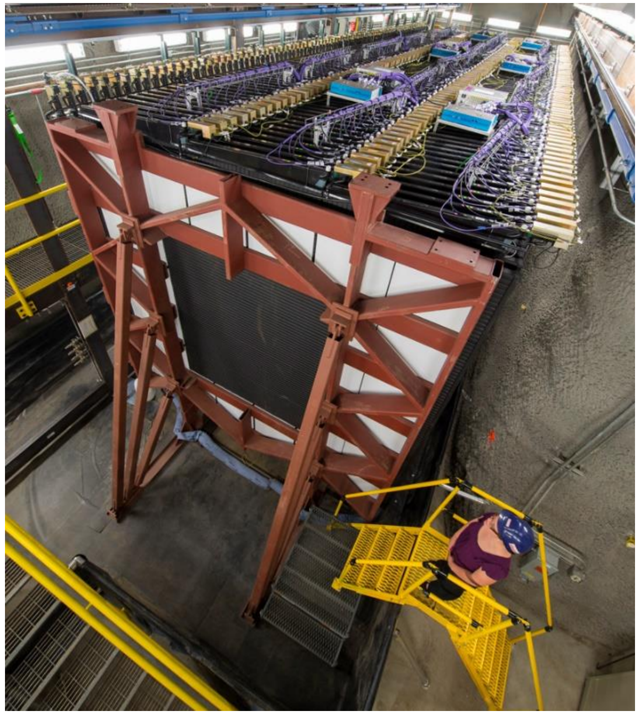


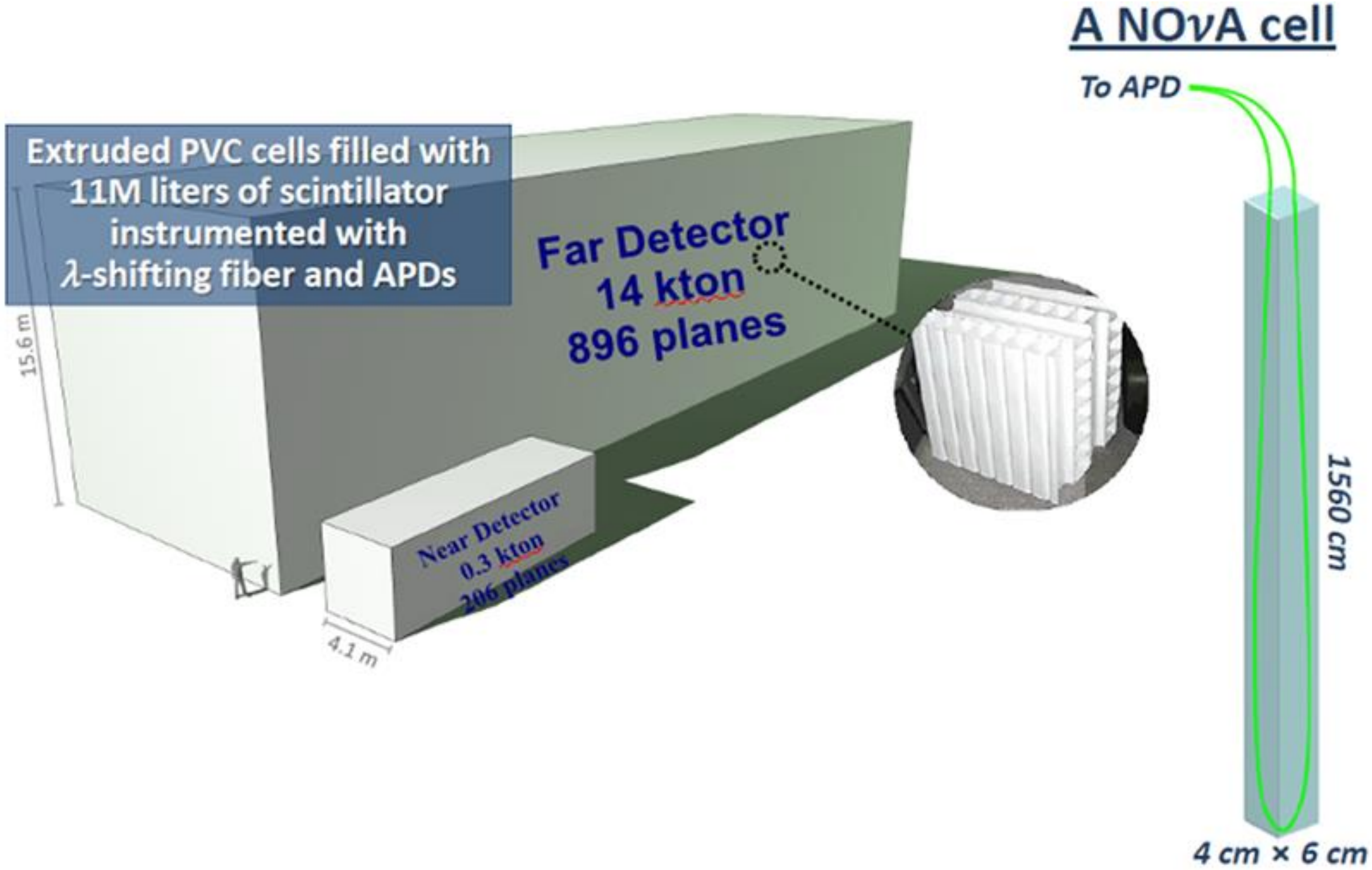


Number of neutrinos produced is proportional to the number of protons on target

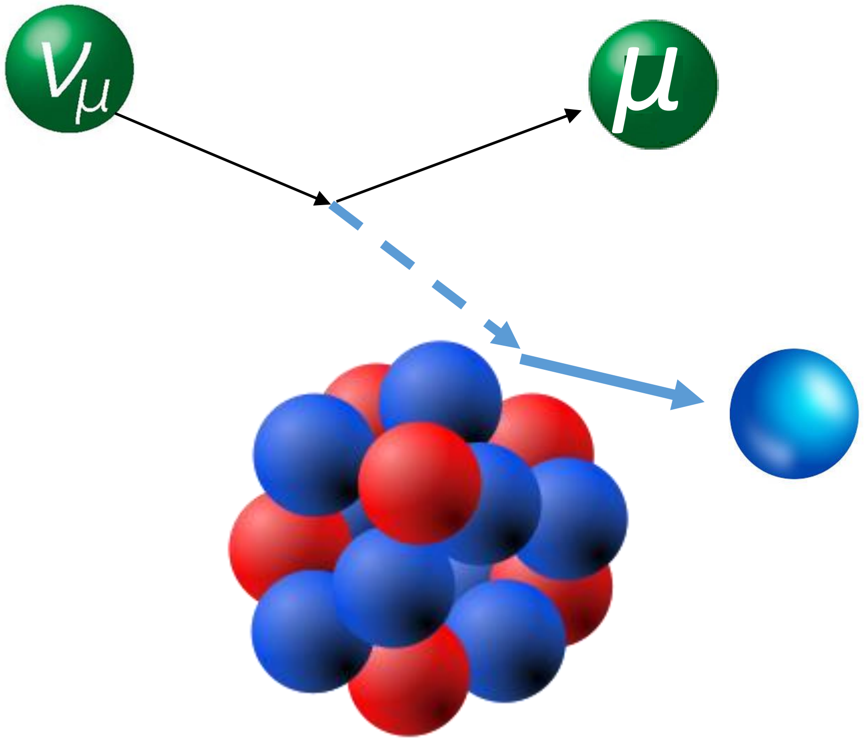
NOvA Detectors





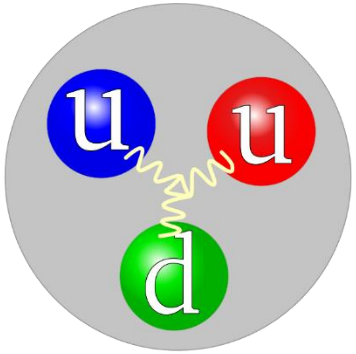


Neutrino Interactions



Nucleus

Proton



Neutrino Flavor

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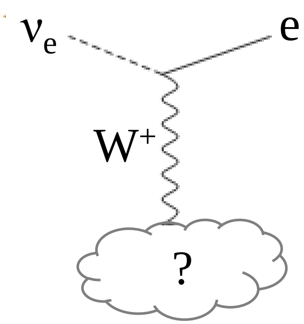
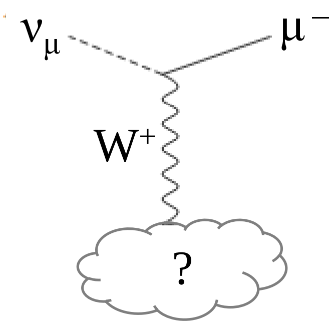
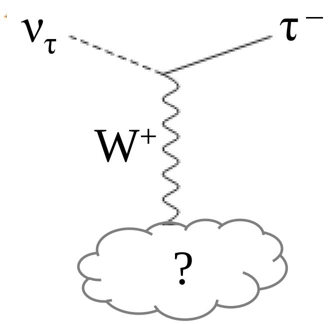
Electron Neutrino



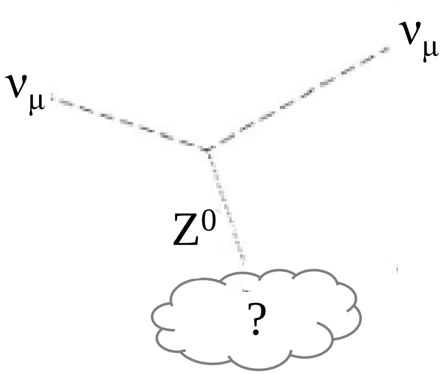
Muon Neutrino



Tau Neutrino

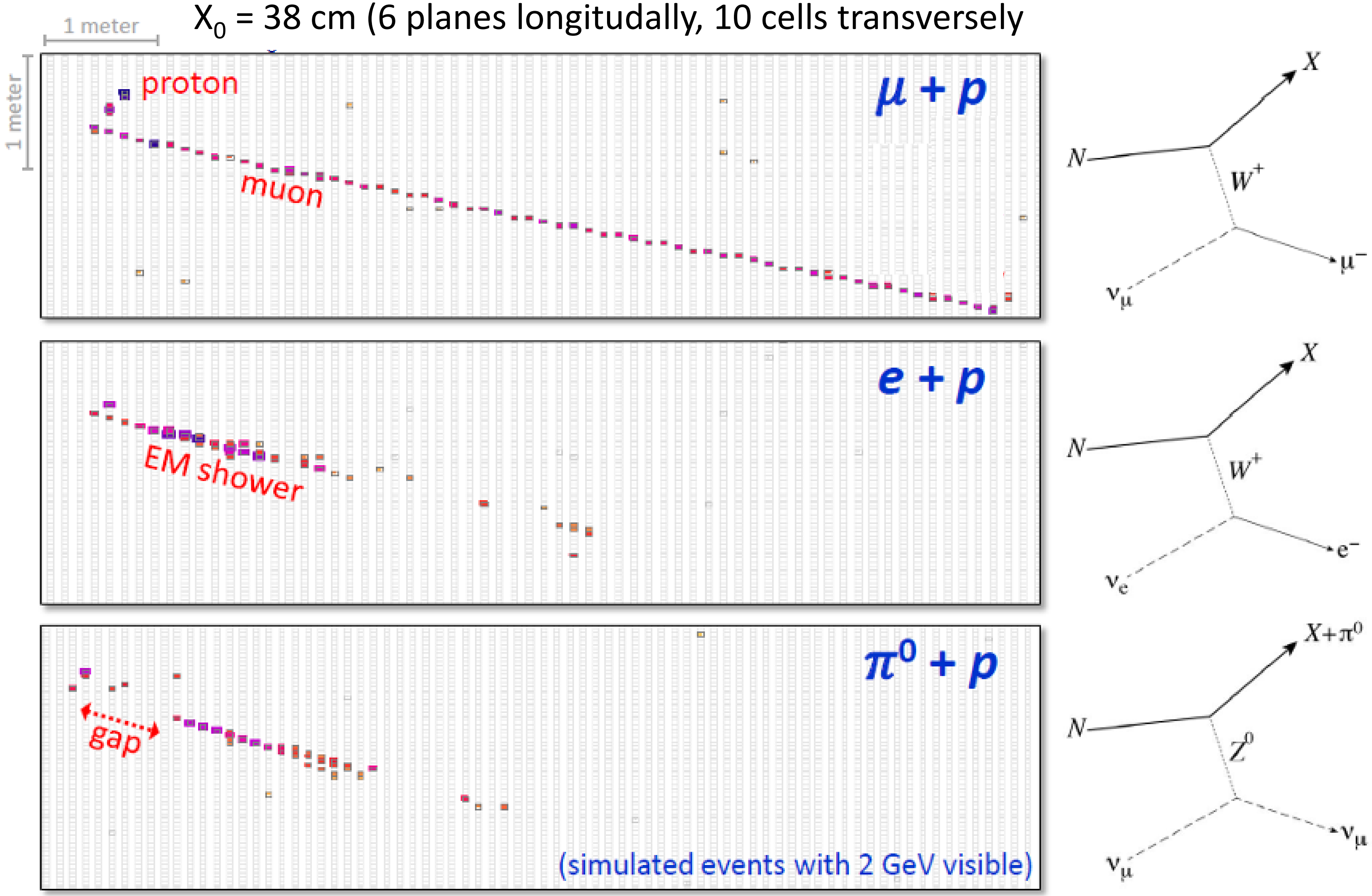


Neutral Current Interaction



Neutrino Interactions

X_0 = 38 cm (6 planes longitudally, 10 cells transversely



NOvA Activity

Look at images of neutrino interactions (Event Displays)

Start by looking at events in the NOvA Near Detector (1 km from neutrino production target)

Try to count the number of muon neutrino interactions vs the number of background interactions

Finish by looking at events in the NOvA Far Detector (810 km from neutrino production target)

Try to count the number of muon neutrino interactions vs the number of background interactions

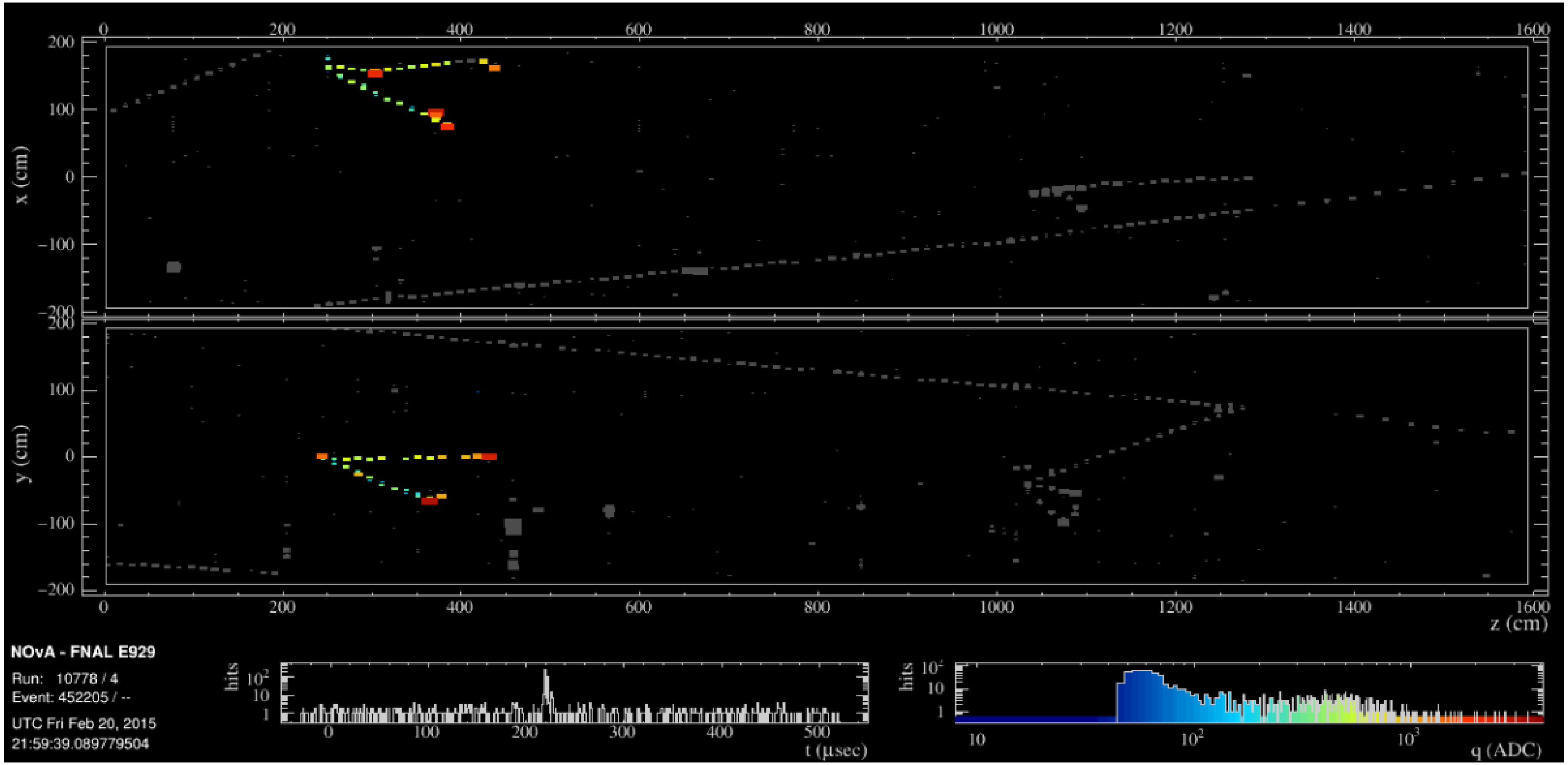
Discuss observations

About the event displays

There are two views

- One in which all of the cells are vertical
- One in which all of the cells are horizontal

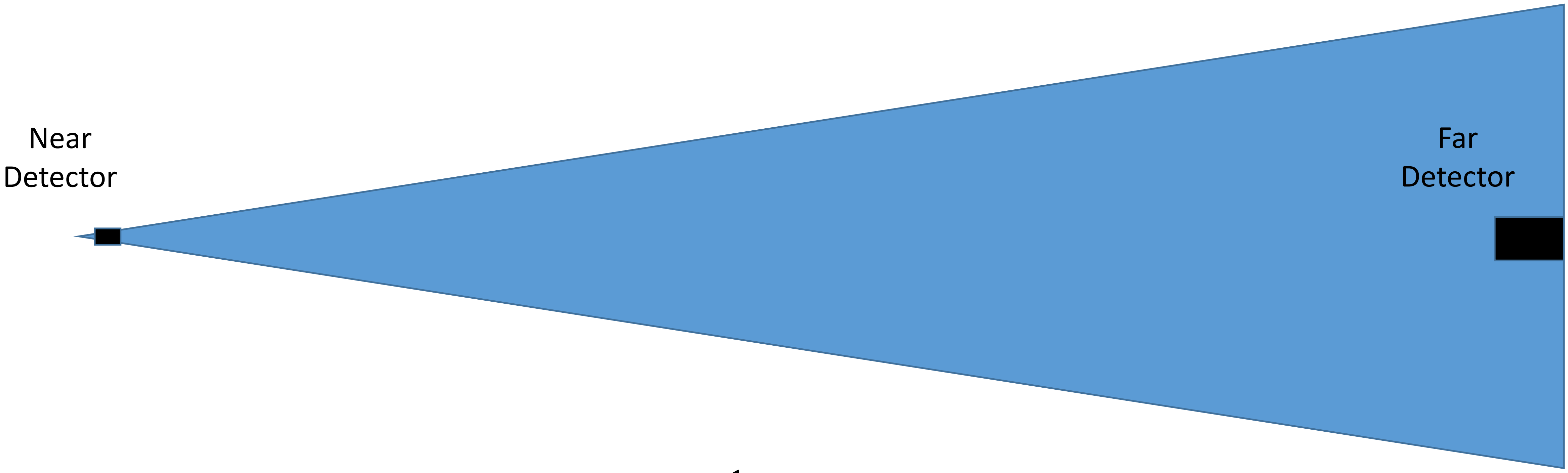
Color indicates energy that is deposited in the cell by the particle



Notes about the Near Detector

The near detector is much closer to the neutrino source than the far detector

$\rightarrow$ greater flux of neutrinos passing through the near detector



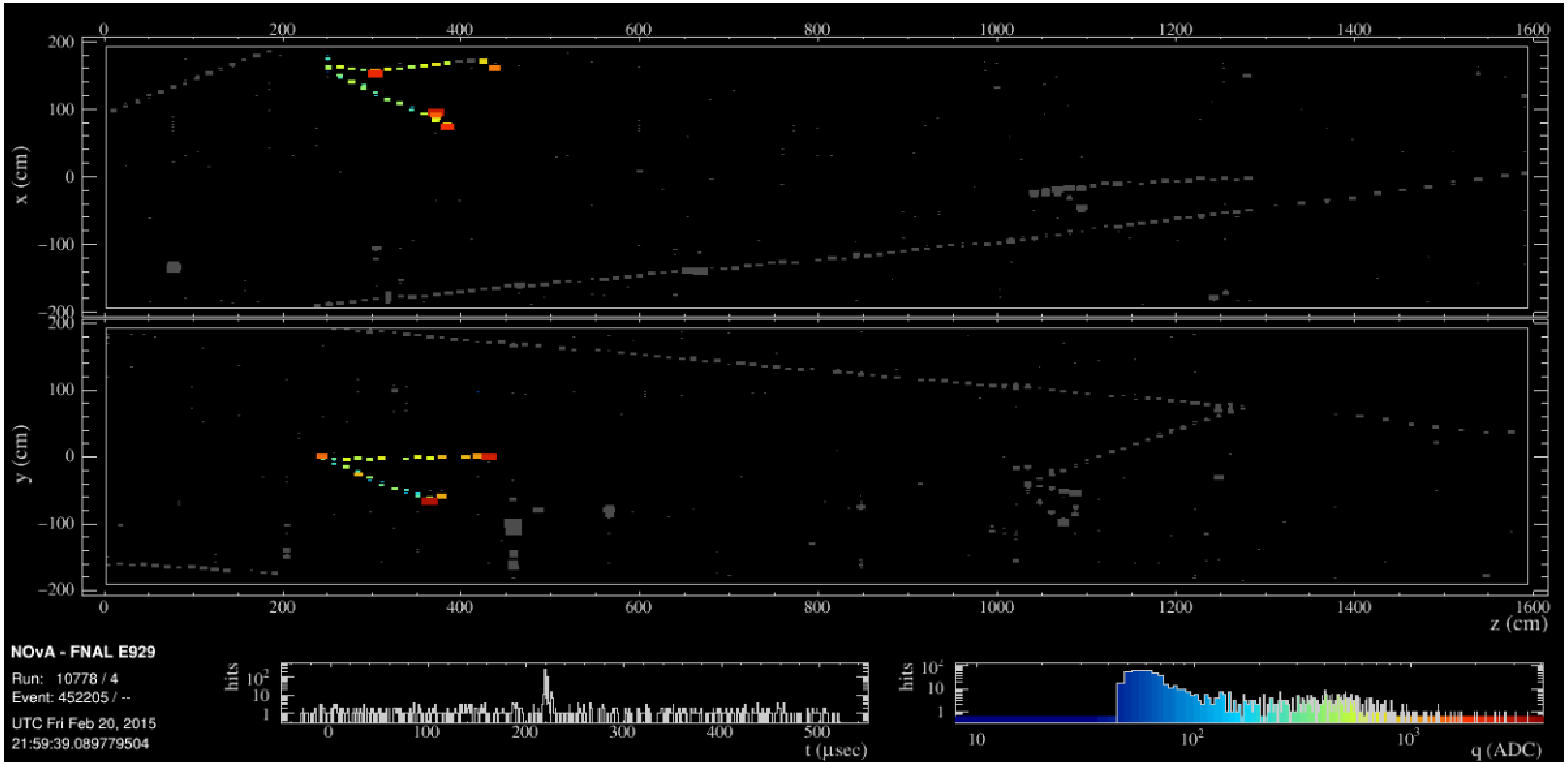
Events decrease by $\sim \frac{1}{R^2}$ and increase with the mass of the detectors

Notes about the Near Detector

The near detector is much closer to the neutrino source than the far detector

→ greater flux of neutrinos passing through the near detector

→ multiple neutrinos interacting in a time recording window

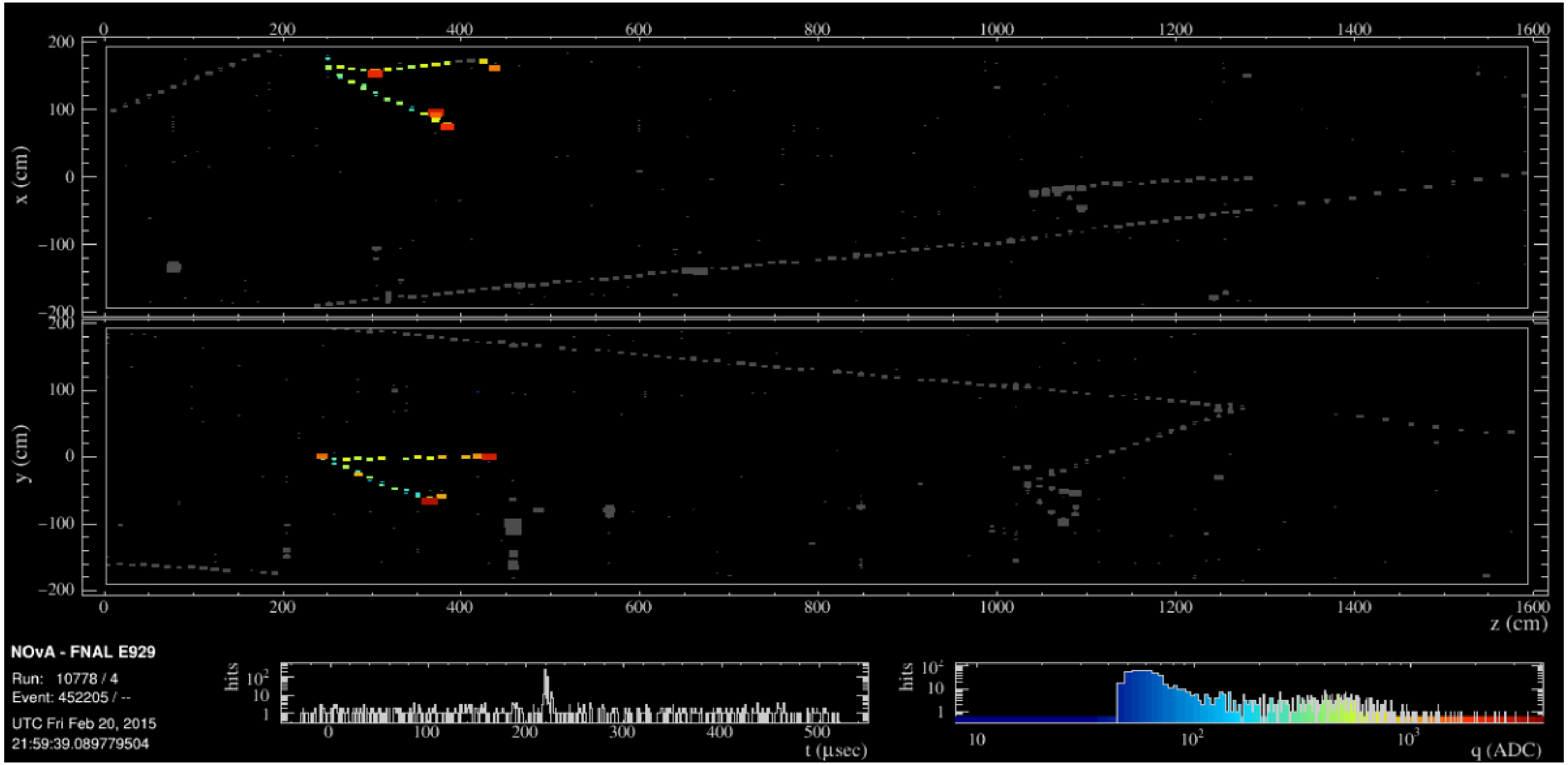


Notes about the Near Detector

The near detector is much smaller than the far detector

→ long muons can escape out the back

Sheets of steel are put at the end of the detector (~10x material for distance)



This activity is still crude

The events are just images in google folders

- The FD events and ND events have different styles
- Everyone has the same sequence of events

Note, because the Near Detector is closer to the source, it sees more neutrinos than the Far Detector for the same amount of protons-on-target. The Far Detector sample corresponds to more protons-on-target so that you have the same number of neutrinos passing through both detectors

Think about suggestions for the activity

- Should it be a webpage with back and forward links?
- Should there be some code number to randomly assign events?
- How many images is too much or not enough?

Neutrino Interactions

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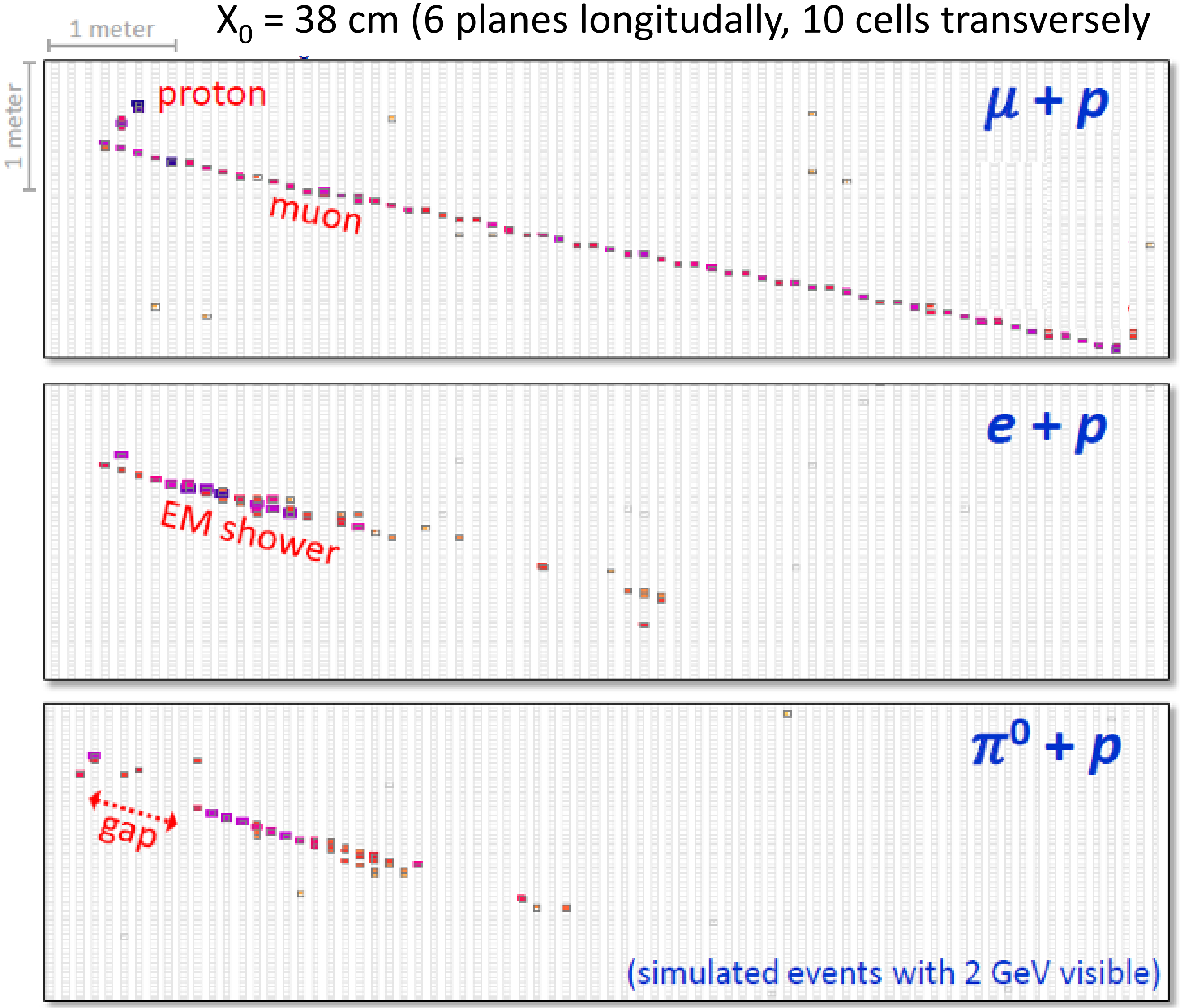
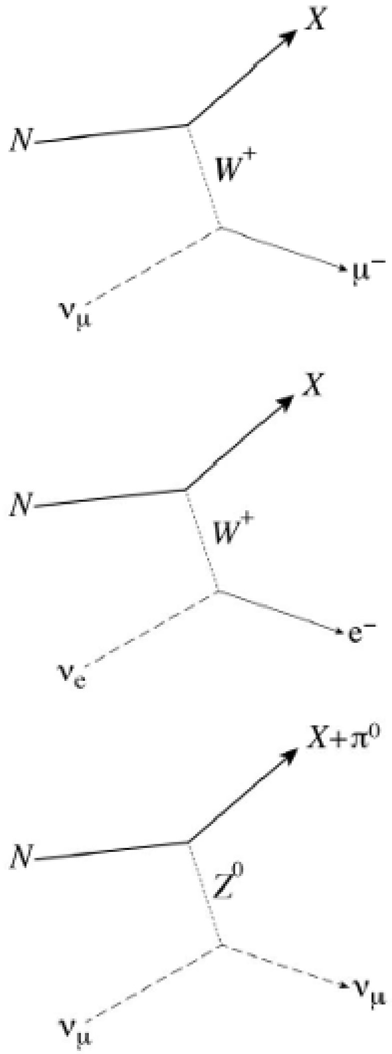
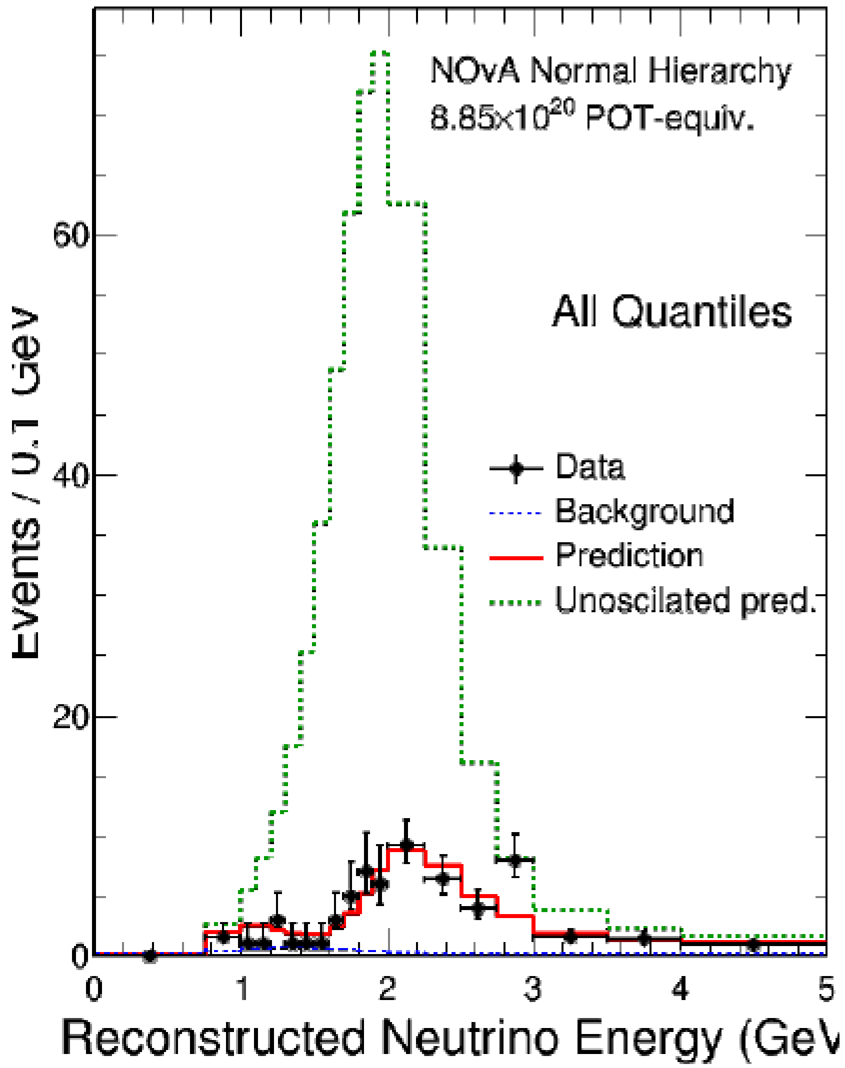




Observed Neutrino Oscillation



What activities should be done?

Should students predict the number of signal and background events?

Should students predict fractionally how much more protons on target the Far Detector needs?

Should they set this number

Should students learn about neutrino oscillation after the activity?

Should students do anything else?