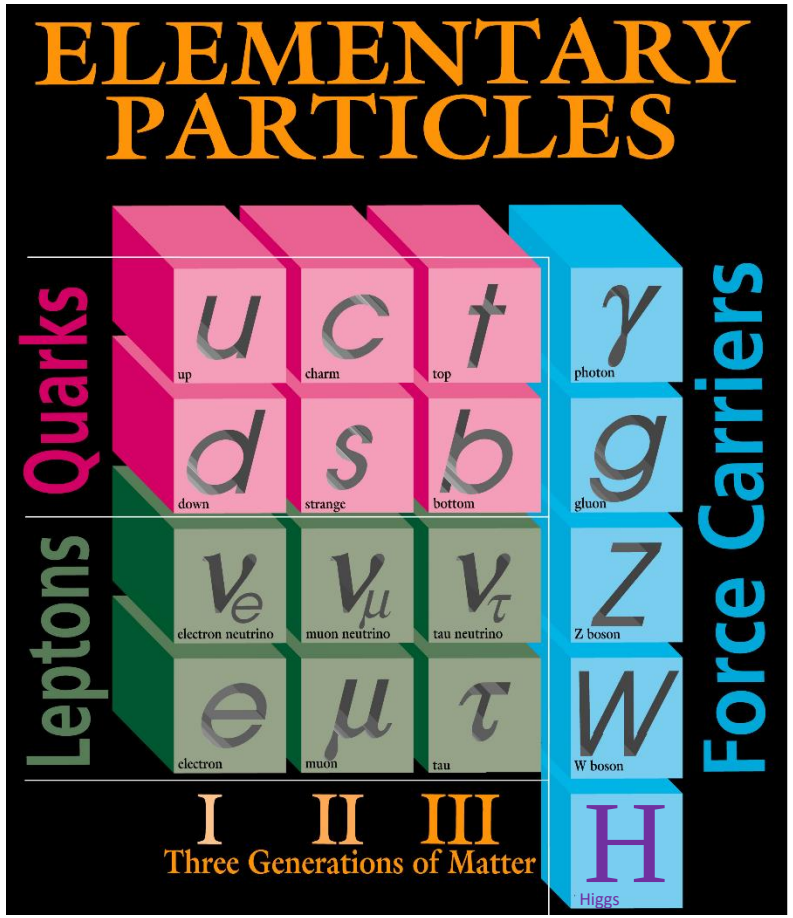

NOvA Experiment
Neutrino Activity

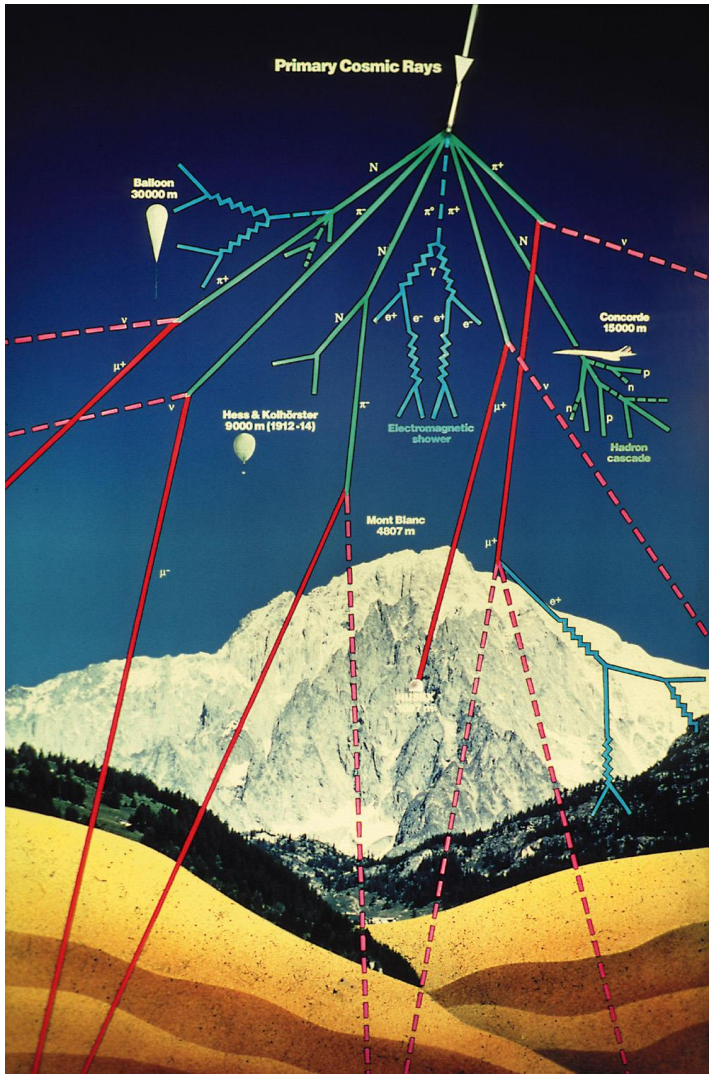
Building Blocks of the universe



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

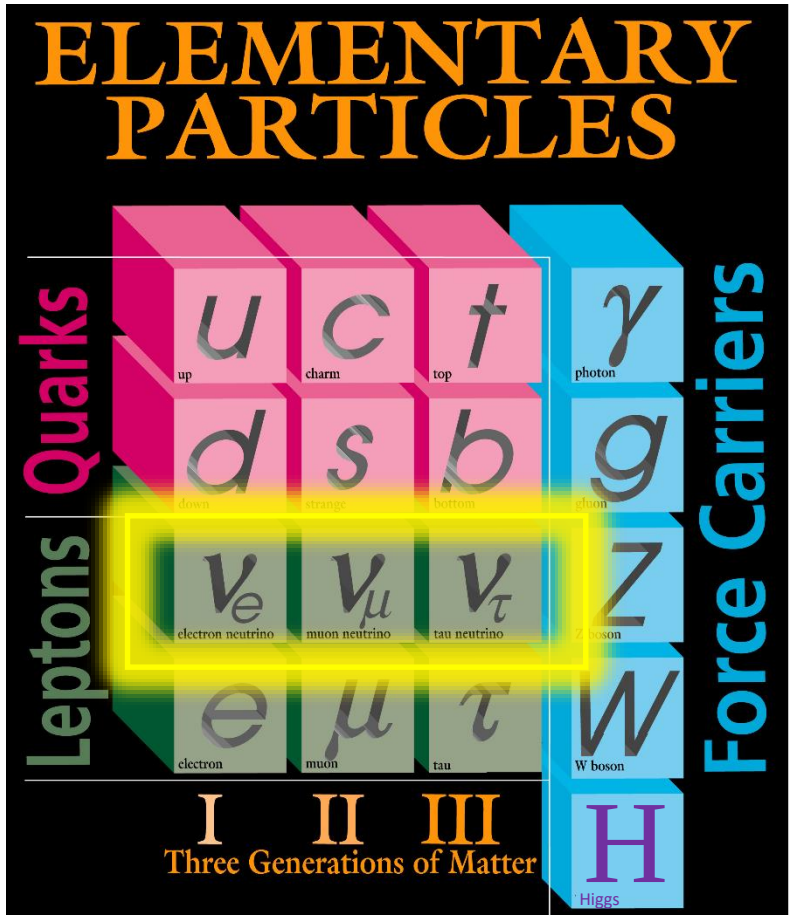
Muon – μ

- 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

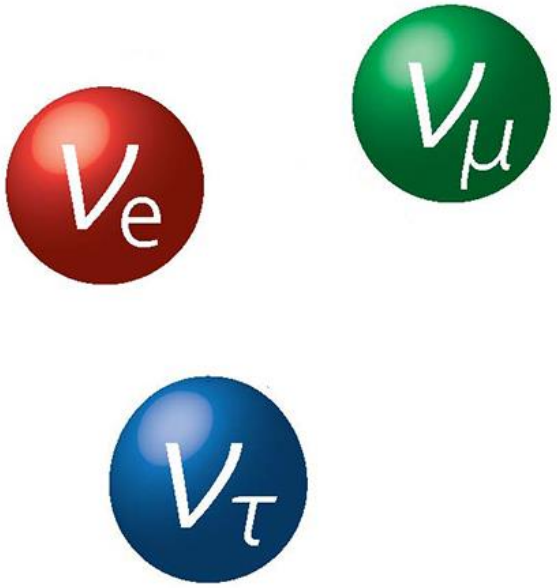
We've known about them for ~100 years

2nd most abundant particle in universe

Θ(100 million) per cubic meter

100 billion solar neutrinos pass through your finger nail each second

What about the neutrinos



How they're different

No electric or color charge
- No EM or strong interactions

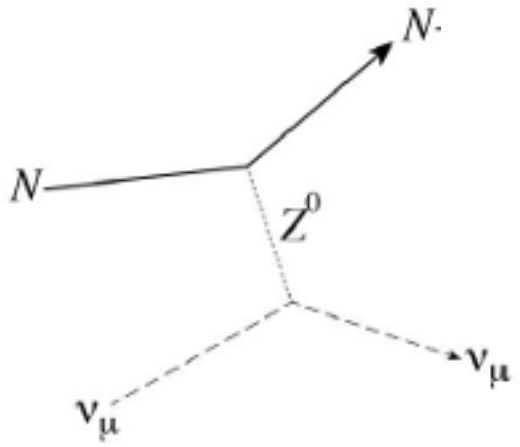
Extremely tiny mass
- At least a million times less massive than an electron

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

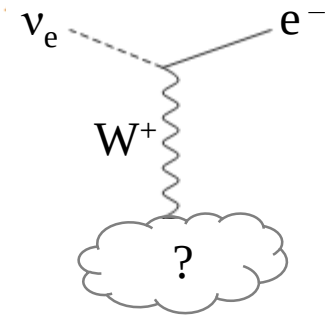
Think Heisenberg Uncertainty → Rare chance to create mass energy → Rare chance to interact



Neutrino Flavor

Identify neutrino flavor through charged-current (CC) interaction

Electron Neutrino



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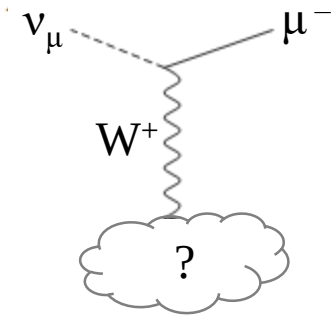
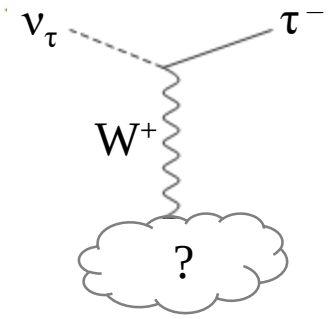
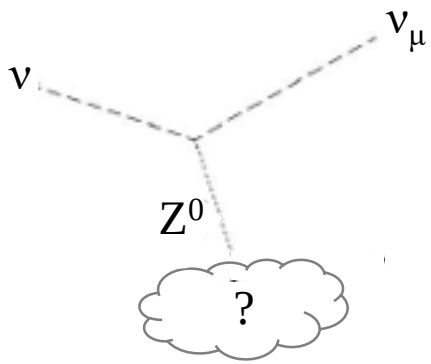


Tau Neutrino



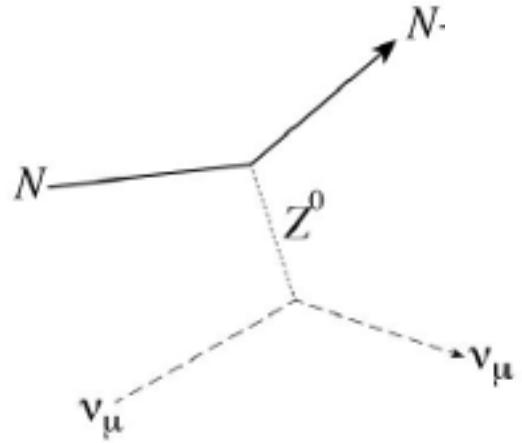
Neutral Current (NC) Interaction

All neutrino flavors look the same



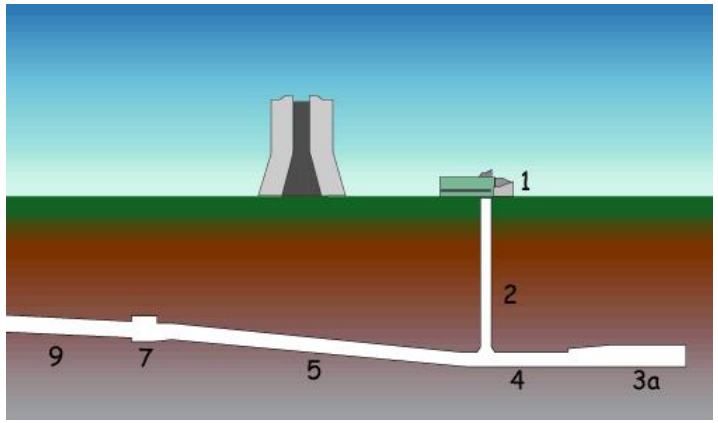
Neutrinos Rarely Interact

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

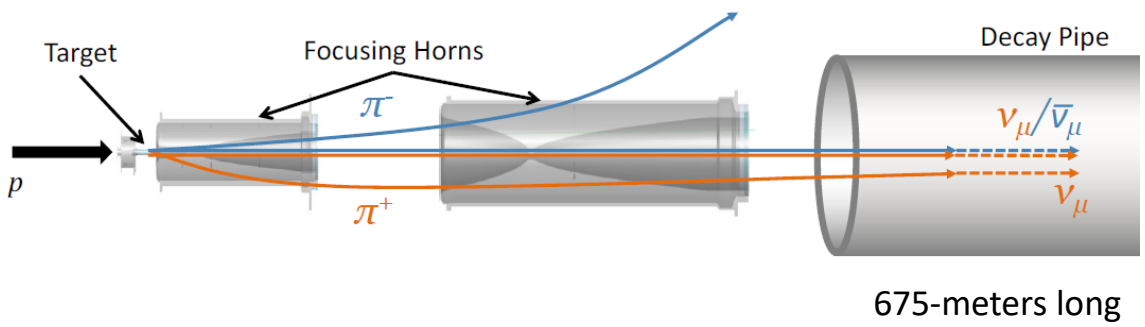


There is some probability that a neutrino will interact at any point
The more neutrinos that pass through a point, the more chances that one will interact at that point

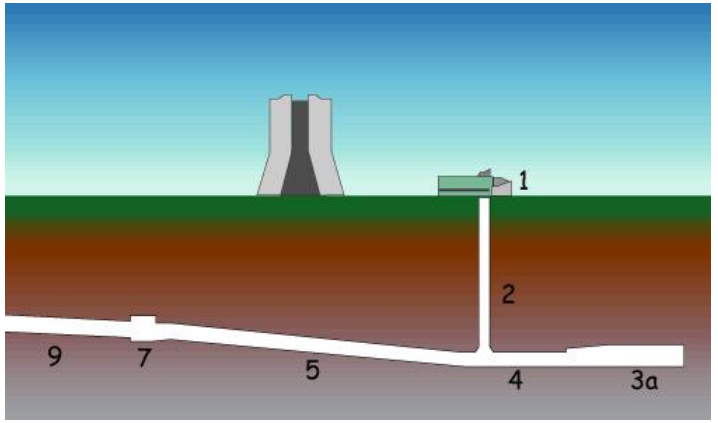
NOvA Experiment



NOvA Neutrino Beam

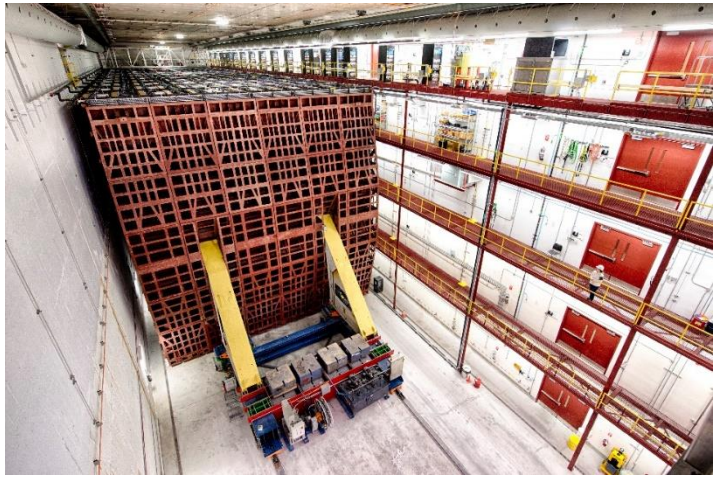


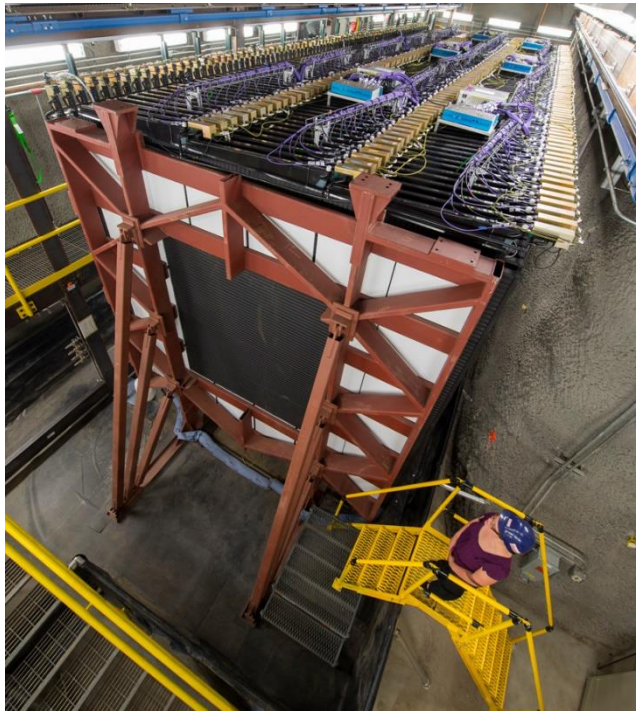
675-meters long

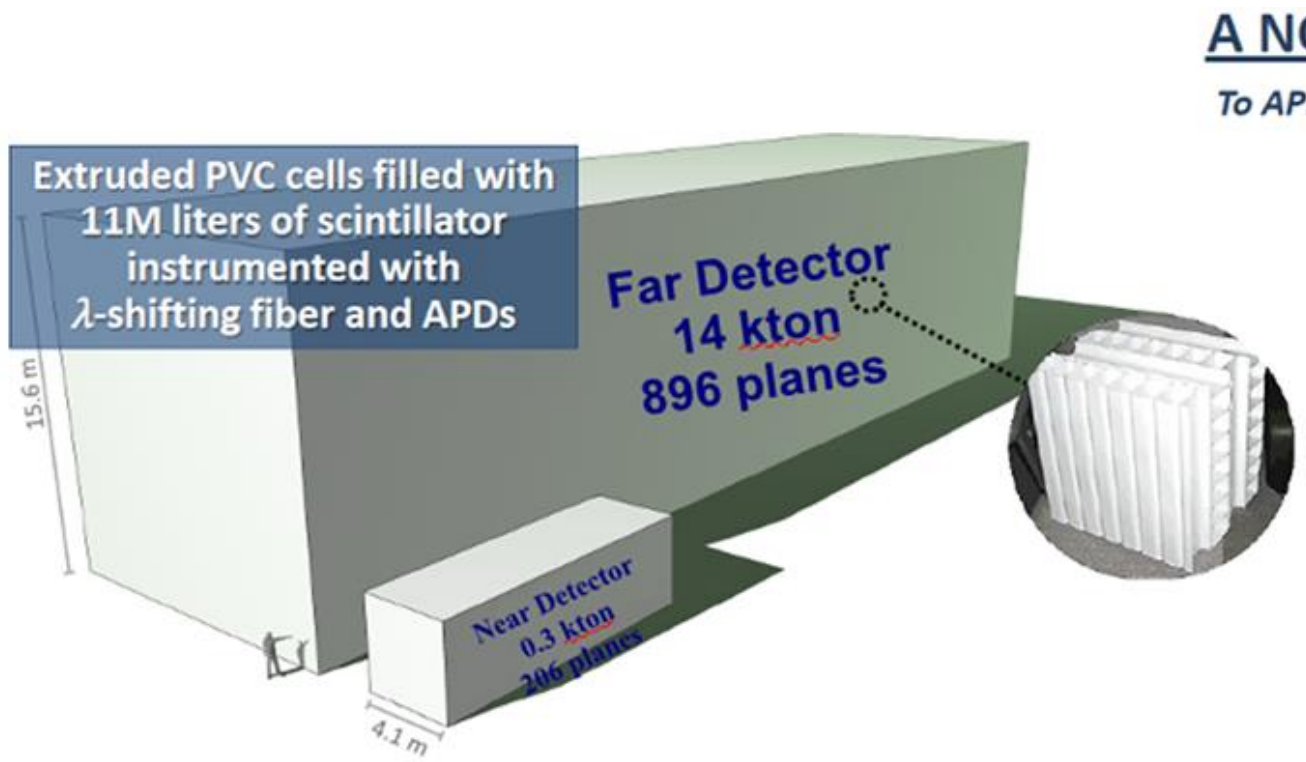


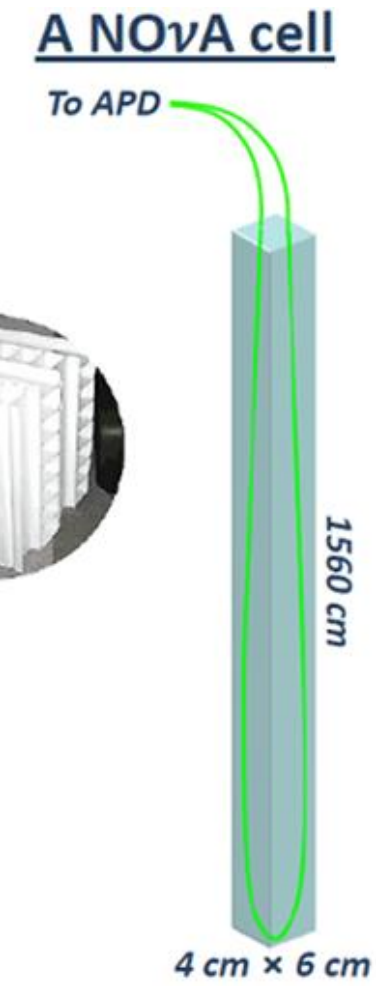
Number of neutrinos produced is proportional to the number of protons on target

NOvA Detectors

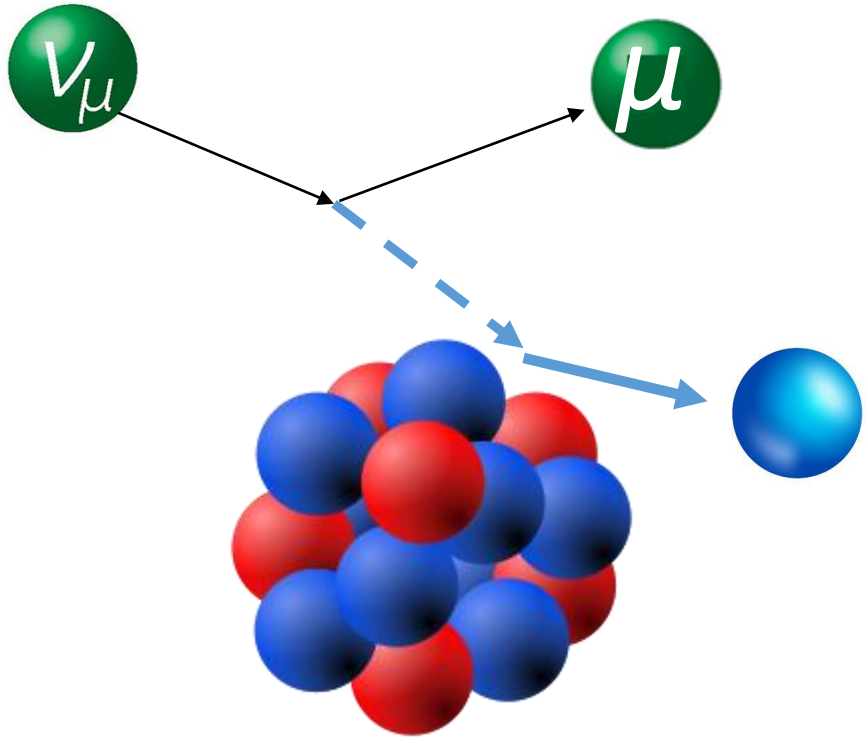






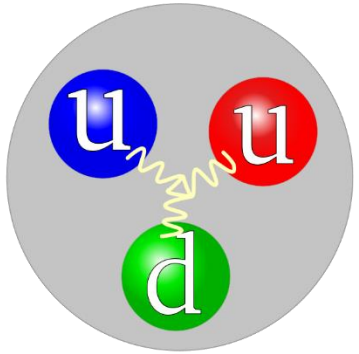


Neutrino Interactions



Nucleus

Proton



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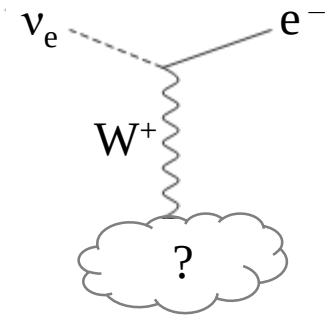

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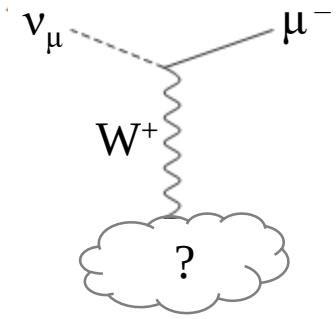

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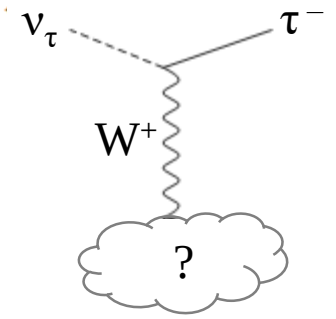

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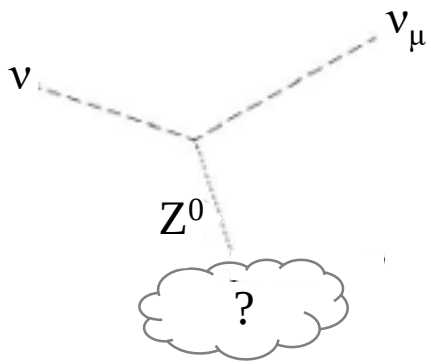

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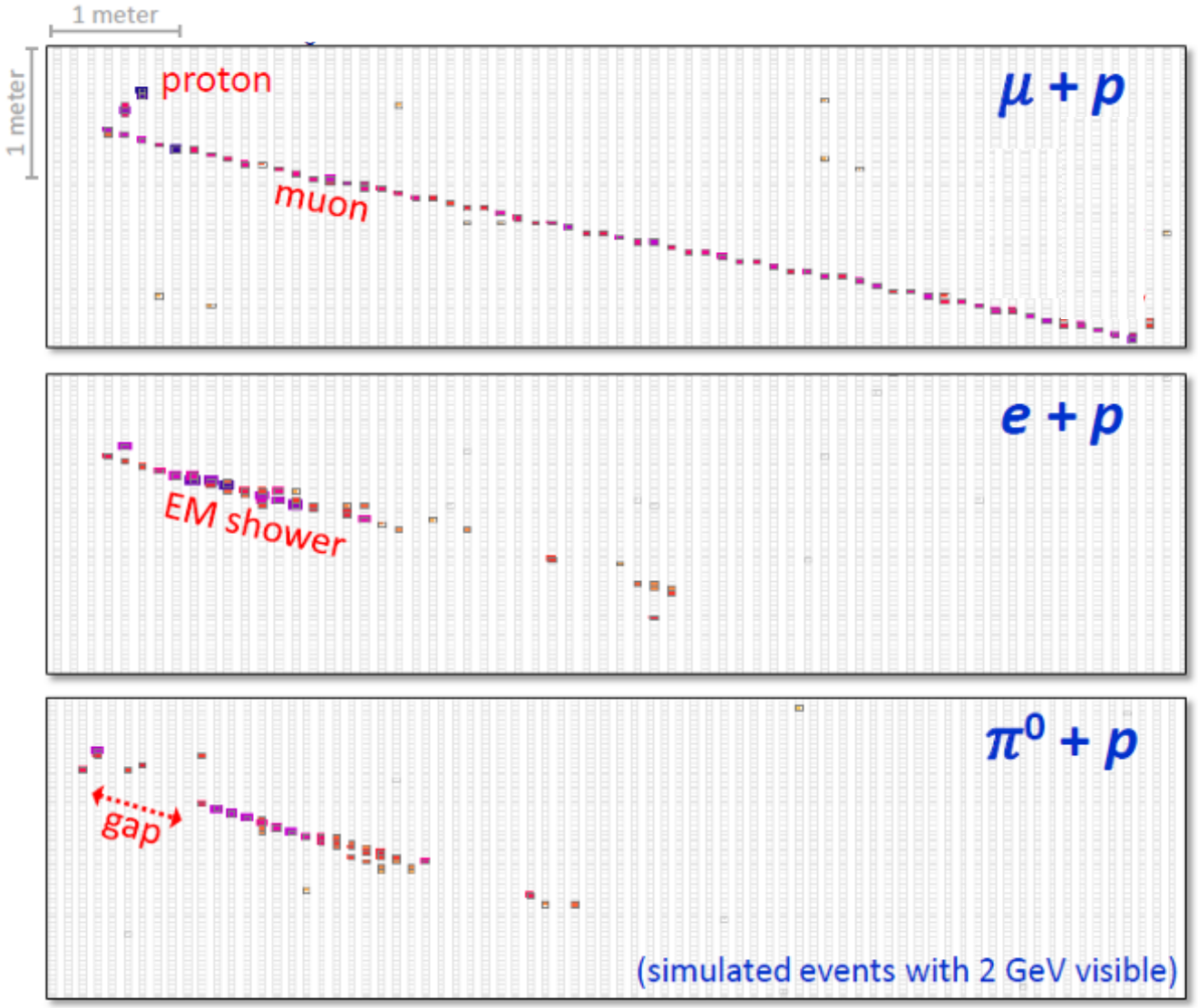
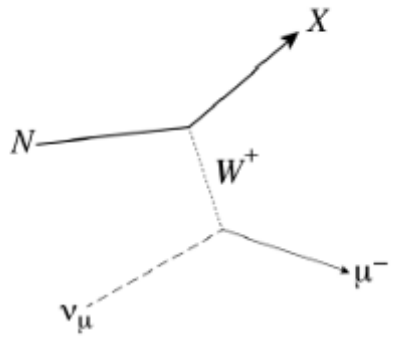
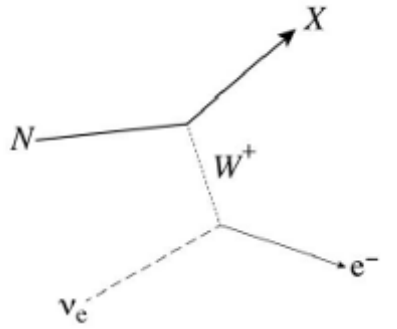
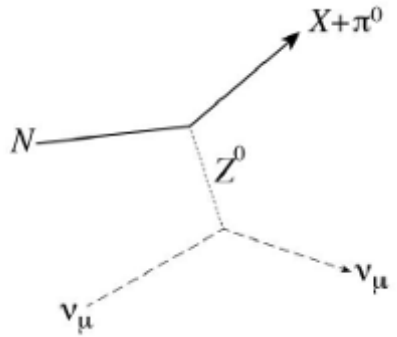








Let's look at FD events

- Students form groups of two and look at FD event displays

- Note for the same exposure of protons-on-target for the NOvA FD data used for this study there are:

  6 NuMu-CC events – only the numu flavor can cause these events

  40 NC events – any neutrino flavor can cause these events

  Relative to a specific selection criteria applied to data sample

- By looking at the images can each group come up with some ***quantifiable*** criterion (or criteria) that could be used to distinguish NuMC-CC events from NC events

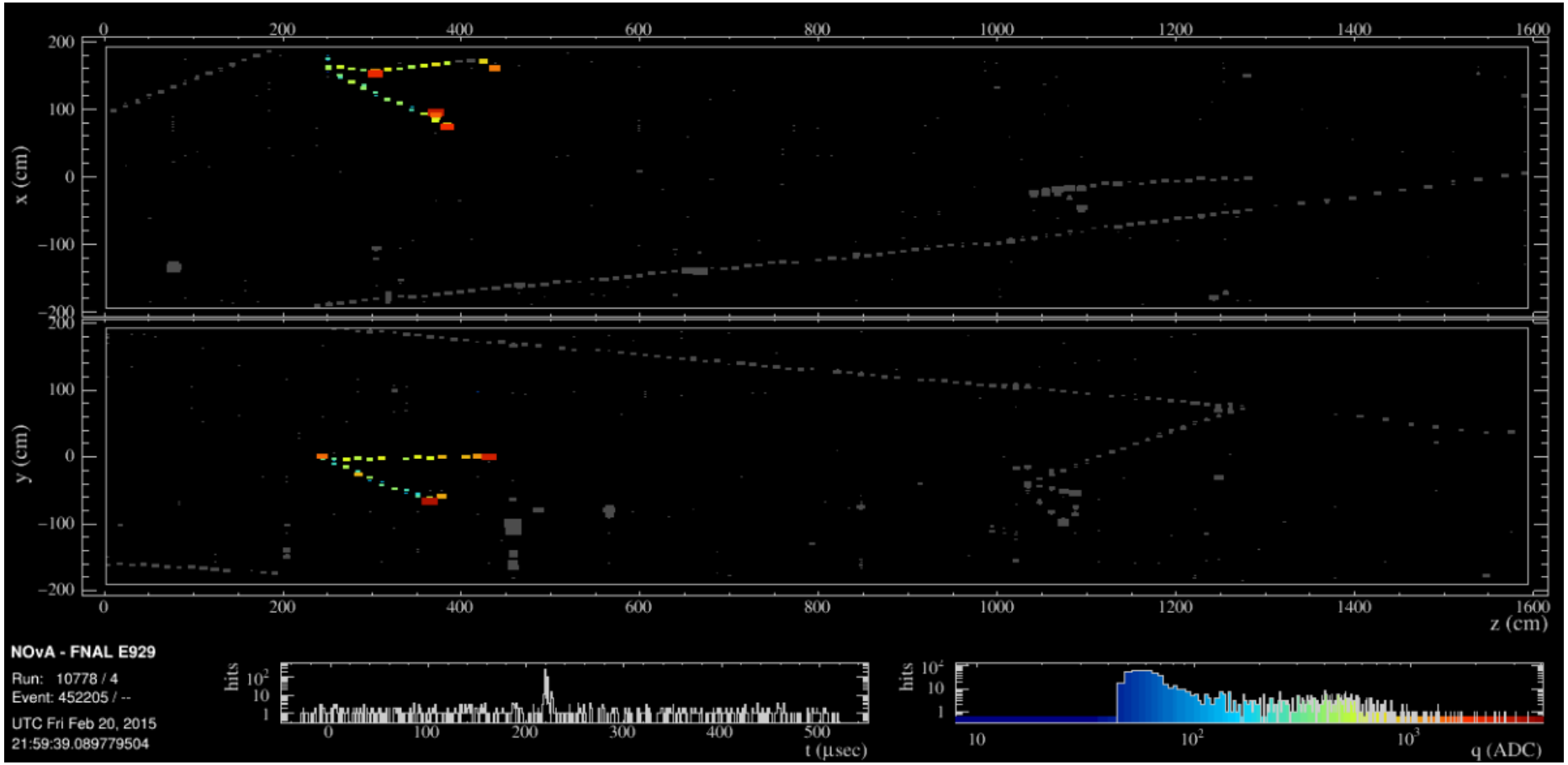
- Discuss groups' thoughts on what ***quantifiable*** criterion could be applied

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



Work as a group

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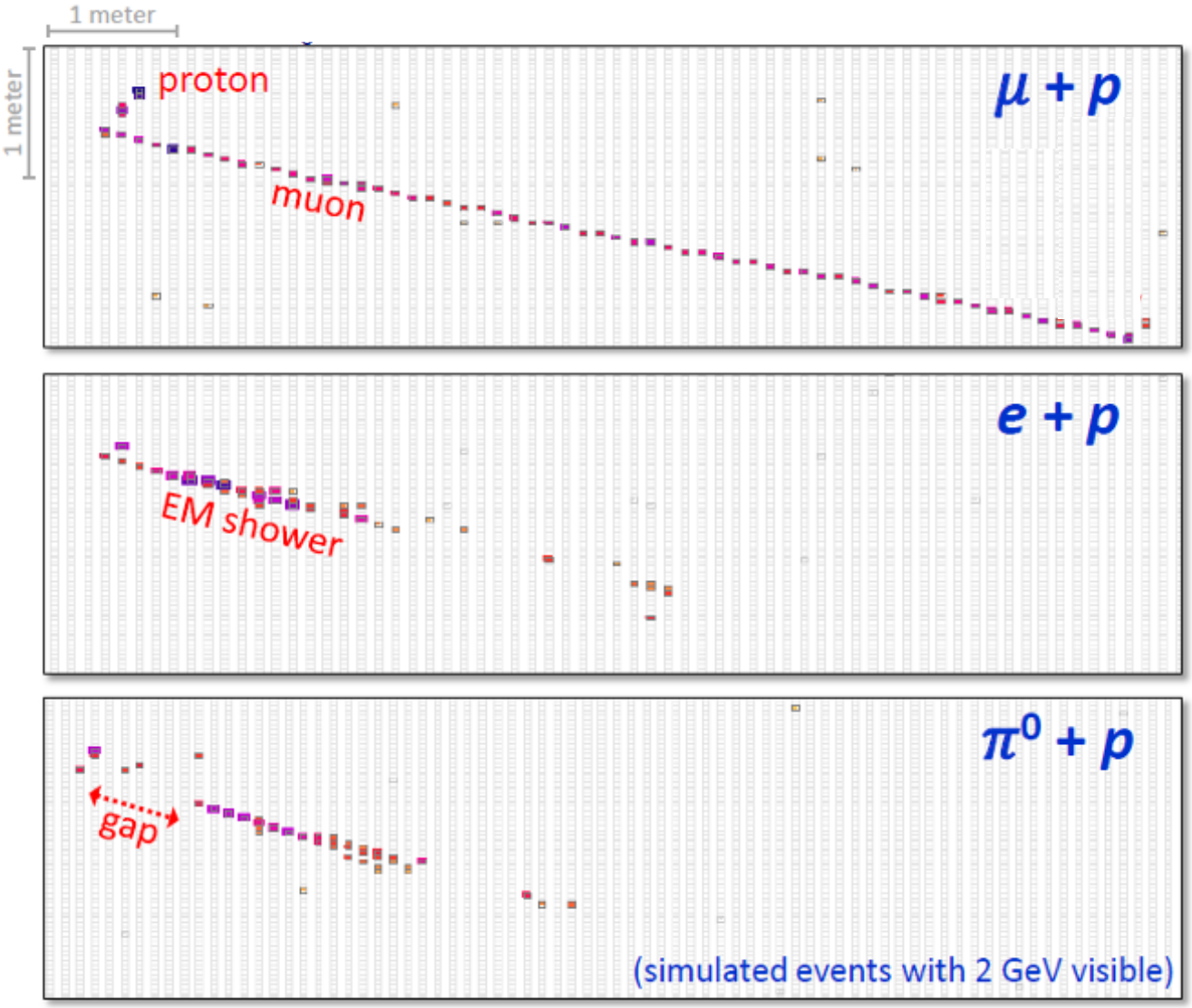
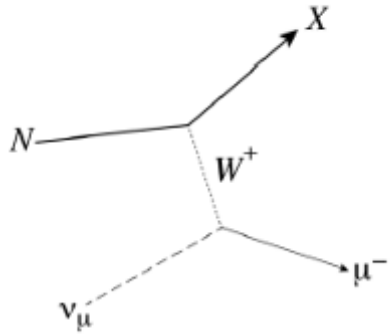
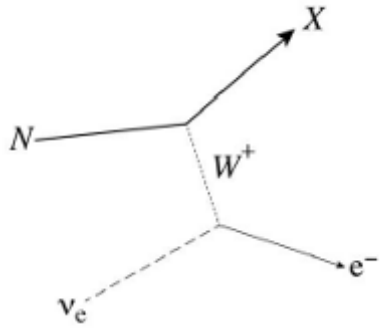
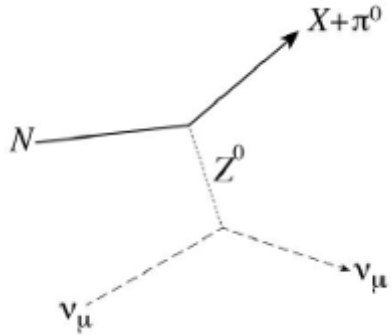
Neutrino Interactions

NuMu's are identifiable through presence of a muon that make a long straight track









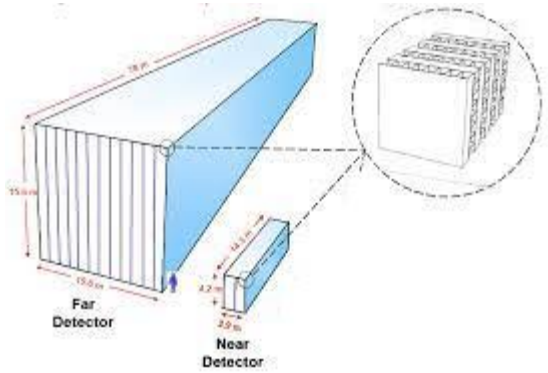
Spreadsheet of ND events

The ND events are collected using a data sample that corresponds to 1/50th the protons-on-target as the FD.

Question for students: Think about what you might expect about a spread sheet with ND events, that corresponds to 1/50th of the beam exposure as the FD. Then open the spread sheet, and discuss if anything meets your expectations or not?

Spreadsheet of ND events

Question for students: Why are there so many events in the ND file compared to the FD even though the ND files is a much smaller amount of protons-on-target?

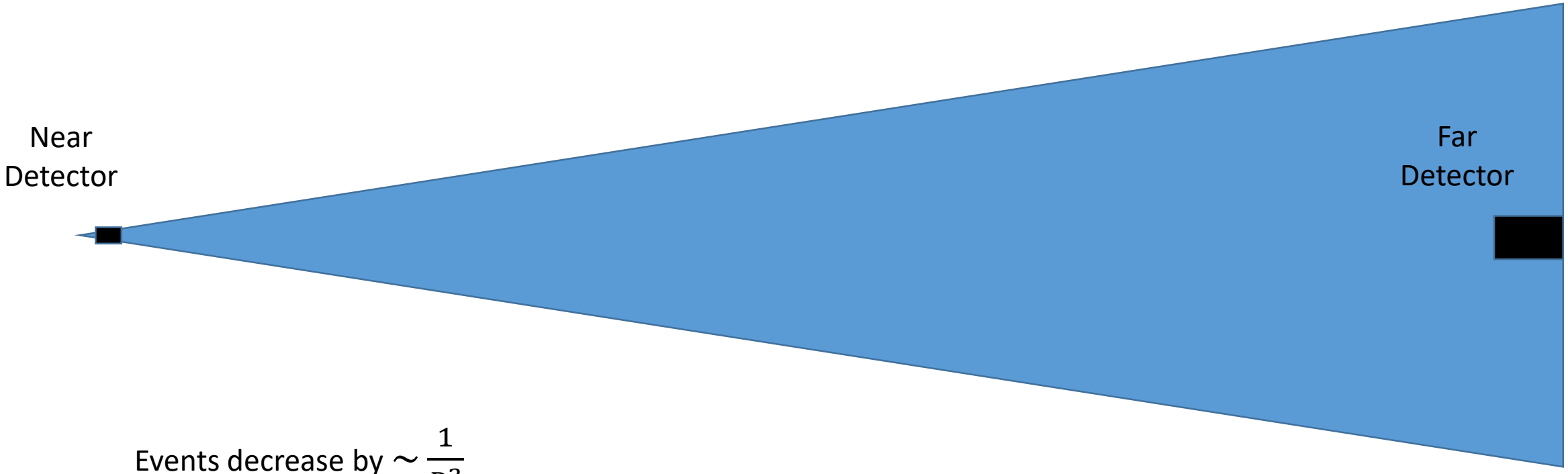


Near Detector

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

→ greater flux of neutrinos passing through the near detector

Think about a flash light shining on a wall when you are close and far away.



Events decrease by $\sim \frac{1}{R^2}$

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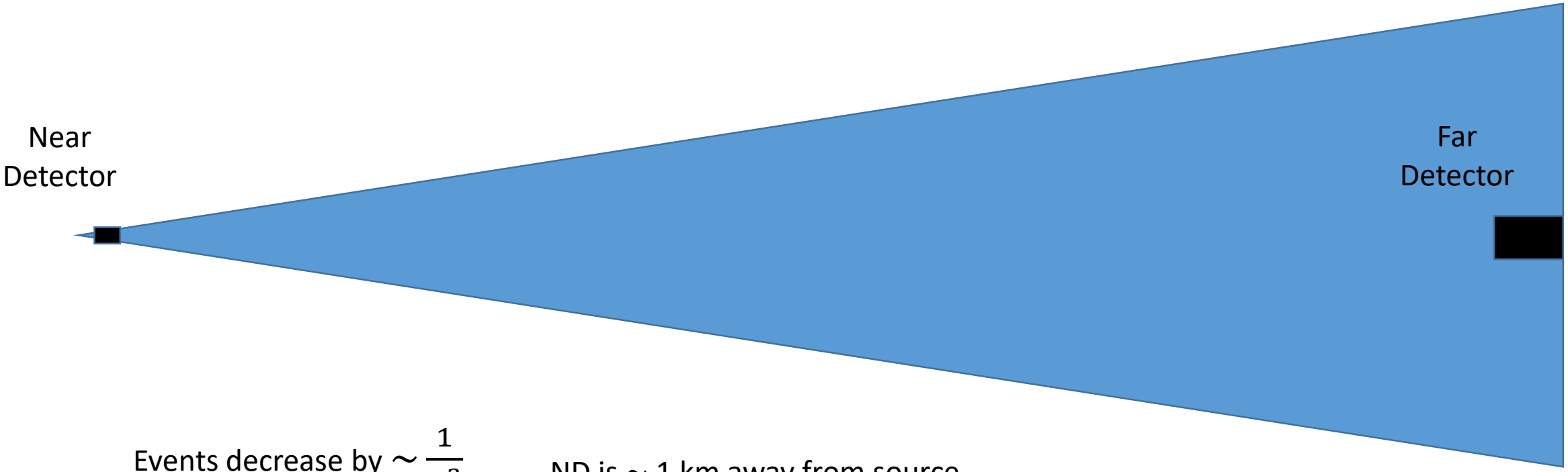


Events decrease by $\sim \frac{1}{R^2}$

ND is $\sim$ 1 km away from source
FD is $\sim$ 810 km away from source

Expect $\frac{810^2}{1^2} \approx 700{,}000$ times the events

Order of magnitude estimates

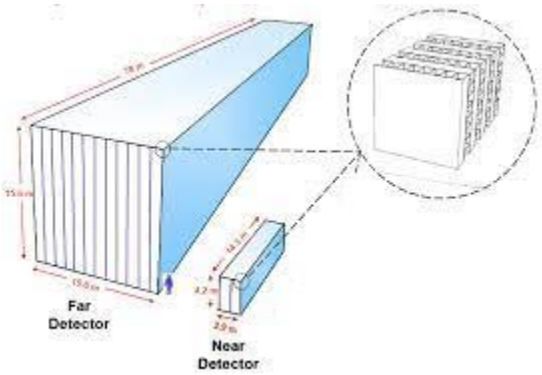
Near Detector

Expect 700,000 times the events

But the ND is much less massive than the FD

Neutrinos interact with proportionally less nucleons

Particles produced in neutrino interactions are more likely to escape smaller ND. Only look at events that are fully contained



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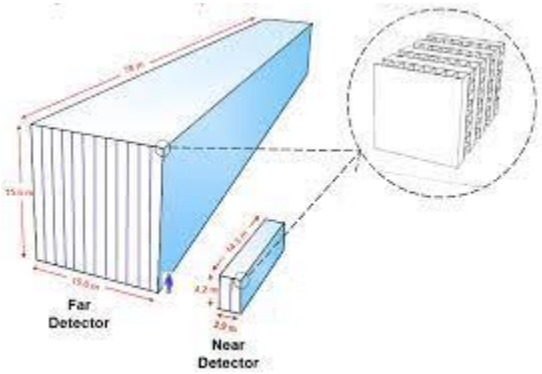

Effect of smaller mass and preselection for these events reduces ND event yields by a factor of ~170 compared to the FD

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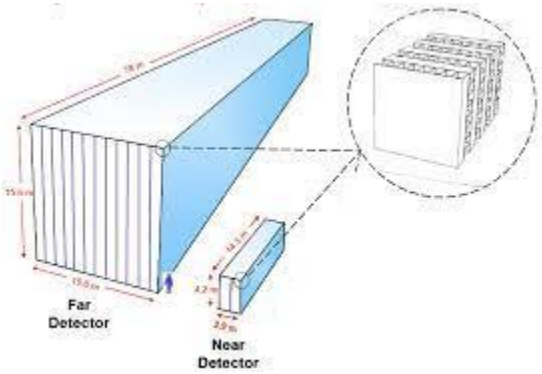

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Roughly expect 700,000/170 ≈ 4000 times more events in ND than FD for same POT

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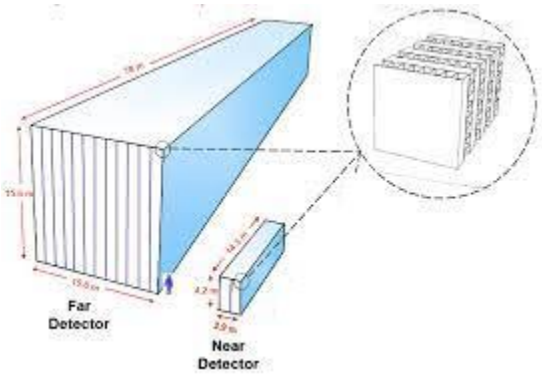

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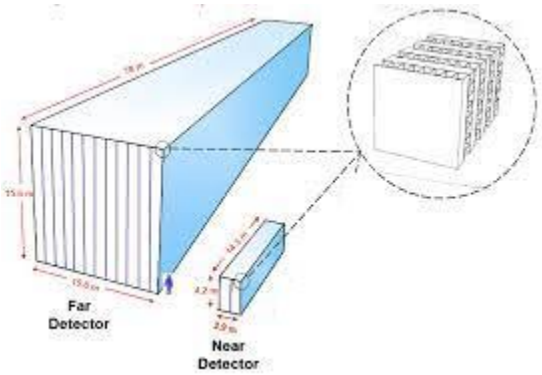

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Does our ND sample match our order of magnitude estimate?

How much of the ND events are CC vs NC?

– Do some coding to identify CC vs NC

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How about just the NC events?

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– What causes NC events and what causes CC events?

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How could ND NC events match your expectations from the FD, but ND CC not?

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How about just the NC events?

How about just the CC events?

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Neutrinos change flavor as they travel!

We call this neutrino oscillation, since they will eventually change back to their original flavor