



Neutrinos

An Invisible yet Tangible Mystery

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SMU Quarknet, 15 July 2025



Clarification



Neutrinos, NOT Nutria !!





Clarification



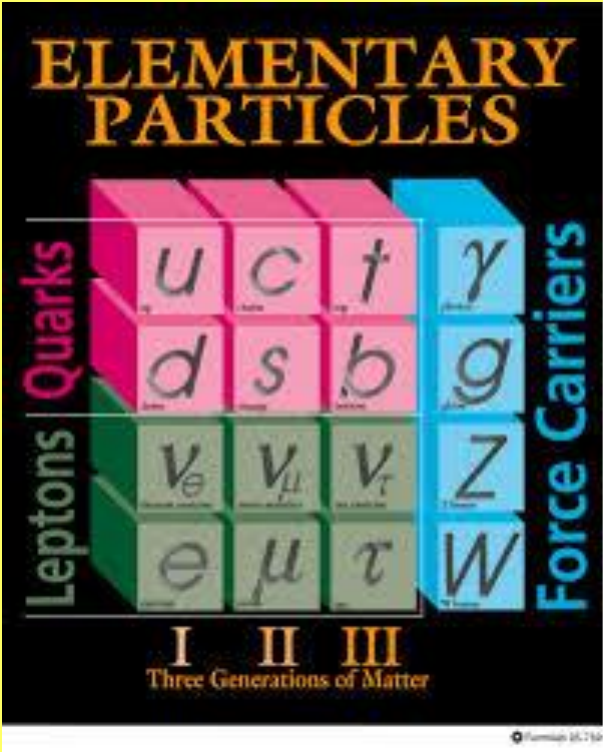
Neutrinos, NOT Nutria !!



Heidi: ...better than then the lunches...



One of the Cast of Characters





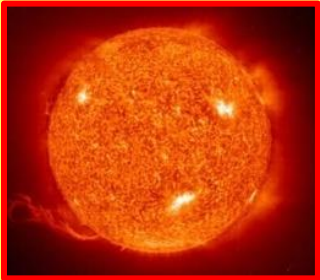
Neutrinos Are Common



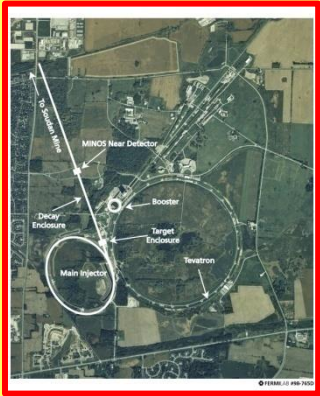
Big Bang vs
unmeasured...



Reactor vs



Solar vs



Accelerator vs



Atmospheric vs



Bone vs



...but unfamiliar



Bone vs

Q: What common fruit is also a neutrino source?

- Hint: fruit is a good source of potassium.



...but unfamiliar



Bone vs

Q: What common fruit is also a neutrino source?

- Hint: fruit is a good source of potassium.
- 2nd Hint: fruit is alleged to forestall hangovers...



...but unfamiliar



Bone vs

Q: What common fruit is also a neutrino source?

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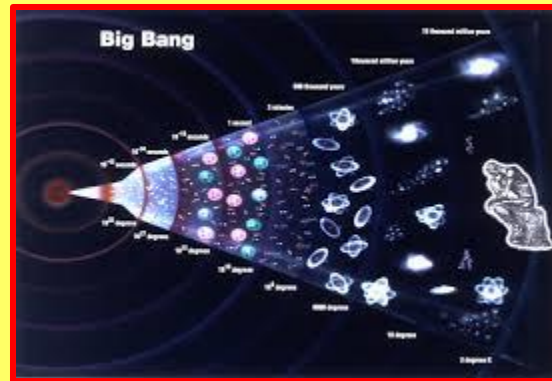
A:



~15 decays/sec



Neutrinos Are Everywhere



Big Bang vs

2nd most numerous particle in Universe !!

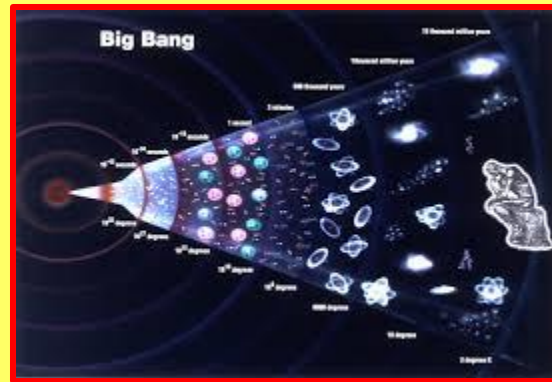
number density $n_\nu \sim 330/\text{cm}^3$

Full disclosure: not yet detected...

Q: what is most numerous particle in universe?



Neutrinos Are Everywhere



Big Bang vs

2nd most numerous particle in Universe !!

number density $n_\nu \sim 330/\text{cm}^3$

Q: what is most numerous particle in universe?

A: Photons ! (Also from BB). $n_\gamma \sim 410/\text{cm}^3$

These have been detected !!



Neutrinos Are “Sizeless”



- OK, they have no measured size.
- Similar to electrons in that sense.
- Like a Euclidean point from HS geometry.
- Dissimilar to protons in that sense.

Q: Speaking of sizes, how big is a proton or atom?



Neutrinos Are “Sizeless”



Q: Speaking of sizes, how big is a proton or atom?

A: Atomic radius ~ 1 “Angstrom” or 10^{-10} meters.

A: Proton radius ~ 1 “Fermi” or 10^{-15} meters.





Neutrinos Masses Unknown



Are known to be “nearly massless”
 $m_\nu \sim 0.1 - 1 \text{ eV}$ (various estimates)

Recall, top quark mass $\sim 175 \text{ GeV}$

$$m_\nu/m_{\text{q(top)}} \sim 5 \times 10^{-12}$$

No one has a clue why this is.



Neutrino “Oscillation”



Since neutrinos have mass, QM says they oscillate

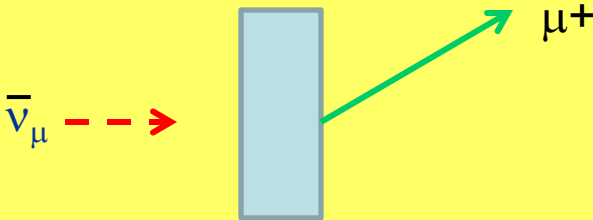
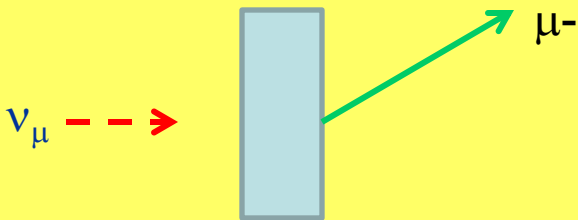
What does that mean?

$$\nu_{\mu} \rightarrow \nu_e$$

$$\nu_{\mu} \rightarrow \nu_{\tau}$$

...

What distinguishes “flavors” ?



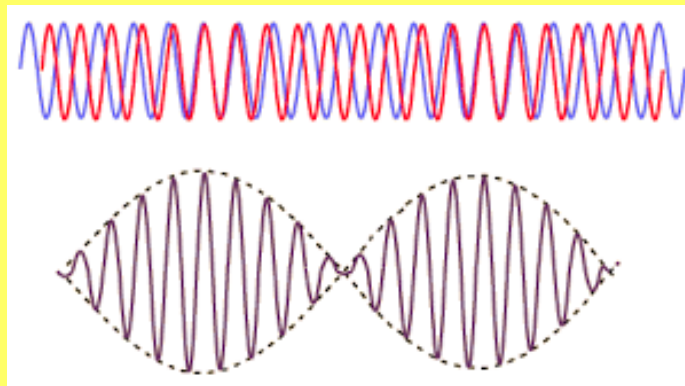


Neutrino “Oscillation” (2)



But why do they oscillate?

- Wave-particle duality
- Different masses (more to this story)
- So their oscillation frequency differs
- Neutrino of one flavor is sum of massive ones (QM)
- Massive particle waves interfere to produce “beats”



See the demo !!

❖ Nodes & antinodes represent neutrino flavors



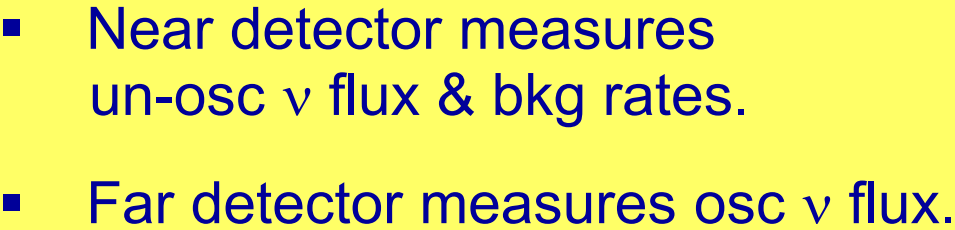
In a nut shell, measures:

$$\begin{array}{ll} \nu_{\mu} \rightarrow \nu_e & \bar{\nu}_{\mu} \rightarrow \bar{\nu}_e \\ \nu_{\mu} \rightarrow \nu_{\mu} & \bar{\nu}_{\mu} \rightarrow \bar{\nu}_{\mu} \end{array}$$

Difference in these rates possibly related to
why Universe has so much more matter than antimatter

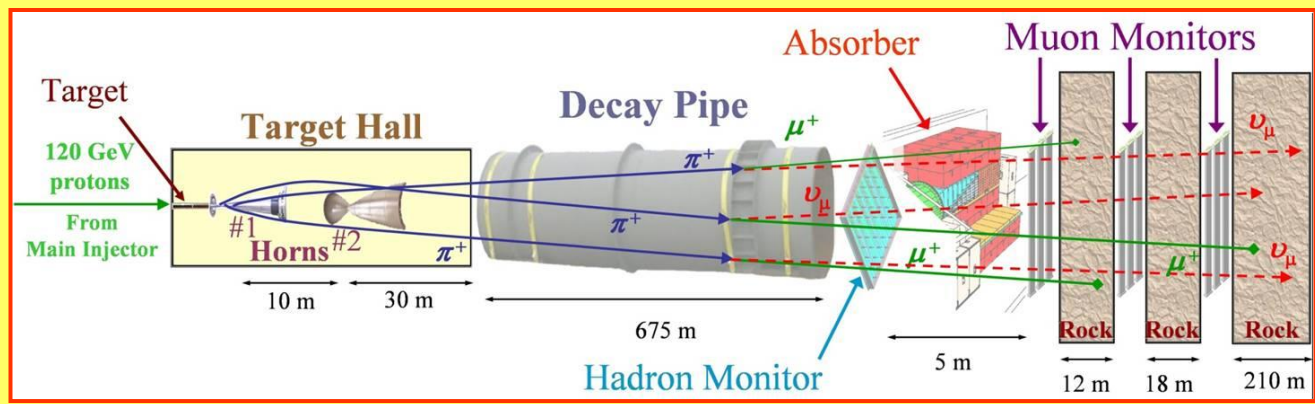
(yes, I'm skipping a few steps !!)







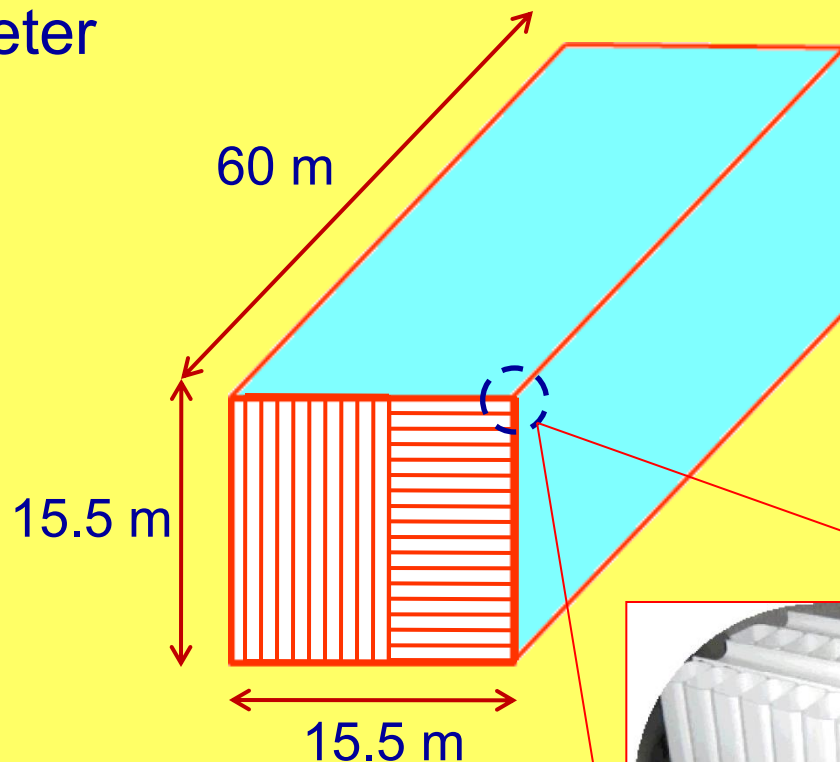
Ram protons into a set of carbon fins



NO ν A Far Detector Overview



- Low-Z tracking calorimeter
65% active
- Surface location
- 14 kT total mass
- 896 Detector planes
Alternate x-y layers
0.15 X_0 /layer
 $R_M = 9.8$ cm (2.5 cells)
- Liquid scintillator cells
32 PEs from far end
- 1-sided readout/plane
via avalanche photodiodes (APDs)

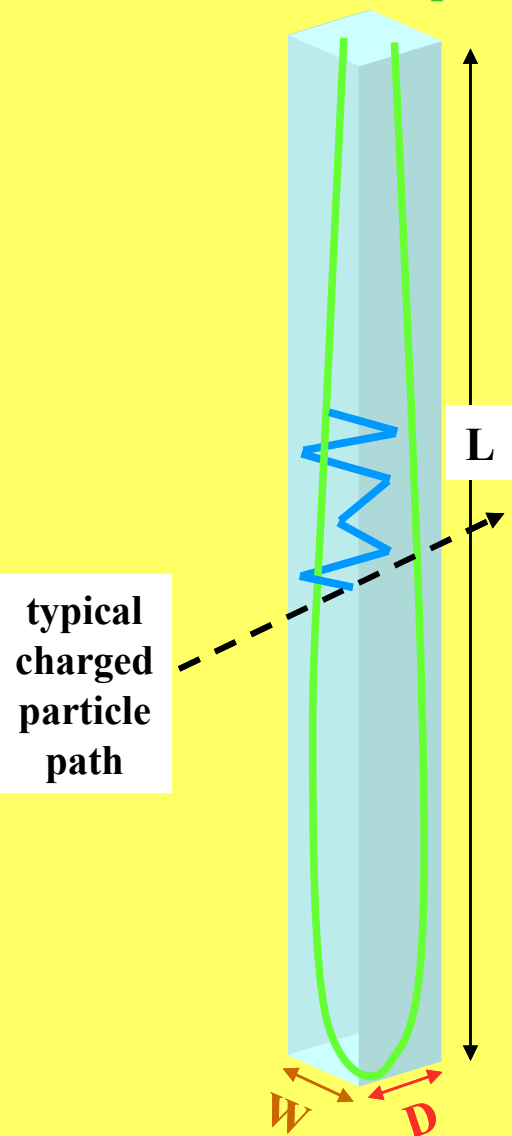




NO_vA Detector “Atom”



To 1 APD pixel



TE Coan/SMU

Liquid Scintillator

Mineral oil solvent: 94.6 % (BW)

Primary scintillator: 5.2% (BW) pseudocumene

Waveshifters: PPO + bis-MSB

Hollow PVC cells provide granularity

15% (BW) TiO₂: high reflectivity walls

Each cell: 3.6 cm x 5.7 cm x 15.5 m long

Looped Wavelength Shifting Fiber

Maximizes light collection: no mirrors

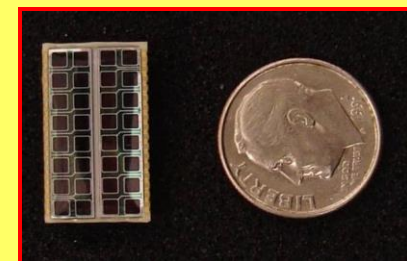
Diameter = 0.7mm, K-27 dye @ 300ppm

Avalanche Photodiode

QE = 85%

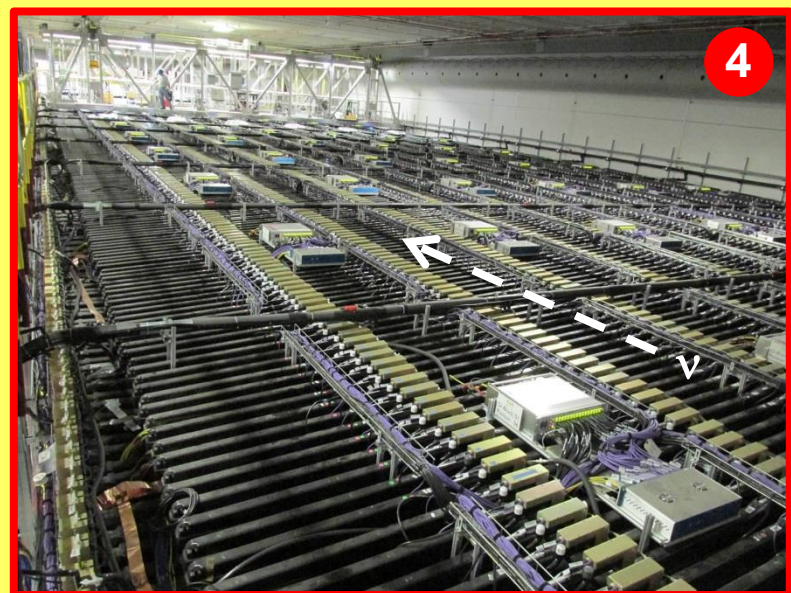
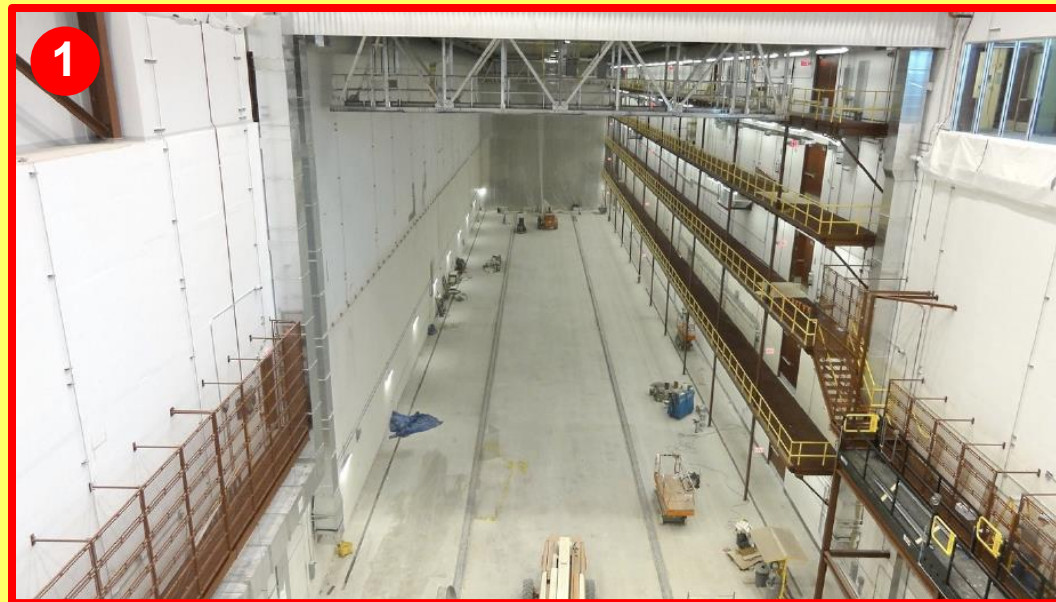
Gain = 100

T_{run} = -15 C





Far Detector Construction

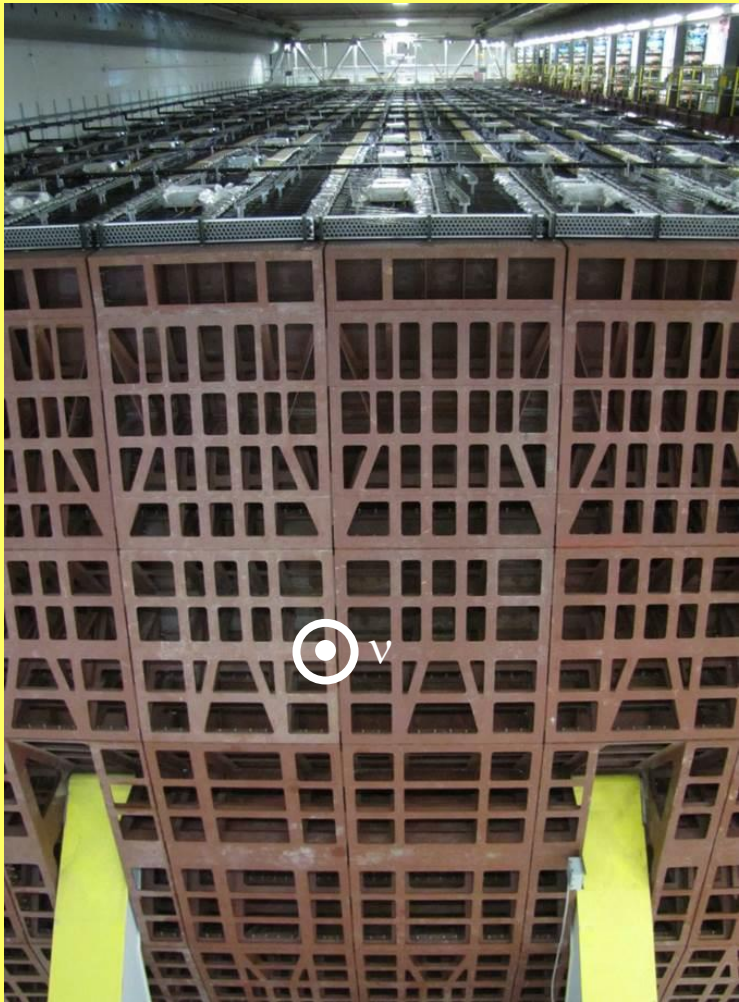




Far Detector Status (2)



Last block installed 25 Feb 2014

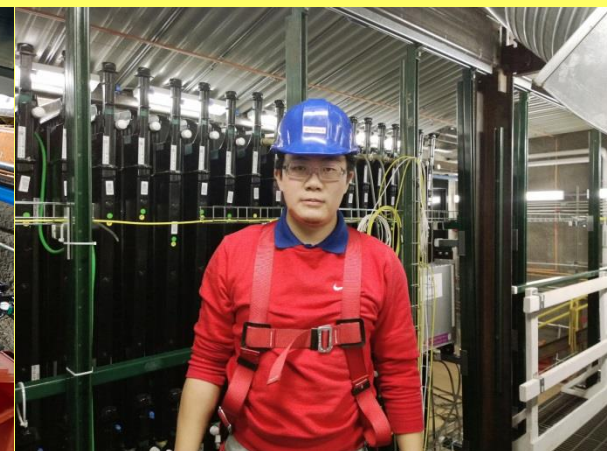
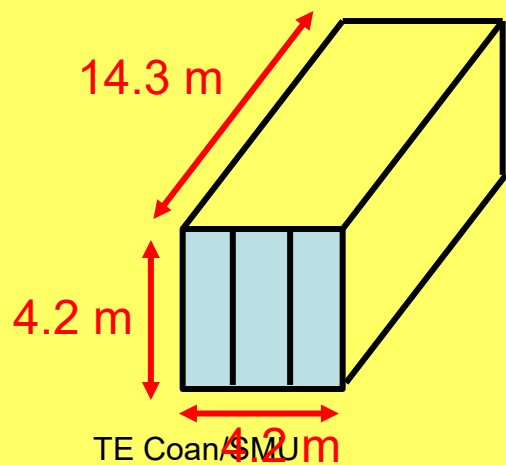




Near Detector Construction



- 0.3 kT mass
- 20k channels
- 1 km from target & 100 m underground
- Cell structure similar to far detector
- Front end & DAQ identical to far detector
- Completion ~May 2014

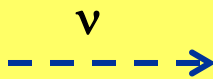
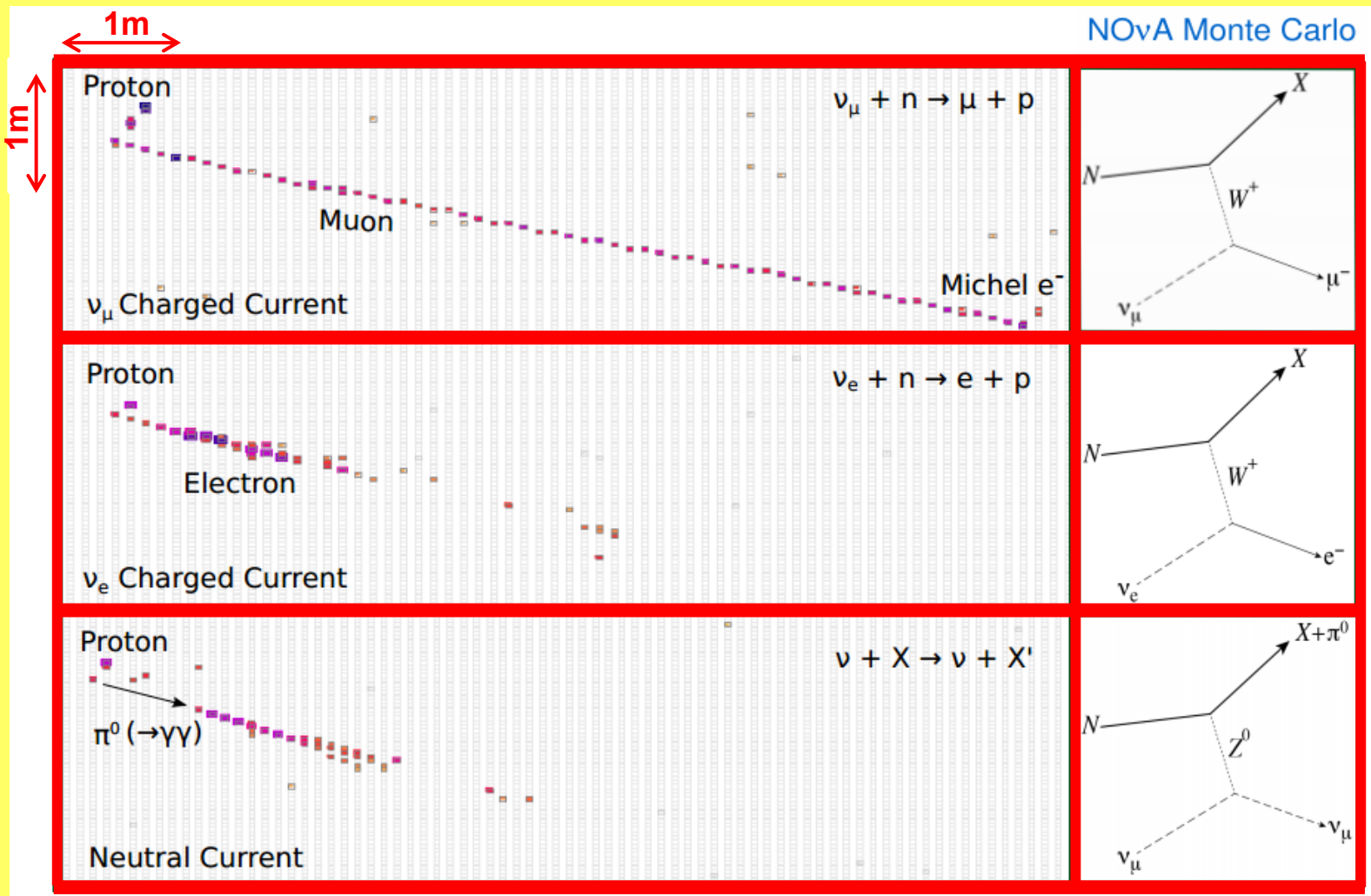


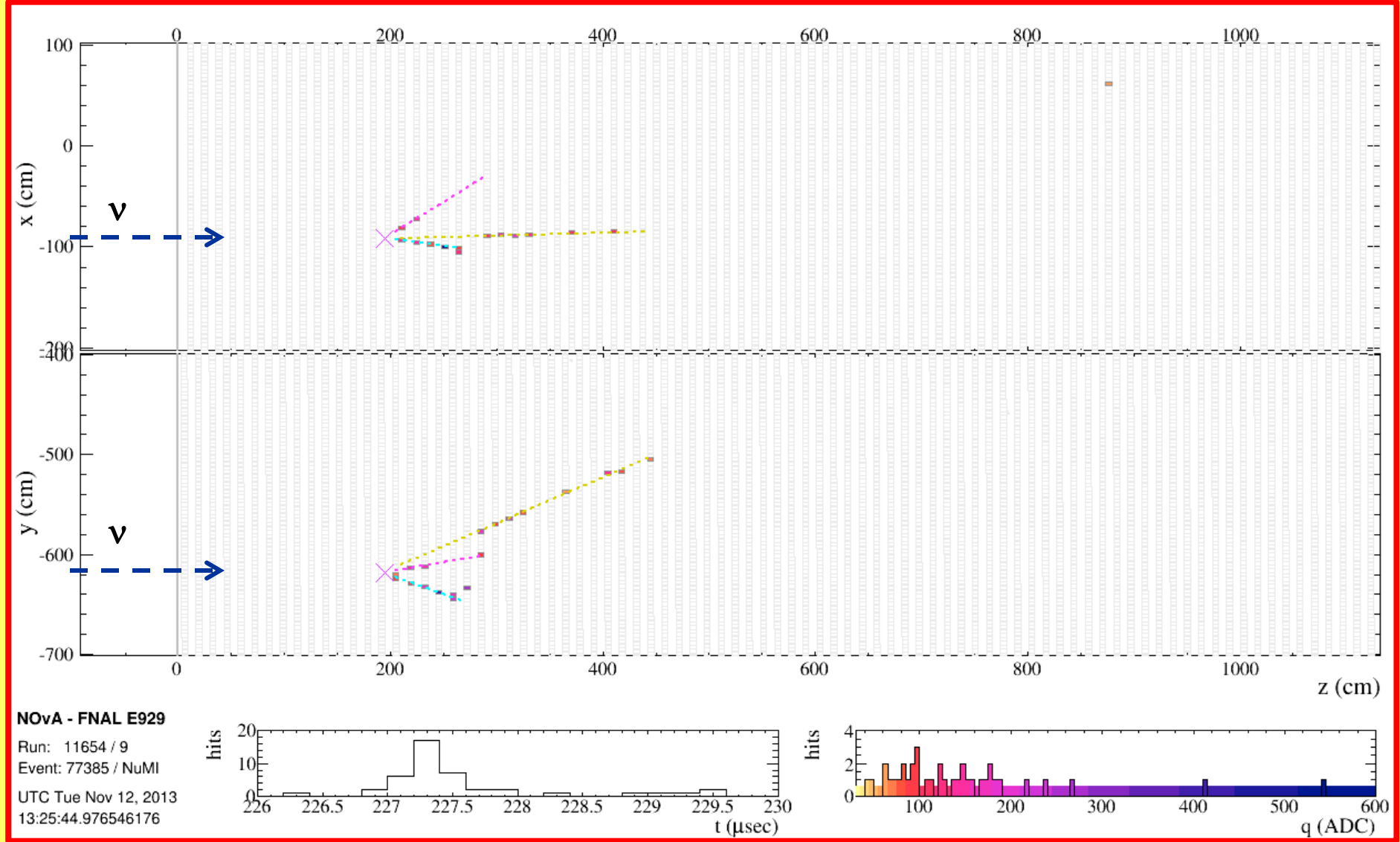


Final State Topologies



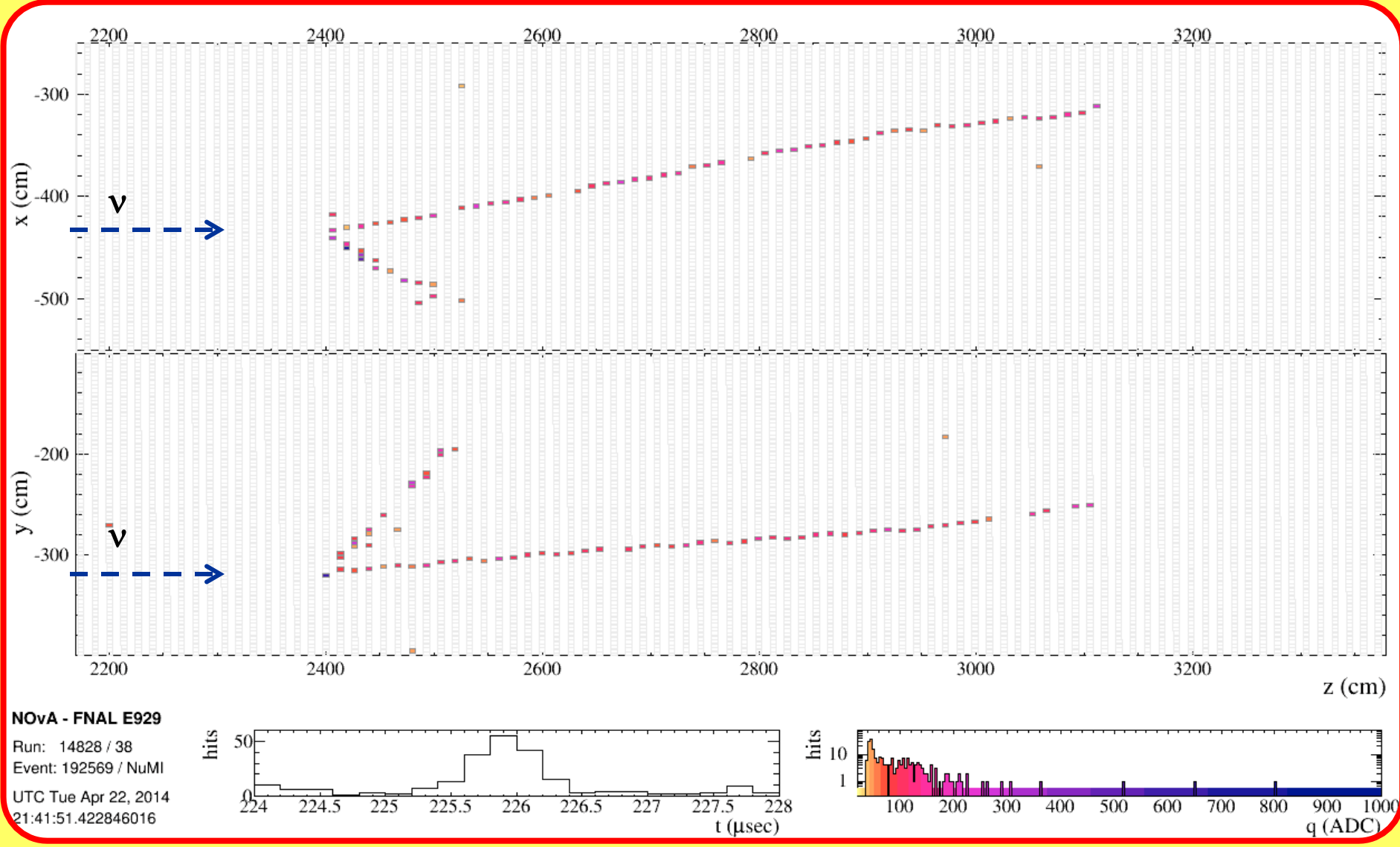
NOvA Monte Carlo







FD ν_μ Charged Current Event





Physics Measurement Scheme



NOvA measures probability of 4 reactions:

$\nu_{\mu} \rightarrow \nu_e$	$\bar{\nu}_{\mu} \rightarrow \bar{\nu}_e$	“appearance” measurements
$\nu_{\mu} \rightarrow \nu_{\mu}$	$\bar{\nu}_{\mu} \rightarrow \bar{\nu}_{\mu}$	“disappearance” measurements

Yes, antimatter is a thing...



Questions ???

(No, we have no nutria for tasting)