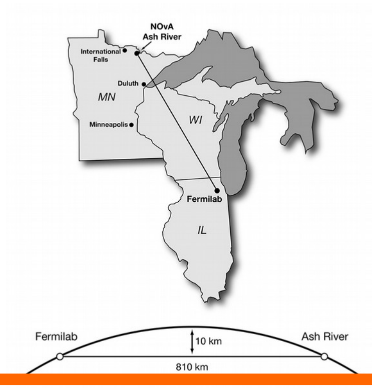
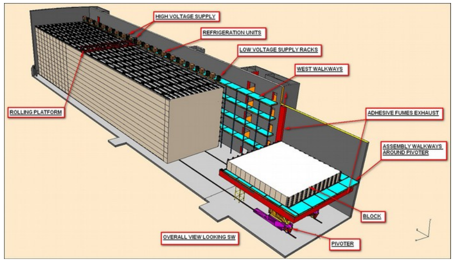
The Fermilab Short-Baseline Neutrino (SBN) Program

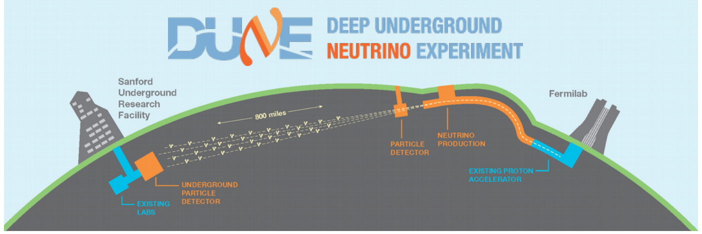
Jonathan Asaadi
University of Texas Arlington

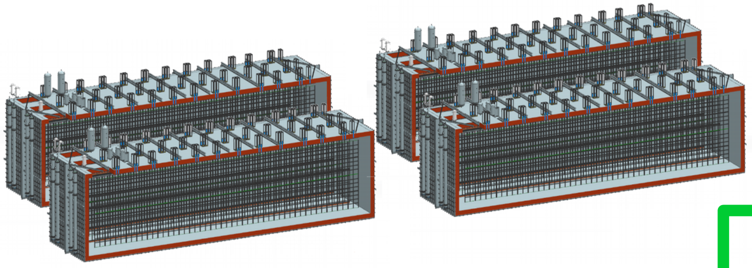
Fermilab is the home for LOTS of neutrino physics



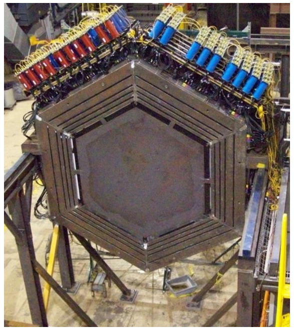


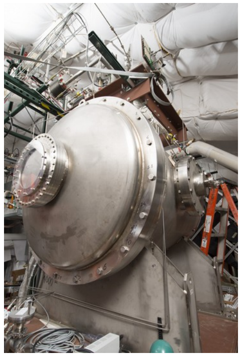
Current Long Baseline Experiments (Nova)



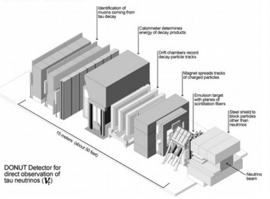


Future Long Baseline Experiments (DUNE)

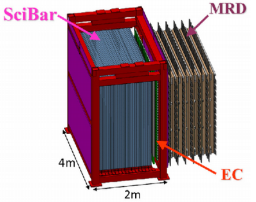




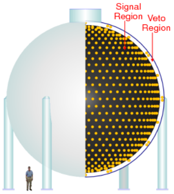
Current precision experiments (Minerνa and LArIAT)



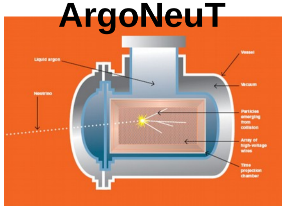
DONUT



SciBooNE



MiniBooNE

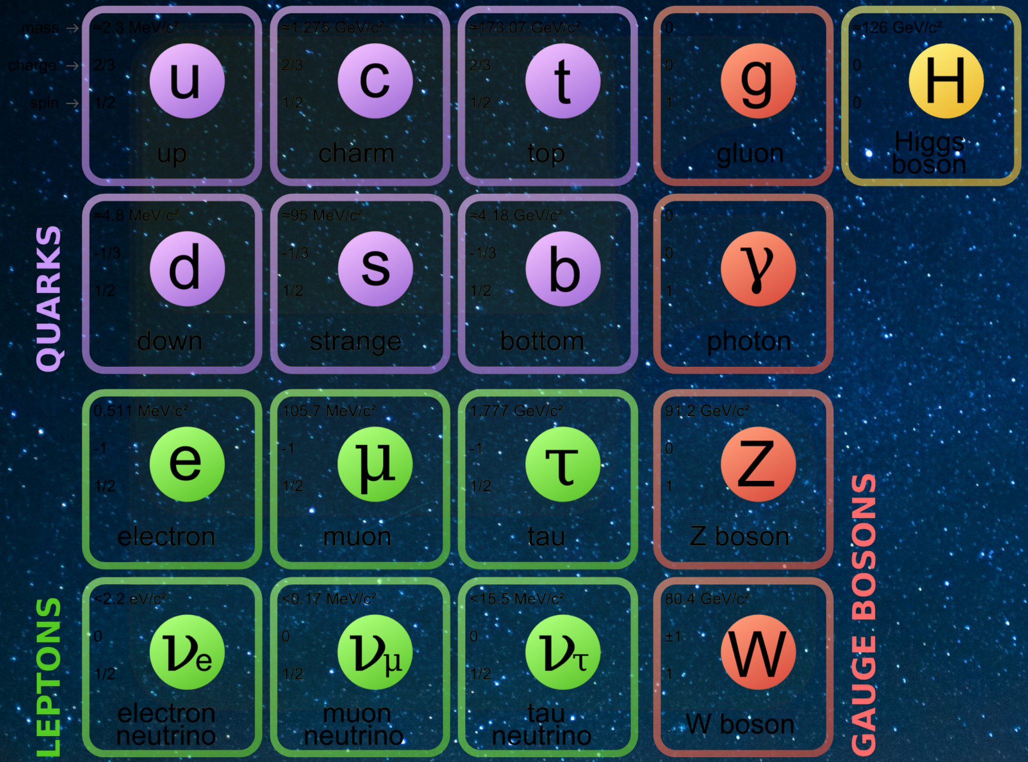


ArgoNeuT

MINOS

And a long history of completed neutrino experiments

Our world made of particles



mass →
charge →
spin →

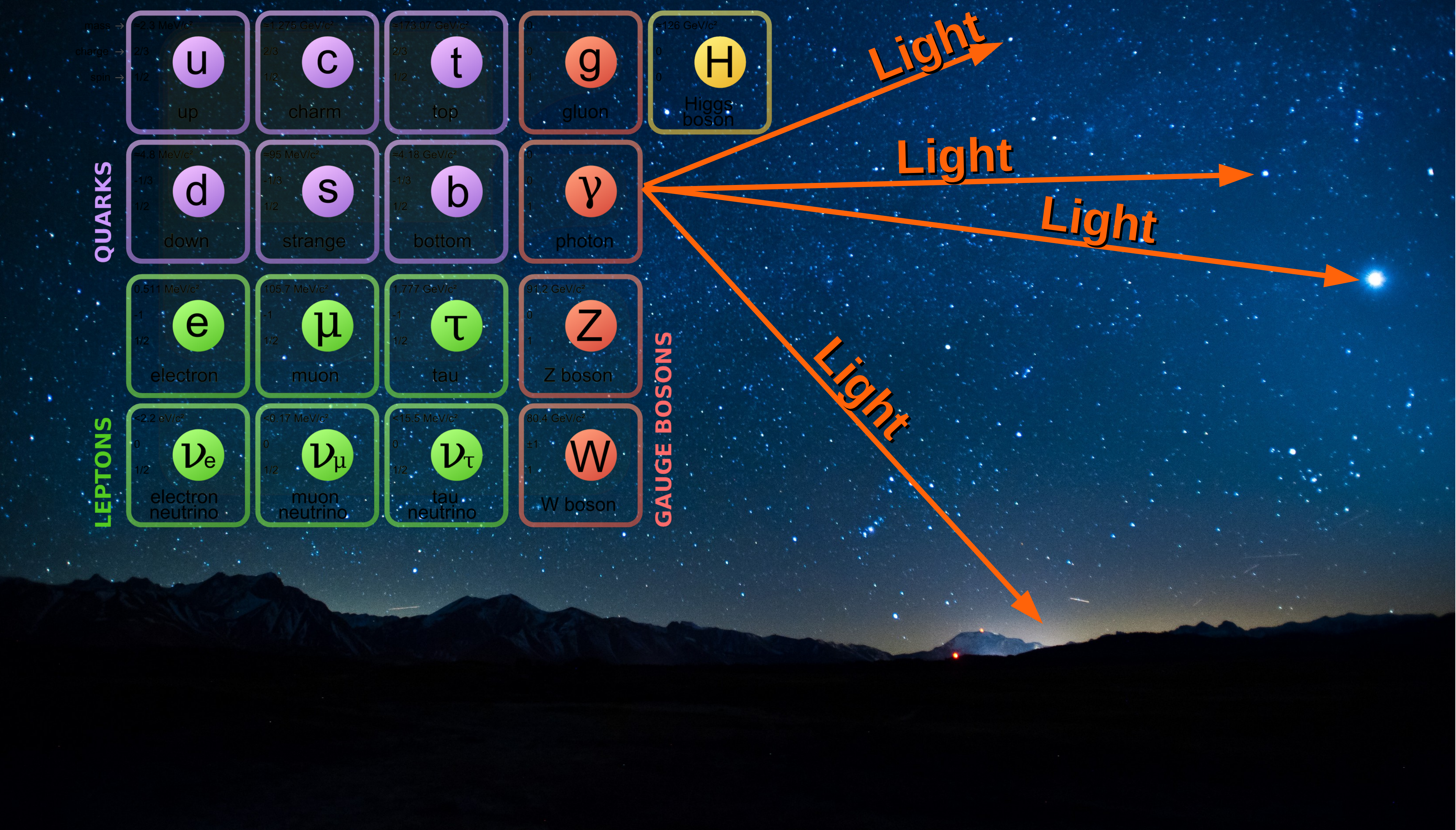
≈2.3 MeV/c² 2/3 1/2 u up	≈1.275 GeV/c² 2/3 1/2 c charm	≈173.07 GeV/c² 2/3 1/2 t top	0 0 1 g gluon	≈126 GeV/c² 0 0 H Higgs boson
≈4.8 MeV/c² -1/3 1/2 d down	≈95 MeV/c² -1/3 1/2 s strange	≈4.18 GeV/c² -1/3 1/2 b bottom	0 0 1 γ photon	
0.511 MeV/c² -1 1/2 e electron	105.7 MeV/c² -1 1/2 μ muon	1.777 GeV/c² -1 1/2 τ tau	91.2 GeV/c² 0 1 Z Z boson	
<2.2 eV/c² 0 1/2 ν_e electron neutrino	<0.17 MeV/c² 0 1/2 ν_μ muon neutrino	<15.5 MeV/c² 0 1/2 ν_τ tau neutrino	80.4 GeV/c² ±1 1 W W boson	

QUARKS

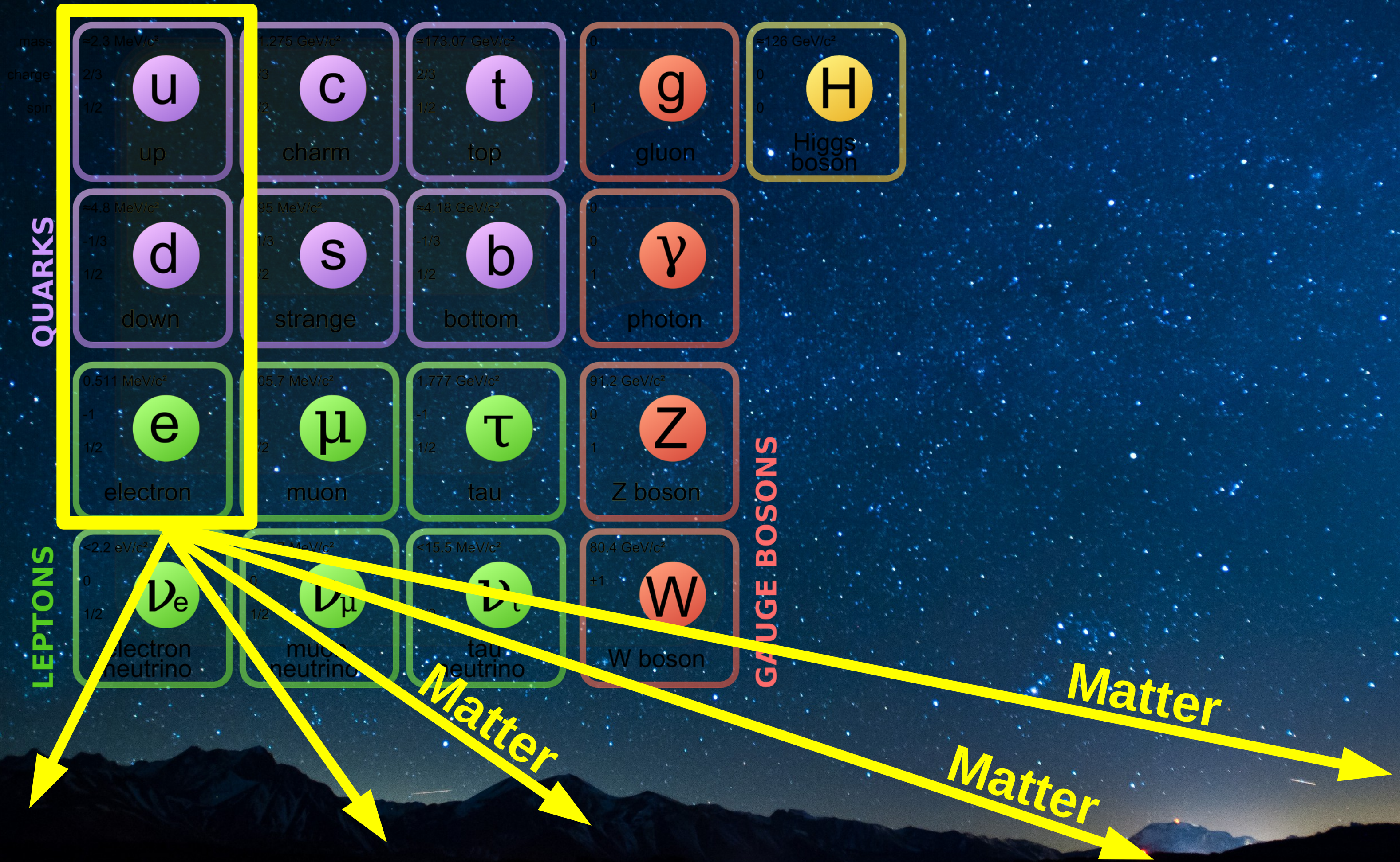
LEPTONS

GAUGE BOSONS

Our world made of particles

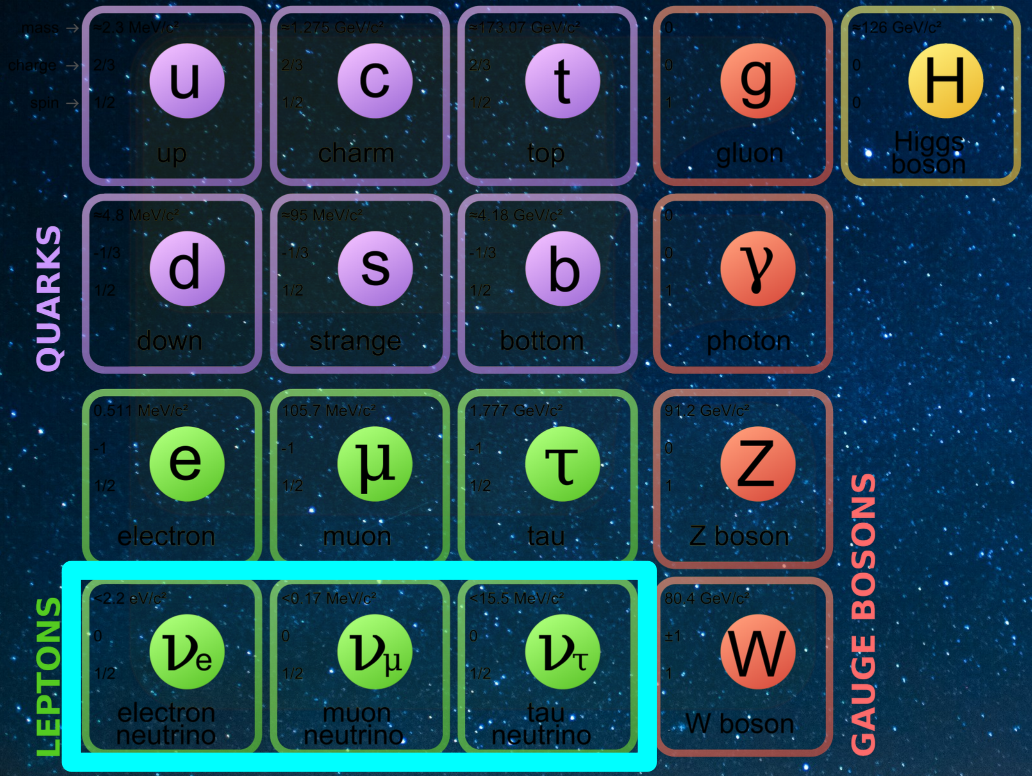


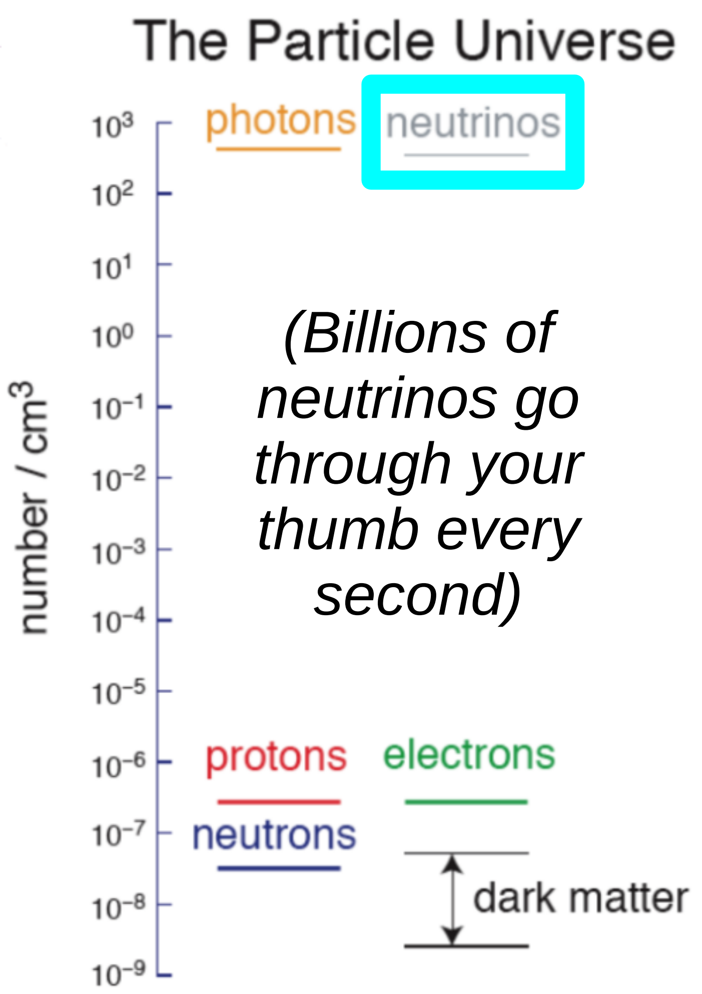
Our world made of particles



Made up of neutrinos

Neutrinos are the universes most common massive particle



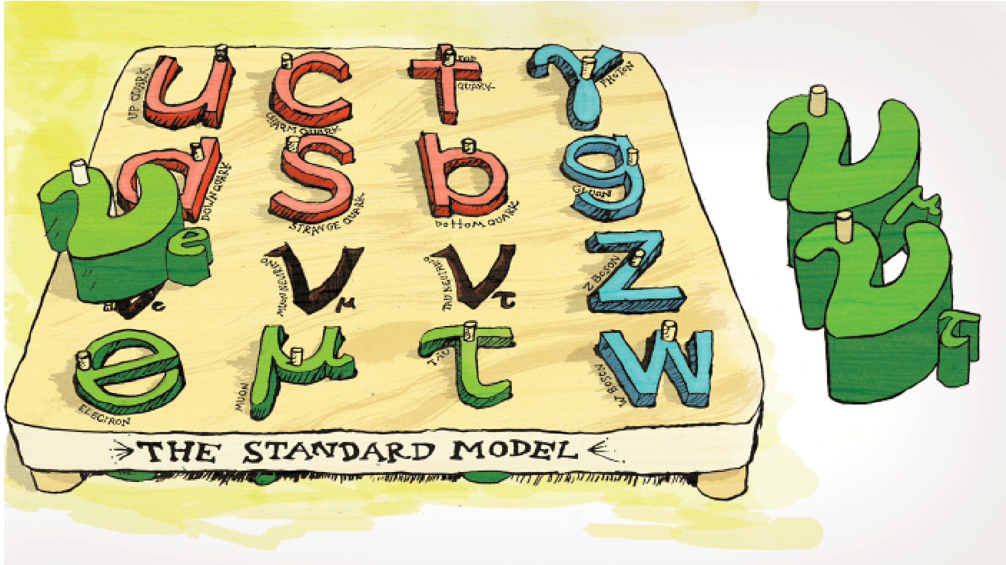


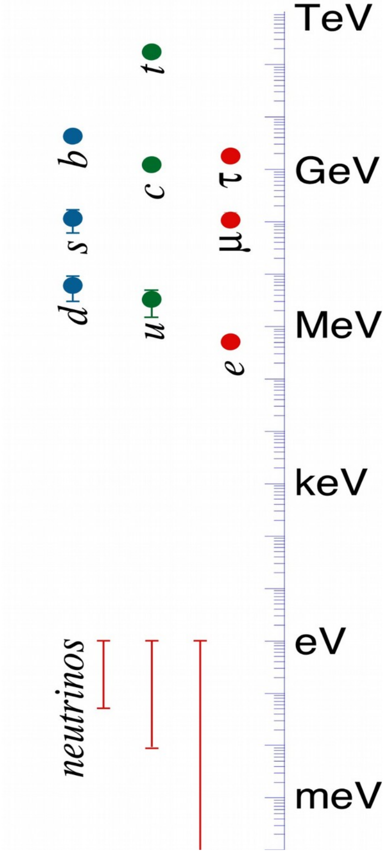
(Billions of neutrinos go through your thumb every second)

How come we don't notice them?

The Standard Model “Misfits”

- Symmetry Magazine 2013





Neutrinos have EXTREMELY small masses

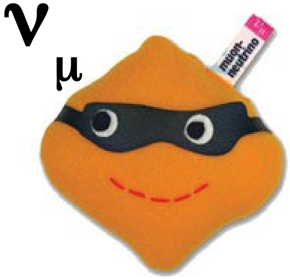
~10^{-6} times lighter than the electron

Neutrinos only interact (talk to the rest of the universe) via the weak nuclear force

Neutrinos only interact via the weak nuclear force

(They carry no charge)

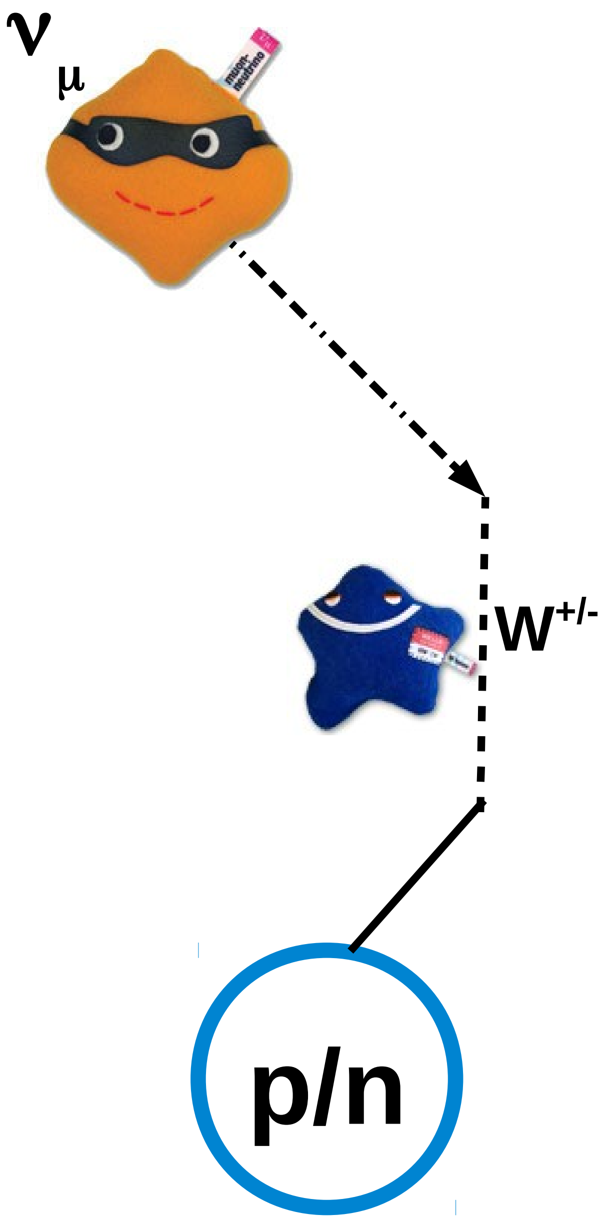
ν_μ



p/n

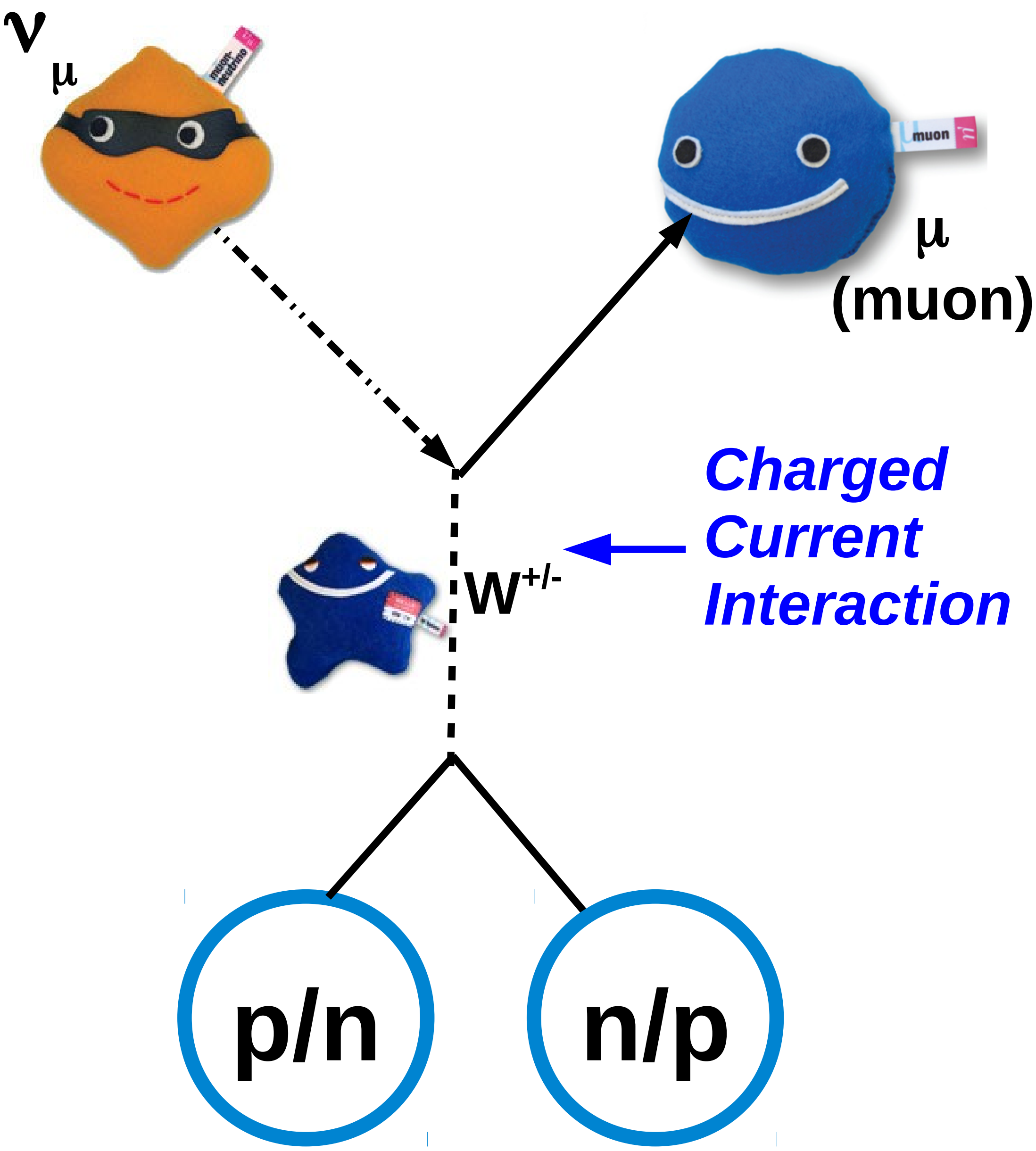
Neutrinos only interact via the weak nuclear force

(They carry no charge)



Neutrinos only interact via the weak nuclear force

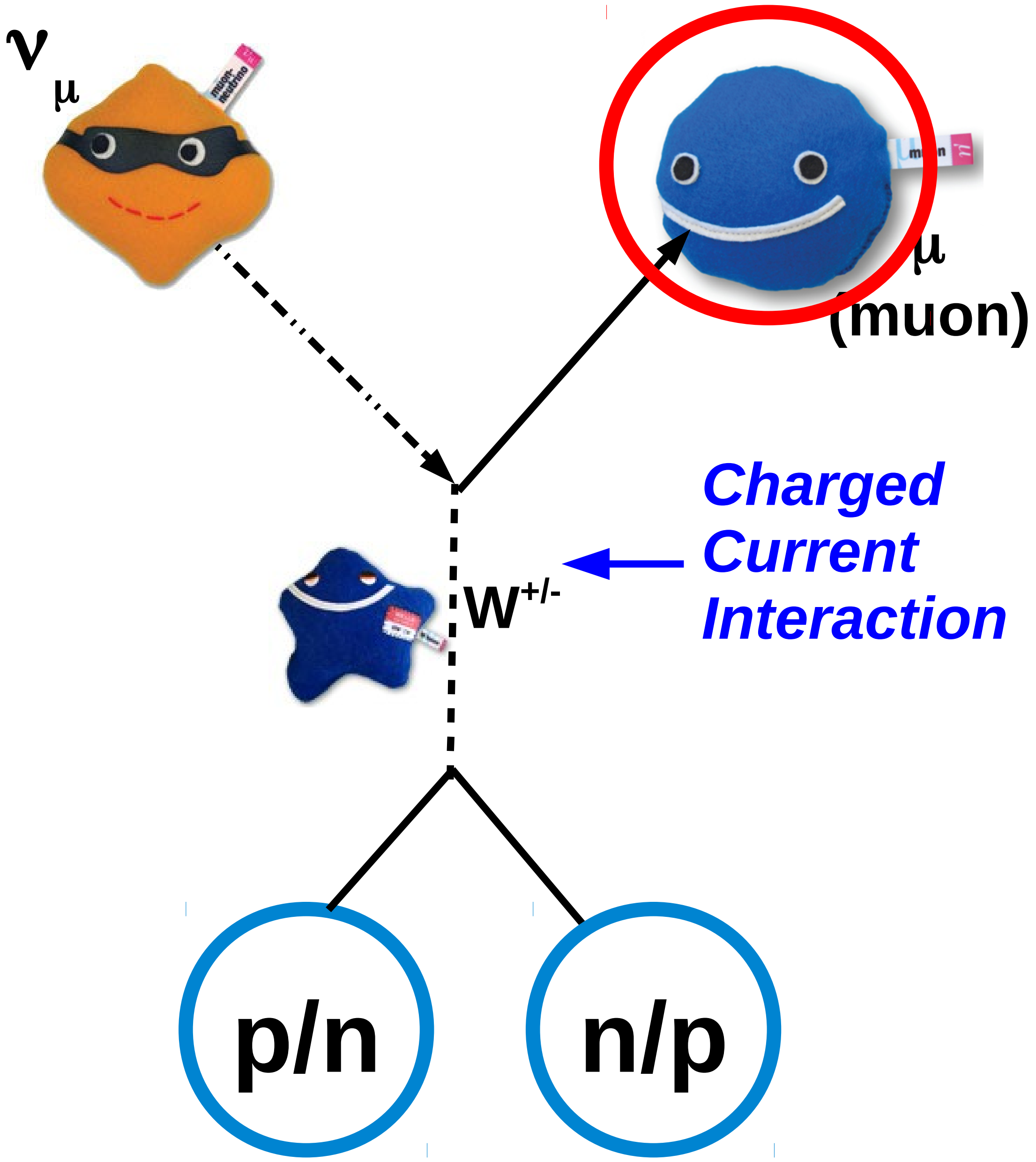
(They carry no charge)



Charged Current Interaction

Neutrinos only interact via the weak nuclear force

(They carry no charge)

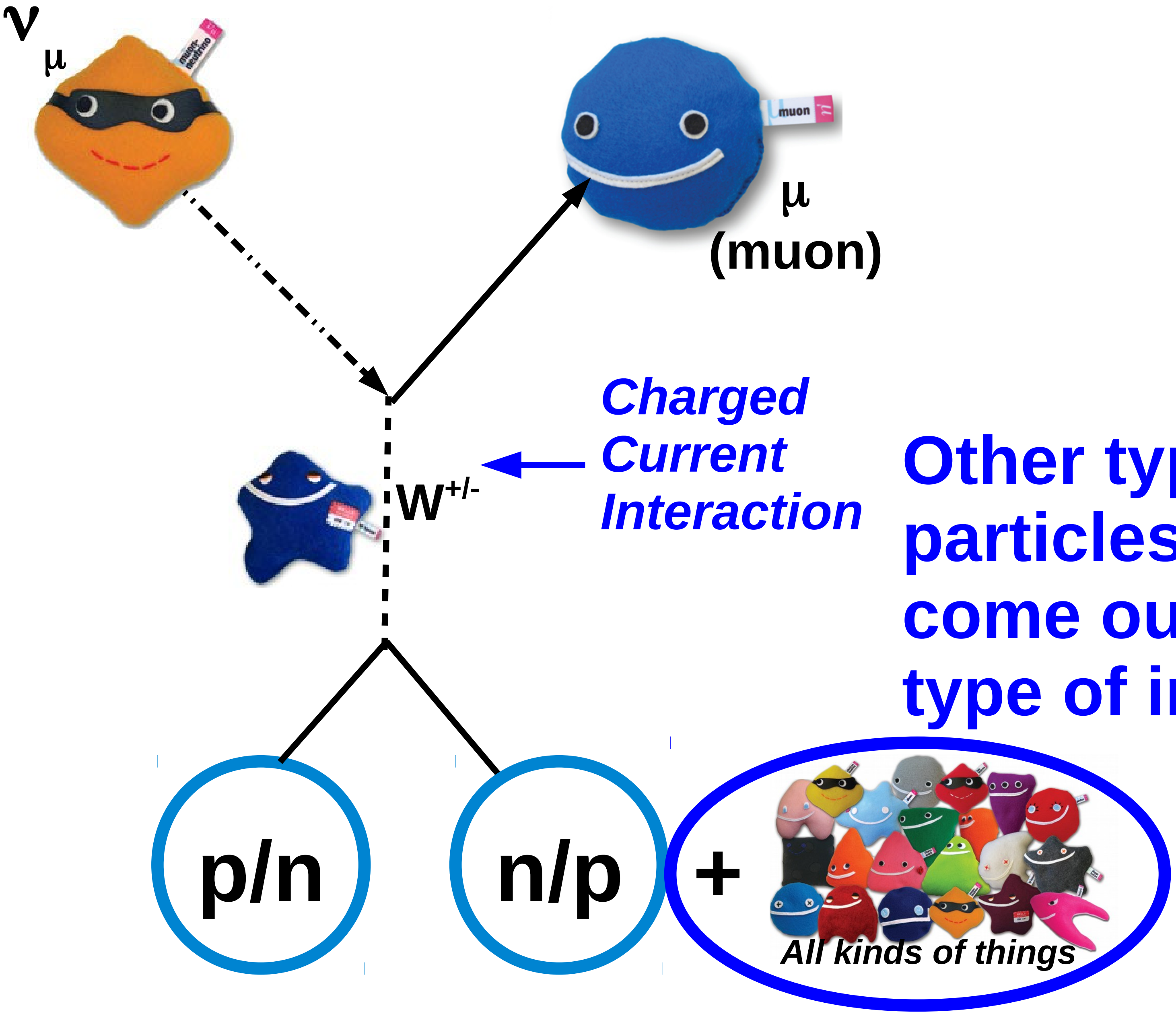


Charged Current Interaction

The type of particle that comes out tells you information about the type of neutrino that interacted

Neutrinos only interact via the weak nuclear force

(They carry no charge)



ν_μ

μ
(muon)

$W^{+/-}$

Charged Current Interaction

p/n

n/p

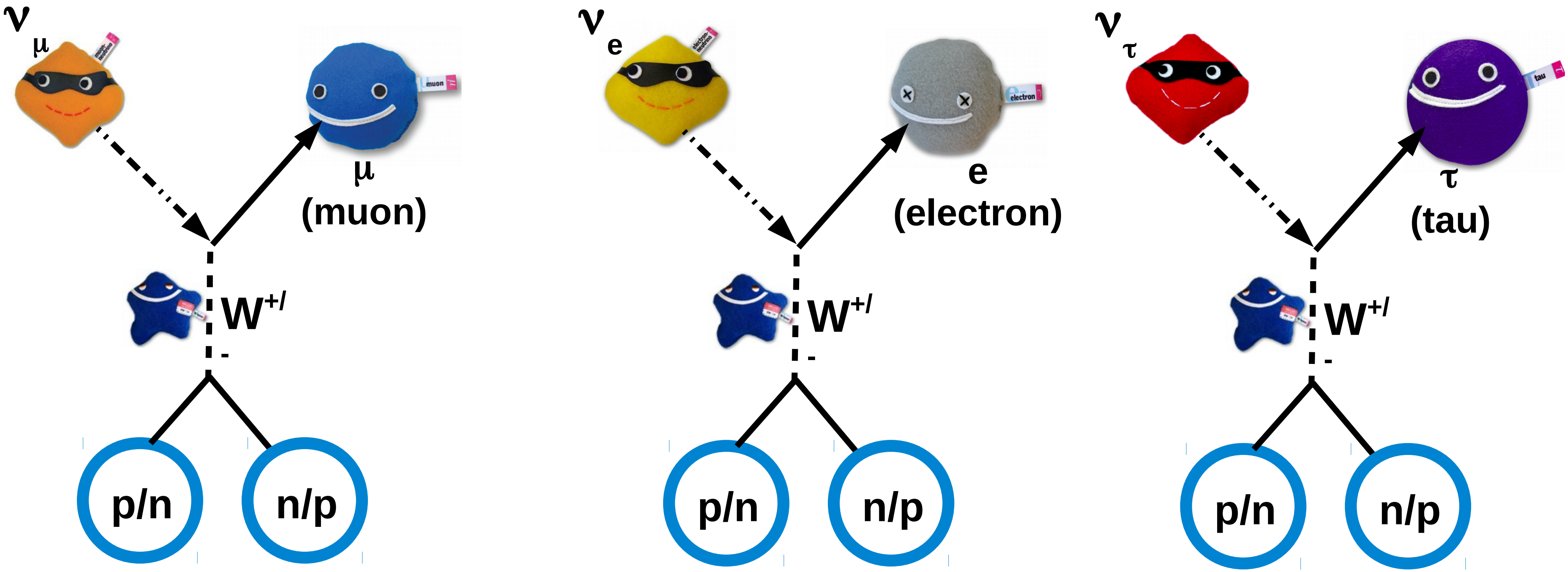
\+

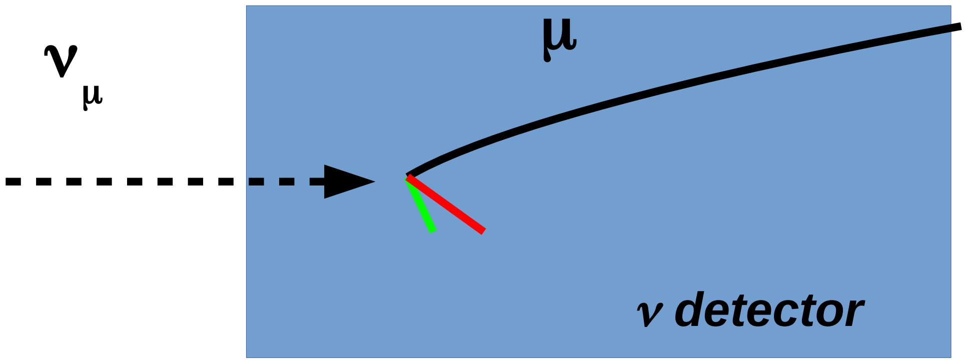
All kinds of things

Other types of particles can also come out from this type of interaction

Neutrinos only interact via the weak nuclear force

(They carry no charge)

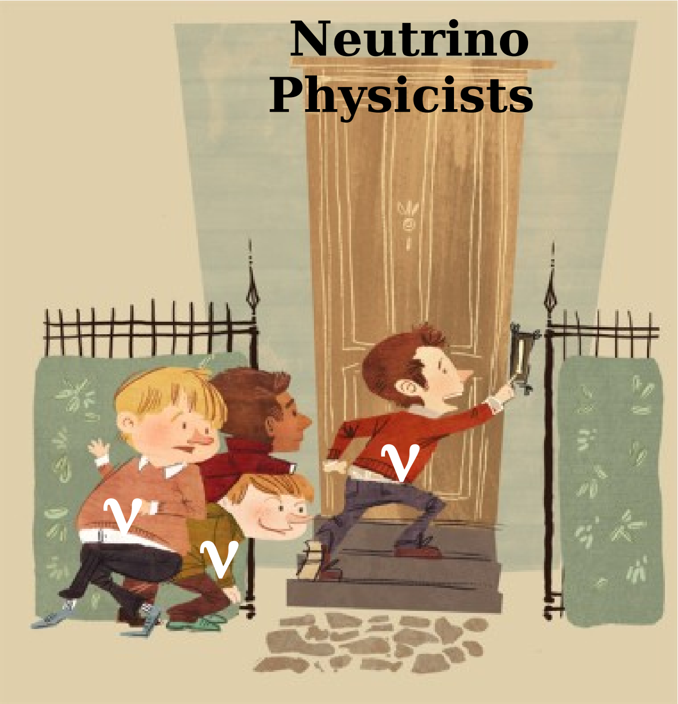




“Nothing” in....something out!

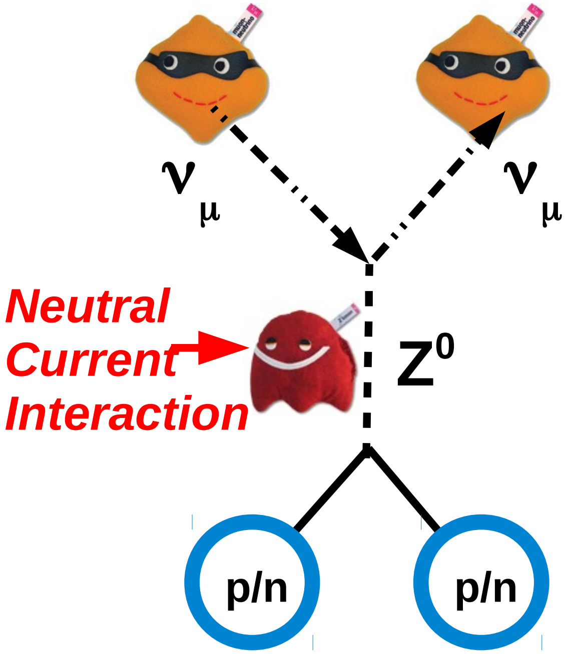
(One of those somethings is a lepton)

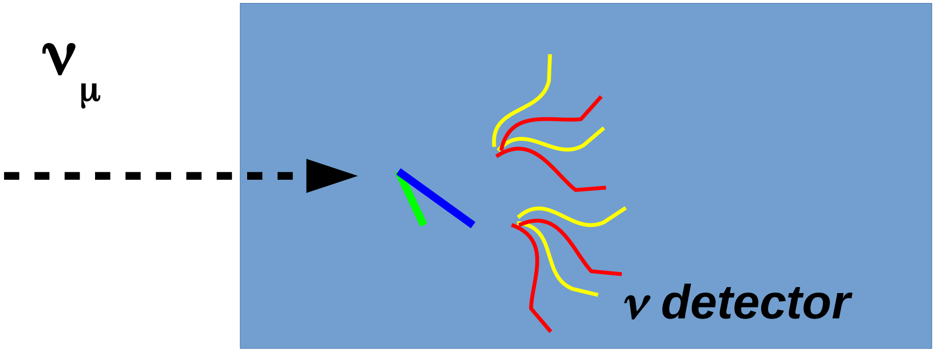
Neutral Current Interactions



"...sometimes, the neutrino opts to play ding-dong-ditch instead, depositing a fraction of its energy in the detector before speeding away. This is called a neutral current event, and, in many cases, it is the bane of the modern neutrino physicist's existence...."

– Symmetry Magazine, May 06th 2014

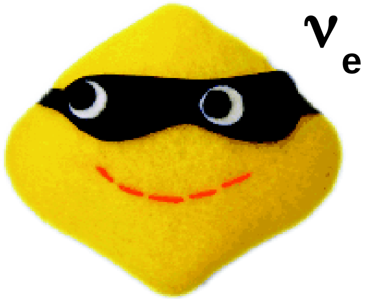




"Nothing" in....something out!

(Those somethings is NOT a lepton)

Neutrino Oscillation Physics



ν_e

ν_μ

ν_τ

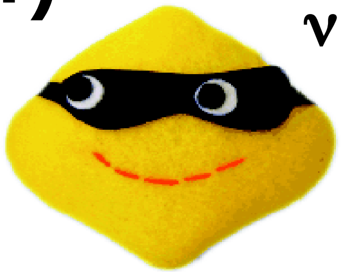
Neutrino Flavor States

Turns out that we observe neutrinos changing (oscillating) their type (flavor)

ν_μ

This means I can start with one type of neutrino

Let it travel some distance



ν_e

And it will have changed its type

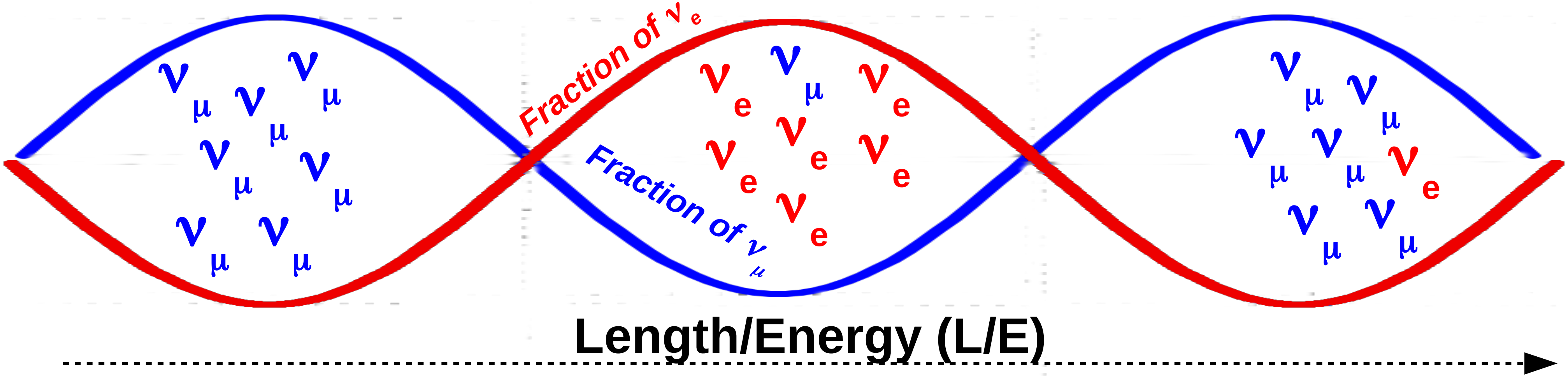
ν_1

ν_2

ν_3

Neutrino Mass States

Understanding Neutrino Oscillations



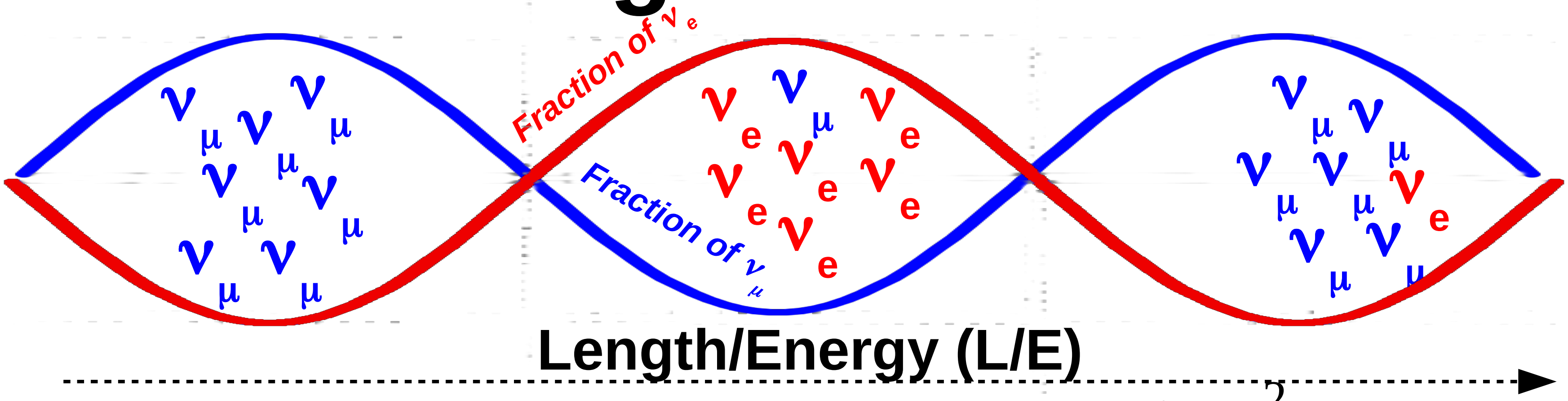
$$P(\nu_\mu \rightarrow \nu_e) = \sin^2(2\theta)\sin^2\left(\frac{\Delta m^2 L}{4E_\nu}\right)$$

This oscillation between different flavors can be understood as a mixing which looks like a sine wave

Mother nature gives us Δm and θ

We use the length the neutrino has traveled (L), and the energy of the neutrino (E) to probe and understand the nature of the oscillation

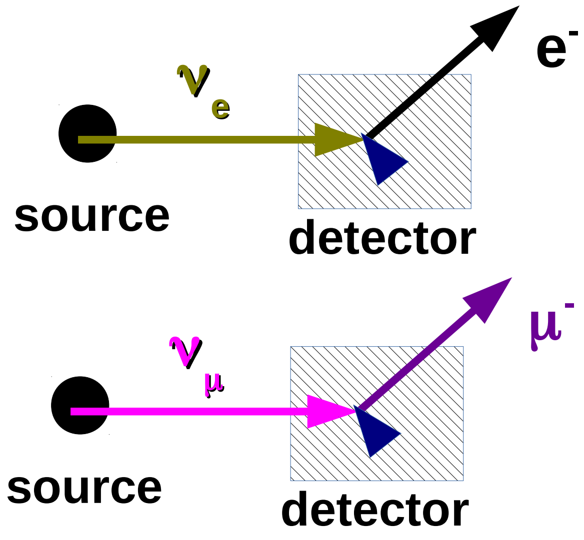
Understanding this weird behavior



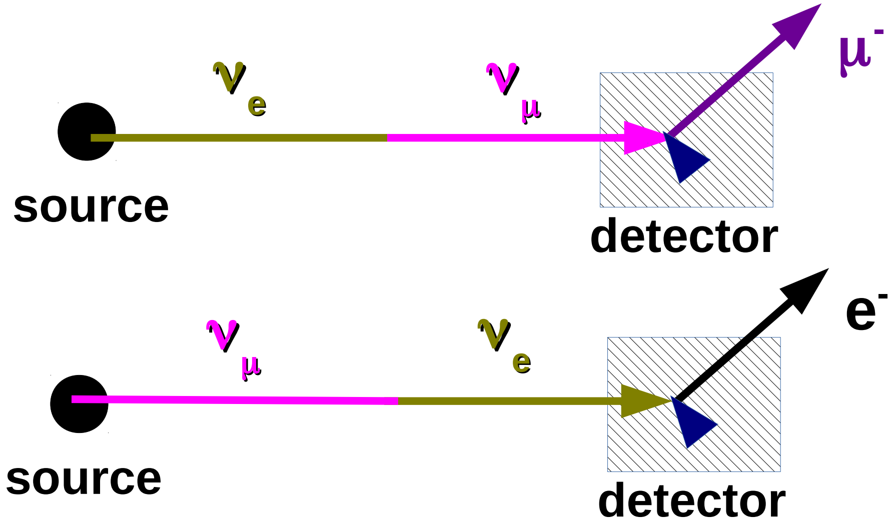
$$P(\nu_\mu \rightarrow \nu_e) = \sin^2(2\theta)\sin^2\left(\frac{\Delta m^2 L}{4E_\nu}\right)$$

What this means for an experimentalist is if I have a source of neutrinos I can study their oscillation behavior

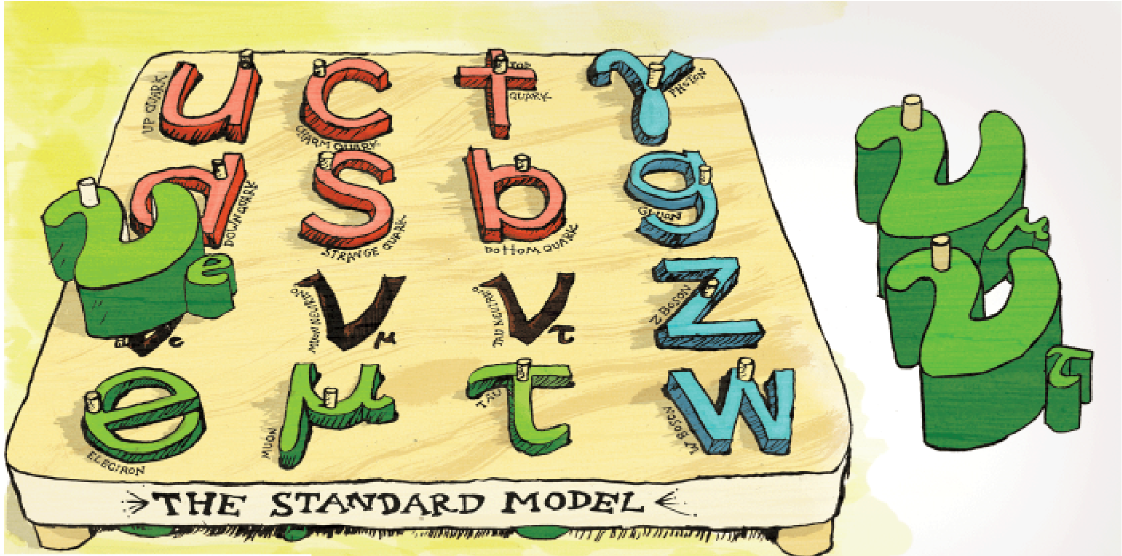
For very short distances

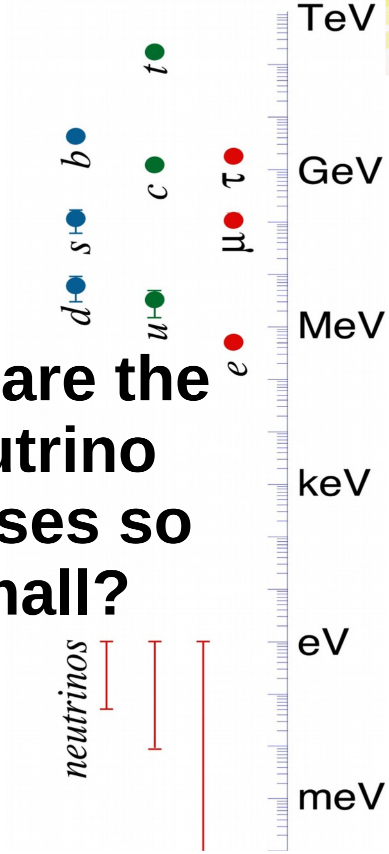


For longer distances

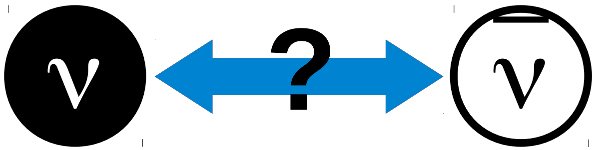


Unanswered “Misfit” Questions

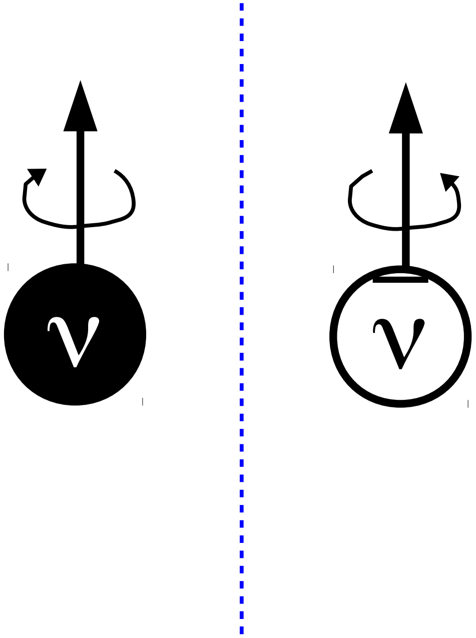




Why are the neutrino masses so small?



Is the neutrino its own anti-particle?



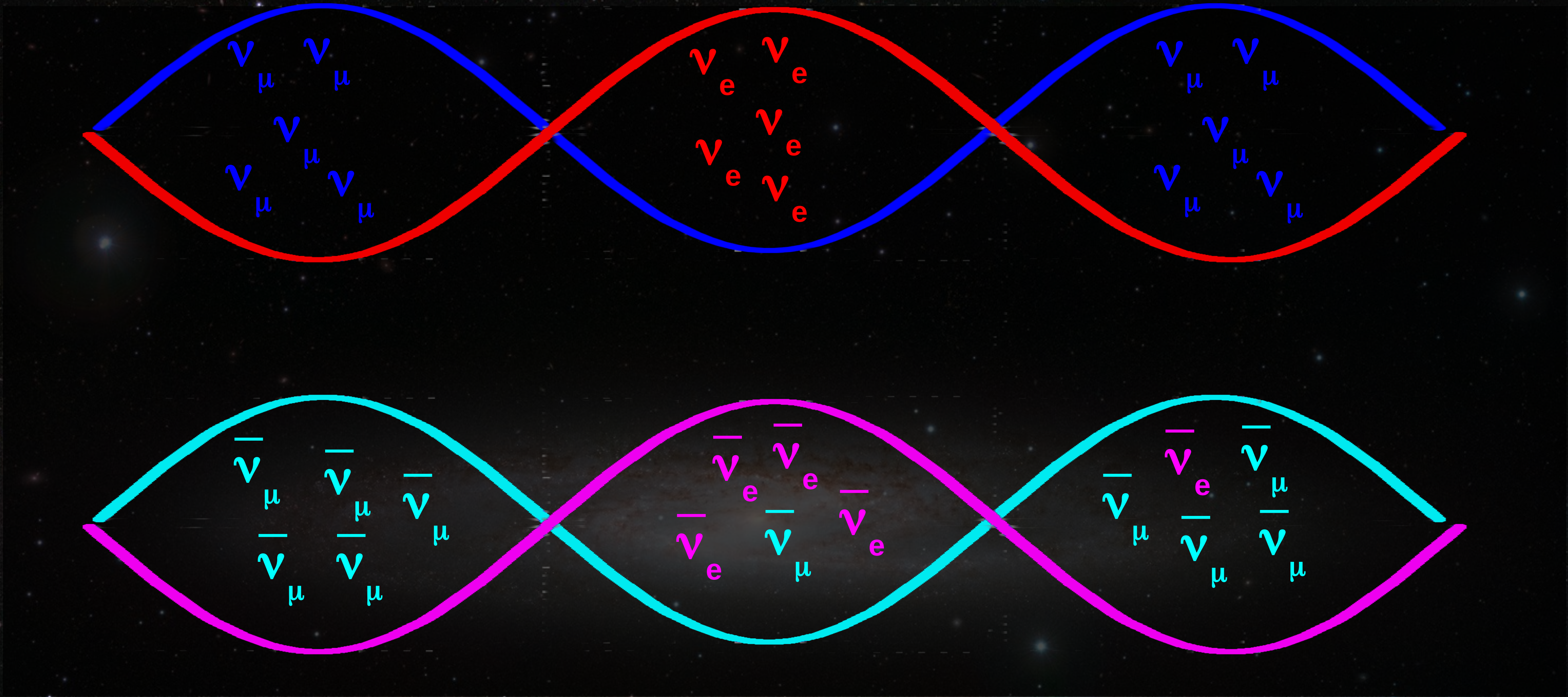
CP- Conservation?

Puzzles in universe addressed with ν's

Puzzles in universe addressed with ν's

Where is all the anti-matter?

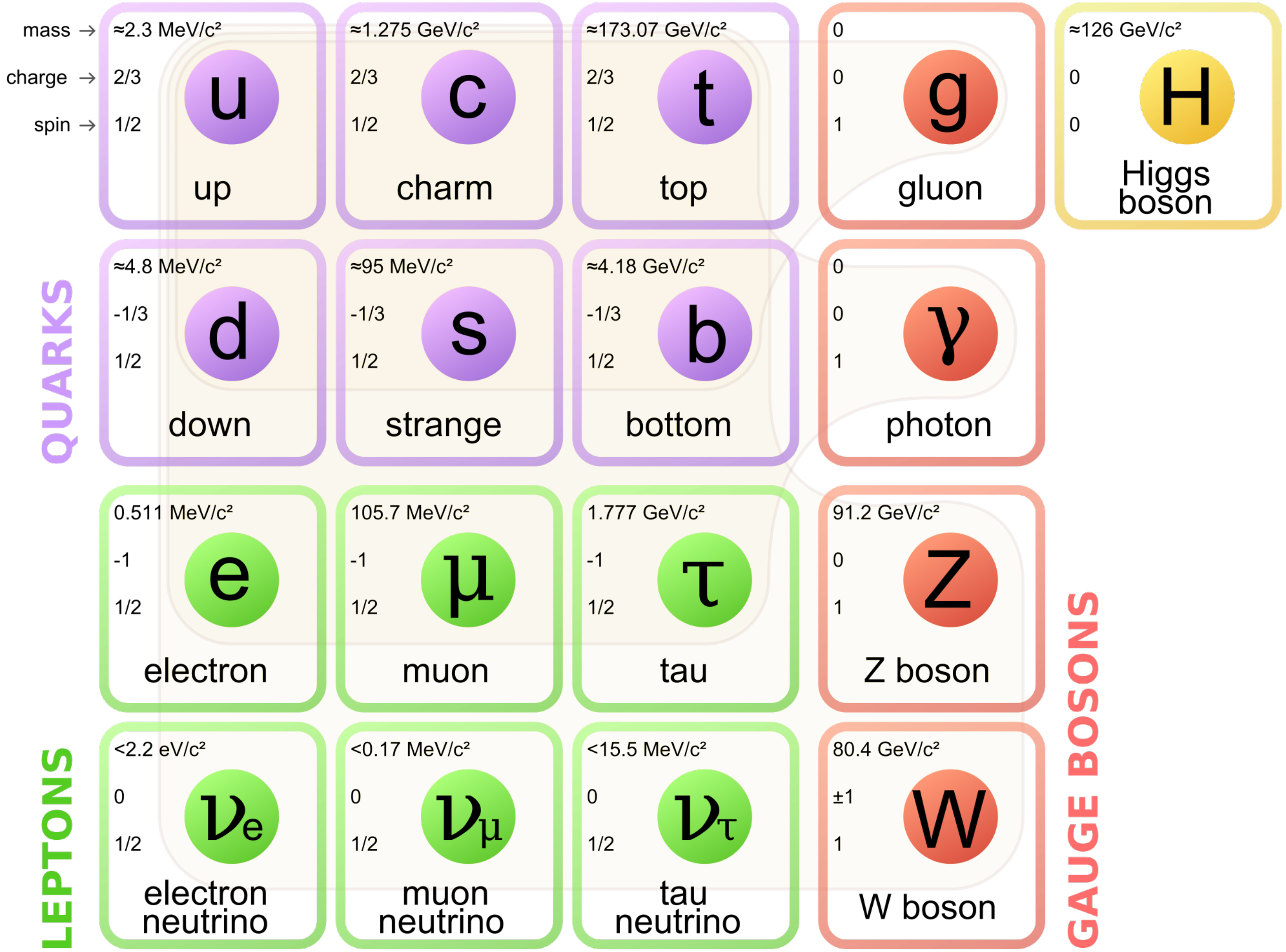
Puzzles in universe addressed with ν's



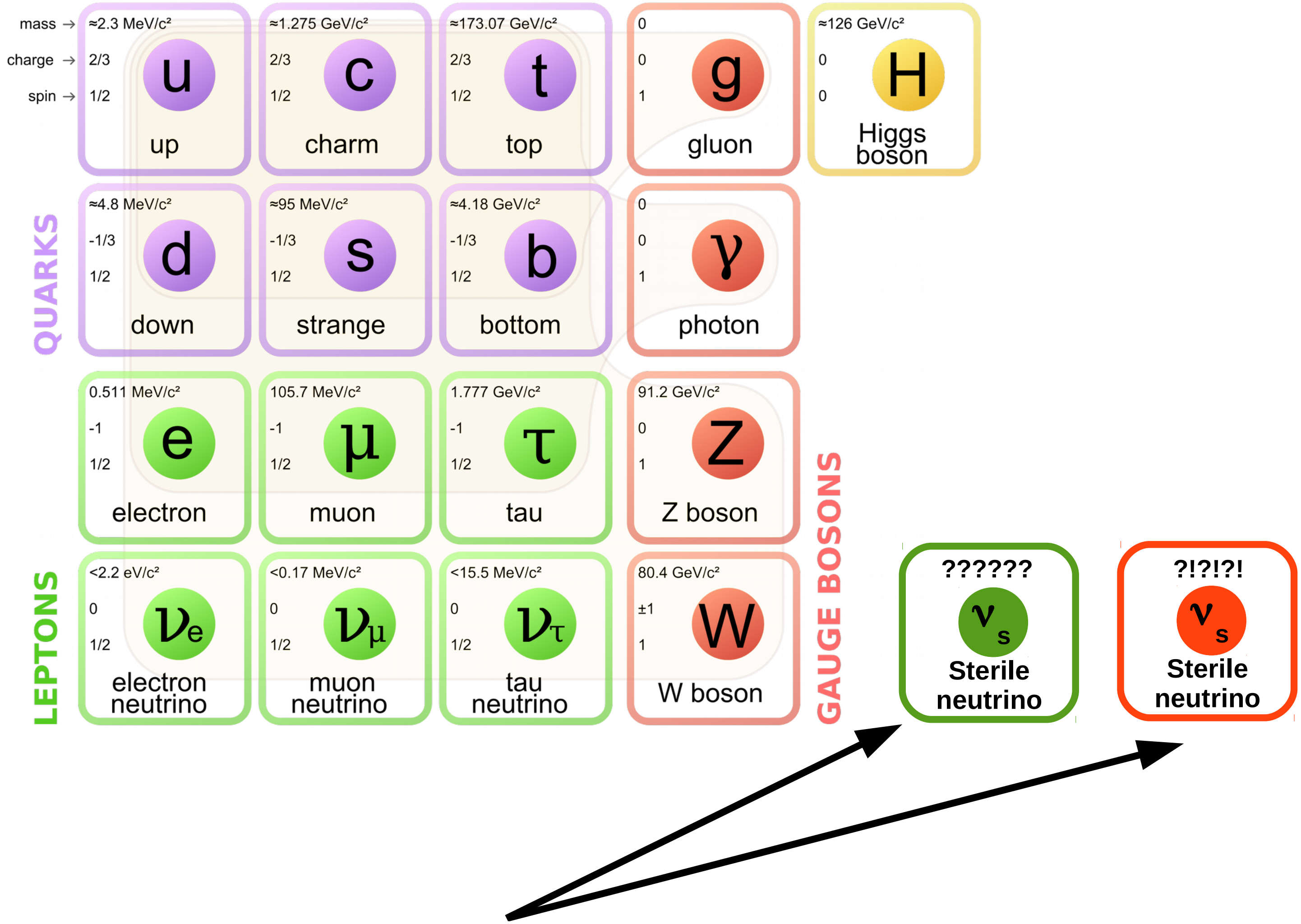
Neutrino oscillation could allow a preferential transition of matter to dominate in our early universe of anti-matter

Puzzles in universe addressed with ν's

Is this picture complete?

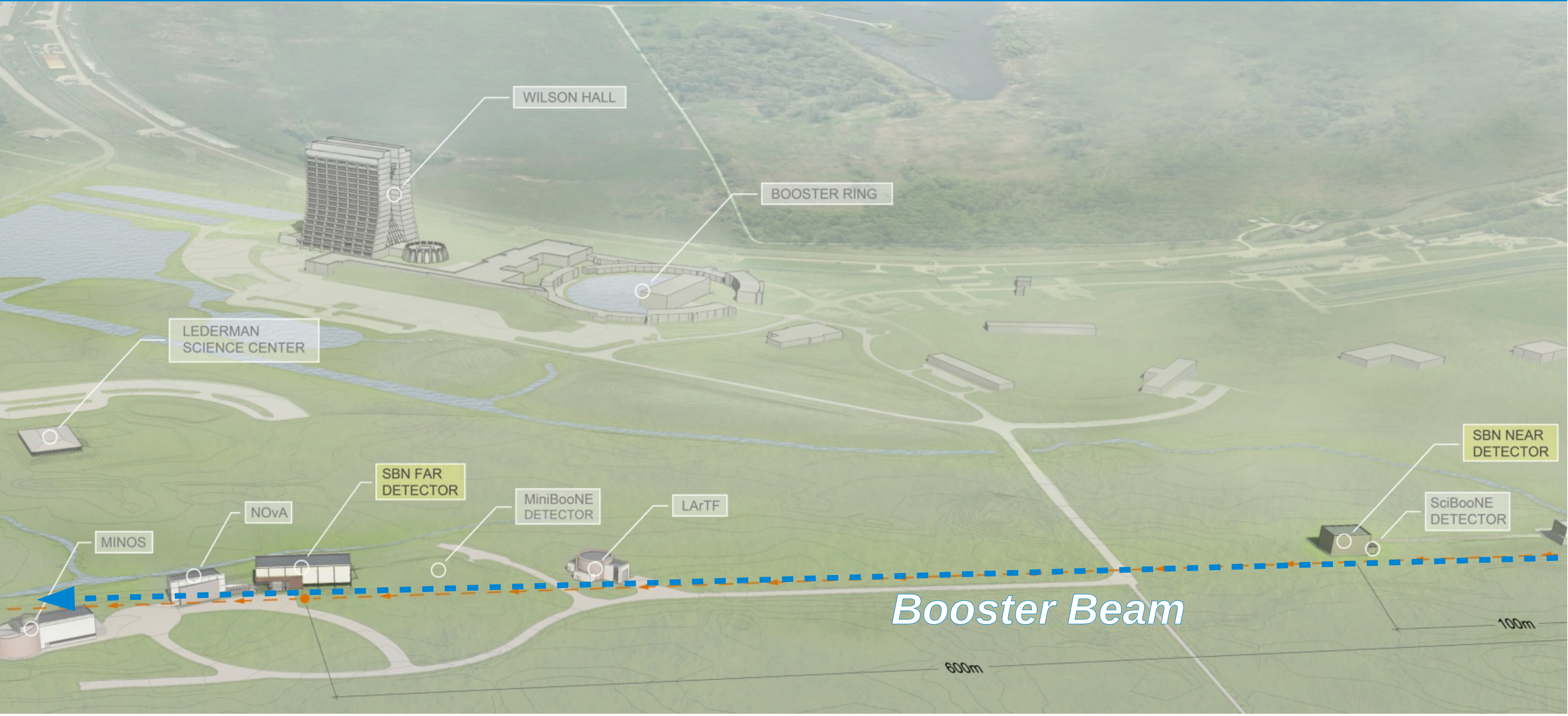


Puzzles in universe addressed with ν's



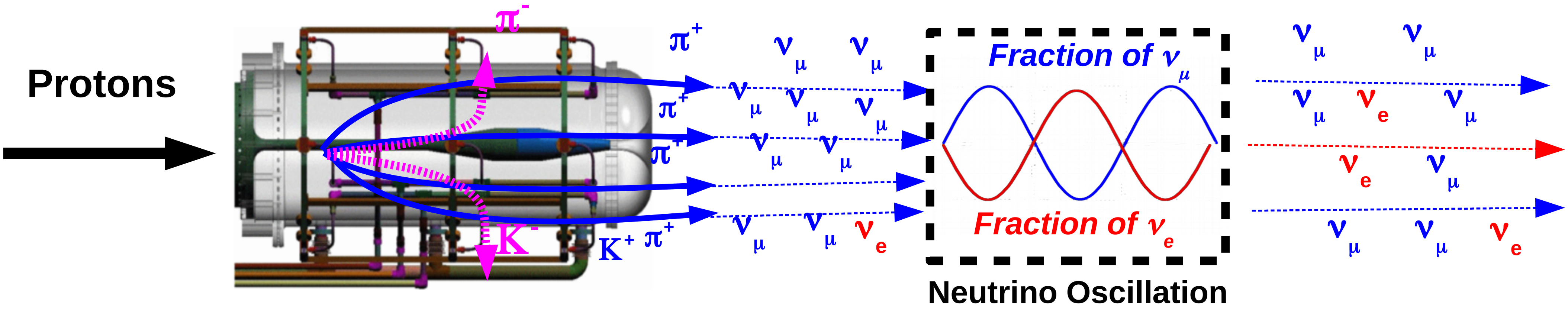
There is an ever growing body of work that suggests the possibility of more neutrinos than the three we know about in the Standard Model

The Short-Baseline Neutrino Program



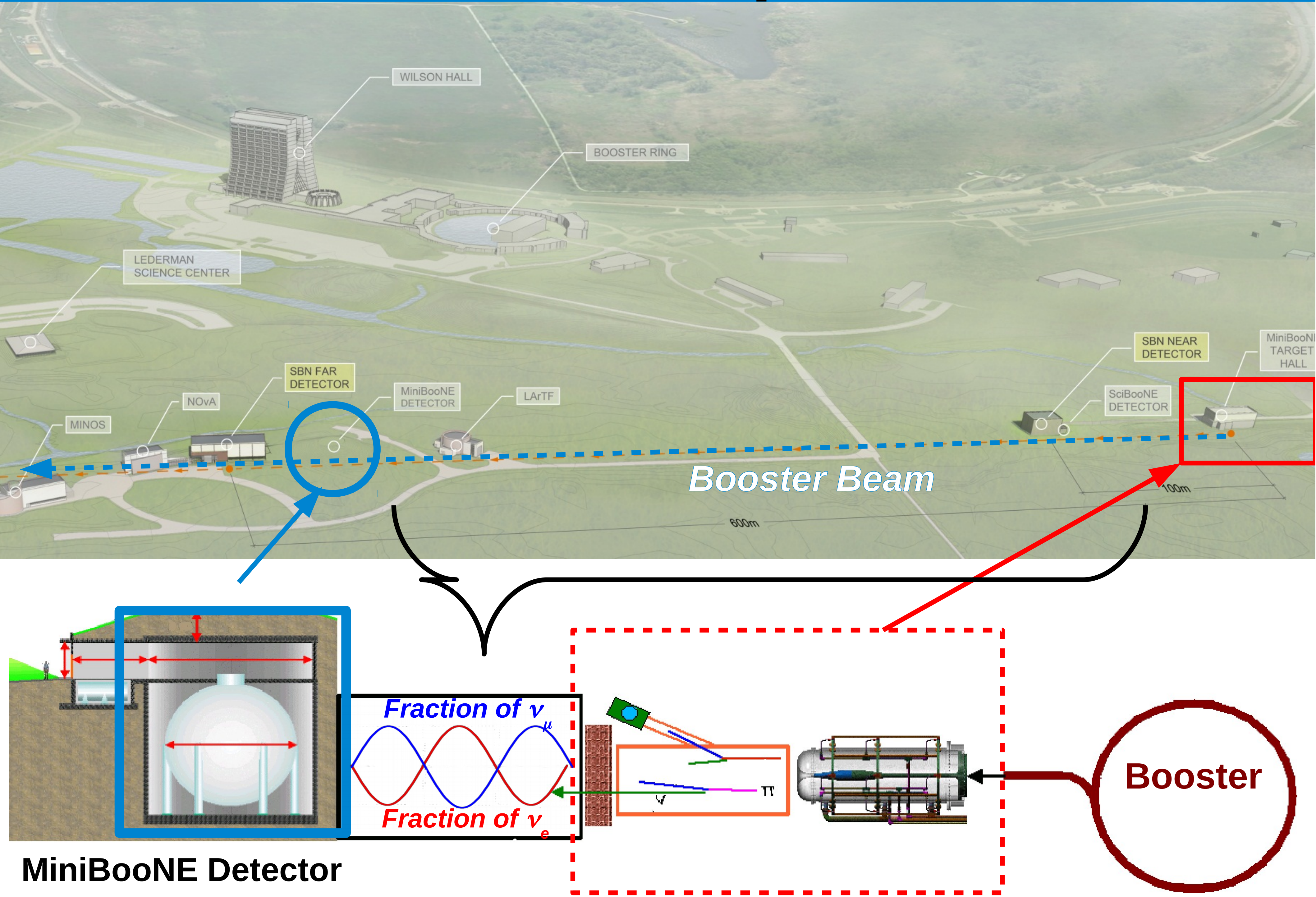
The story of the Short-Baseline Neutrino Program can best be understood through the history of the physics that we've been following

Booster Neutrino Beam



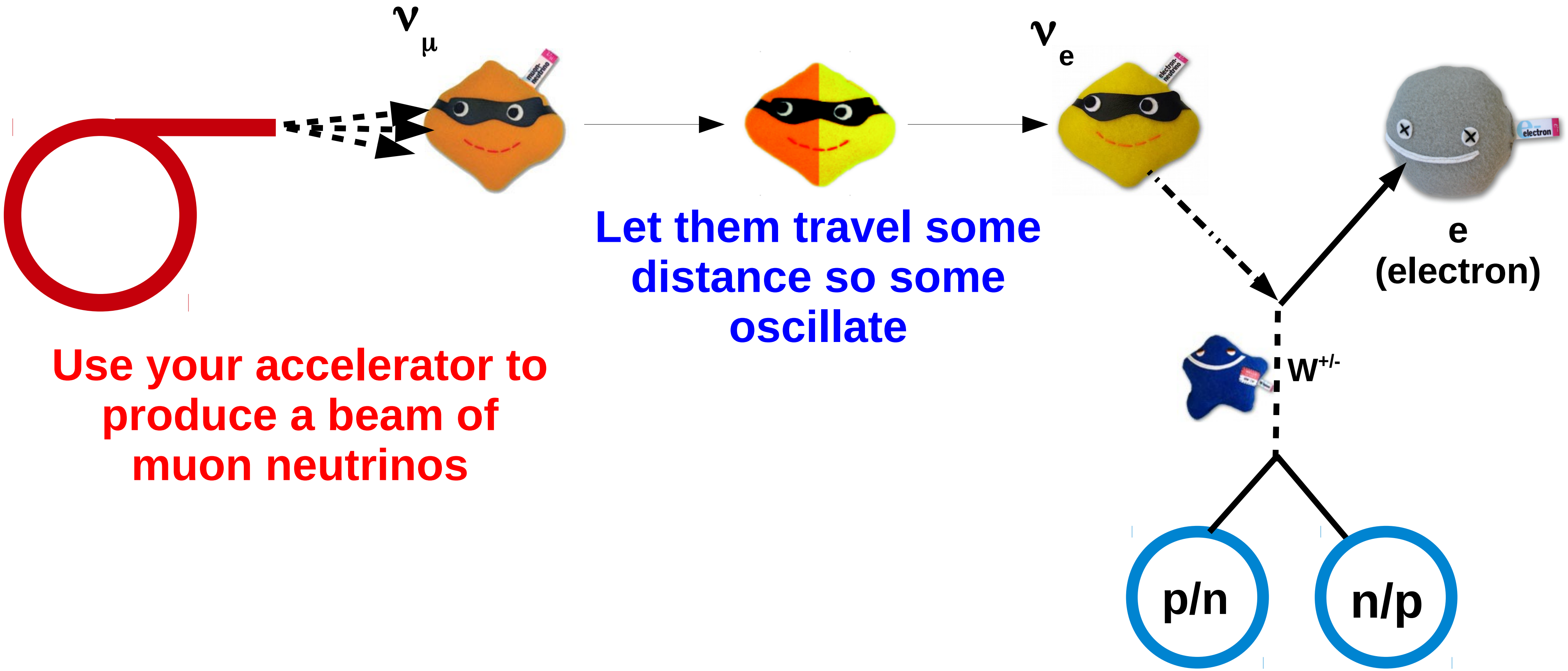
- **Booster Neutrino Beam (BNB) has been operating for a decade!**
  - A very well understood and characterized beam
  - Low (< 0.5%) contamination from intrinsic ν_e
- **Neutrino beam created from 8 GeV protons colliding on a beryllium target and having sign selected pions focused by a magnetic horn**

MiniBooNE Experiment



MiniBooNE Detector

An accelerator based oscillation experiments sees an excess of ν_e events appearing



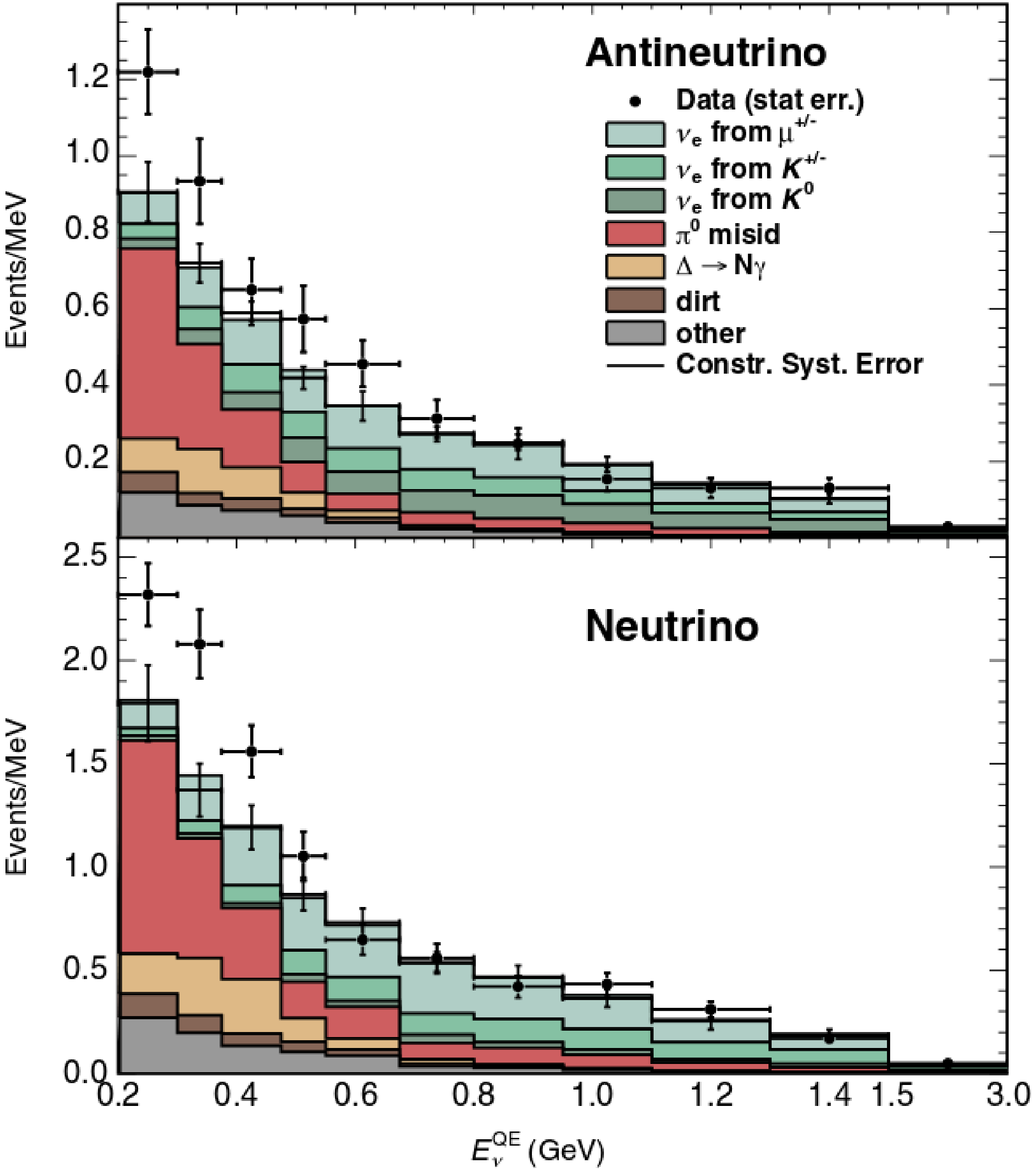
Look for the appearance of the other type of electron neutrinos

Let them travel some distance so some oscillate

Use your accelerator to produce a beam of muon neutrinos

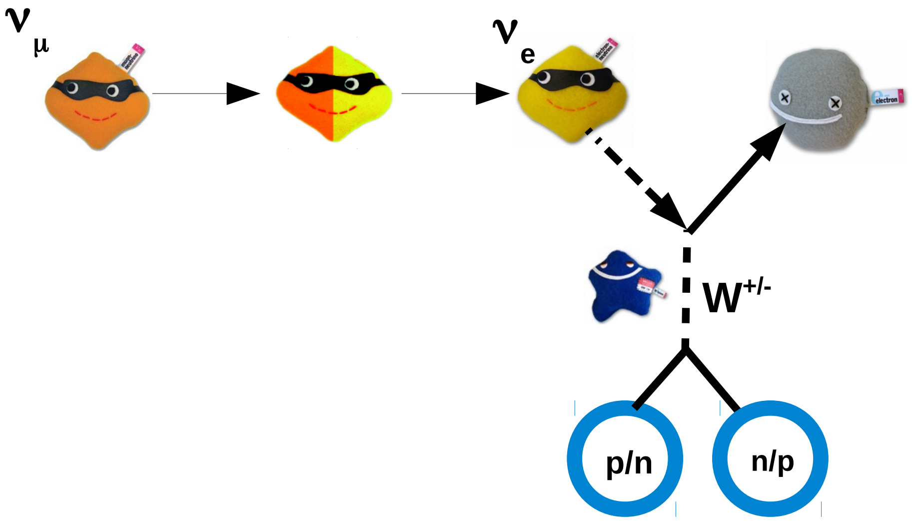
An accelerator based oscillation experiments sees an excess of ν_e events appearing

Phys. Rev. Lett. 110, 161801 (2013)



Mini-Booster Neutrino Experiment (MiniBooNE)

sees an excess of events in $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ and $\nu_\mu \rightarrow \nu_e$ appearance



Could a different oscillation be causing this excess ???

What if there are more types of ν's

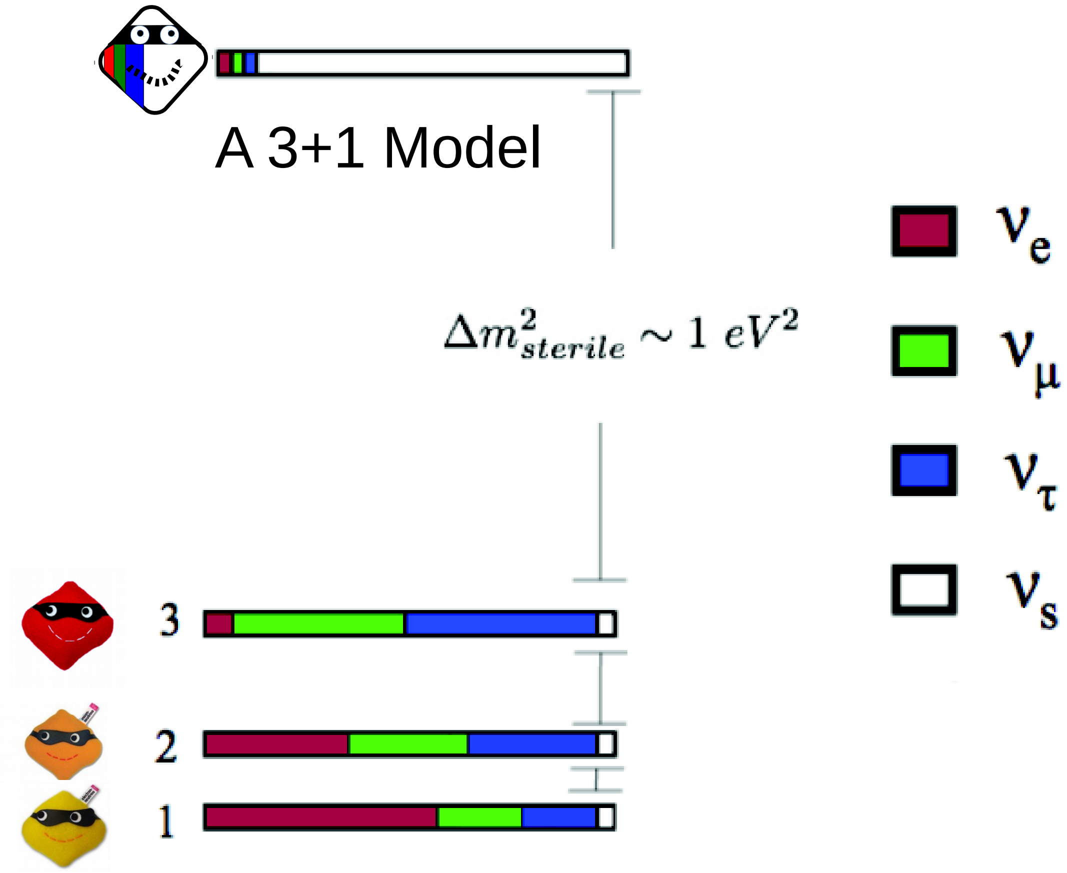
If I start with muon type neutrinos

There are 3+n ways it can oscillate

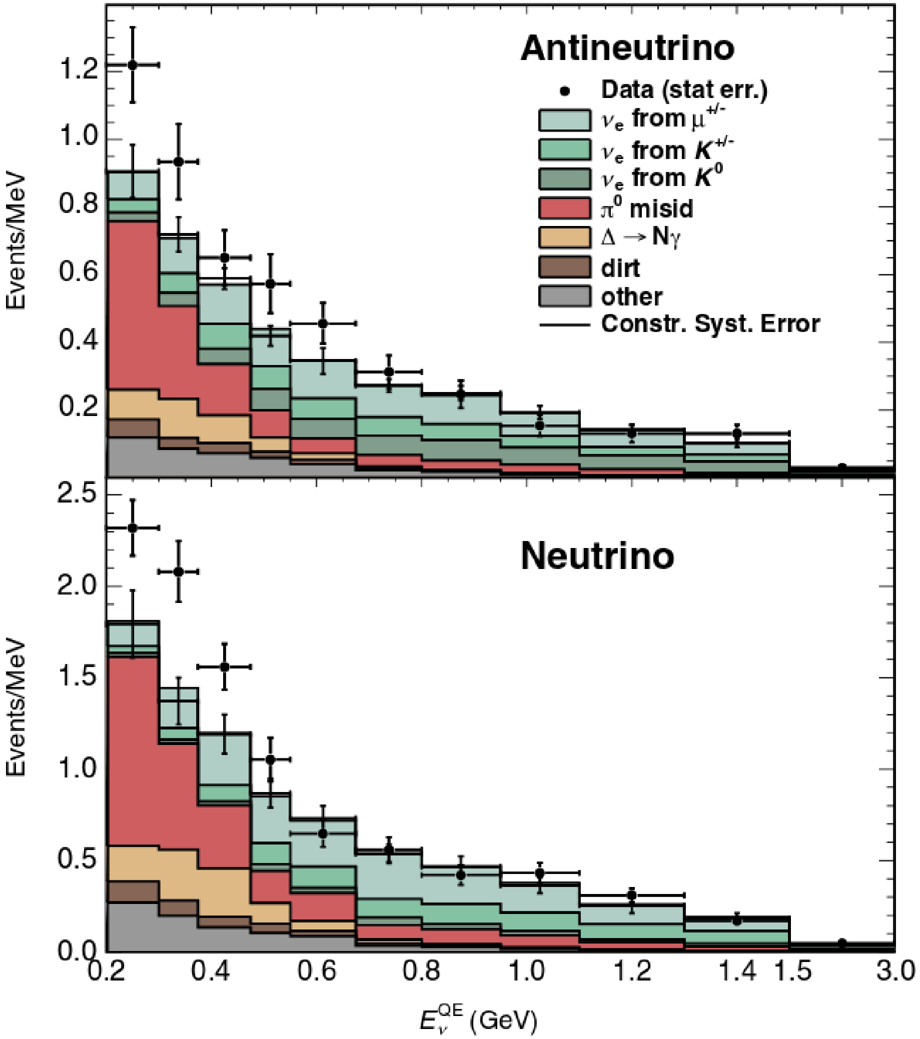
And this will ***enhance*** *the amount of electron neutrinos I observe later*

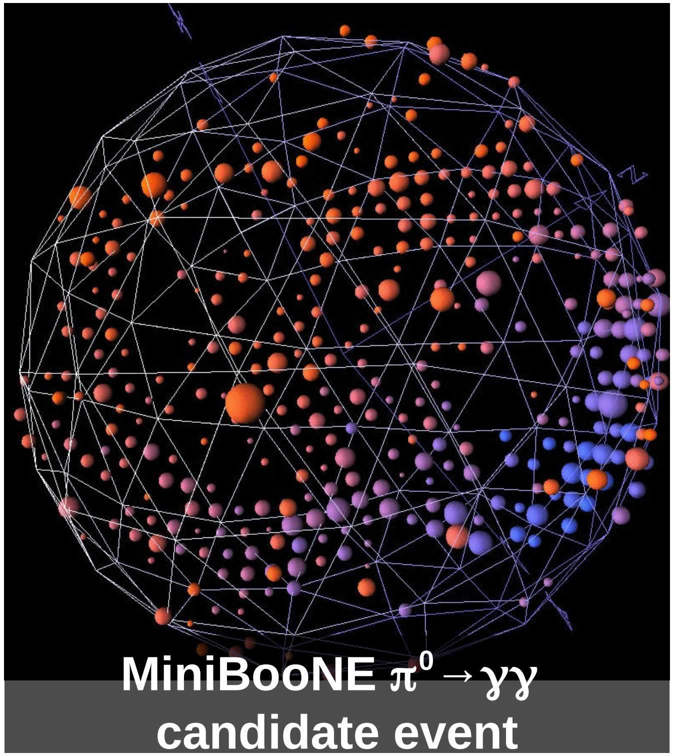
This would imply there are **new particles**

('sterile' neutrinos → neutrinos that don't participate via the weak force)

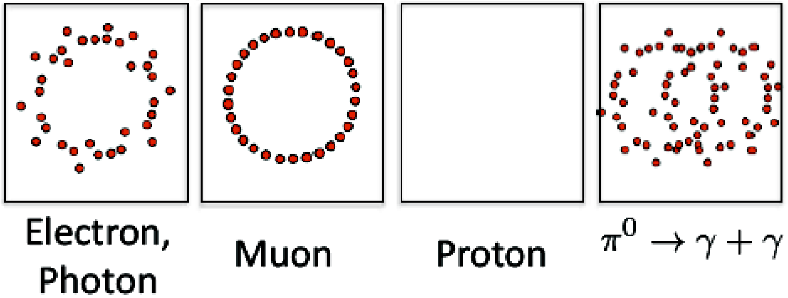


MicroBooNE addressing MiniBooNE



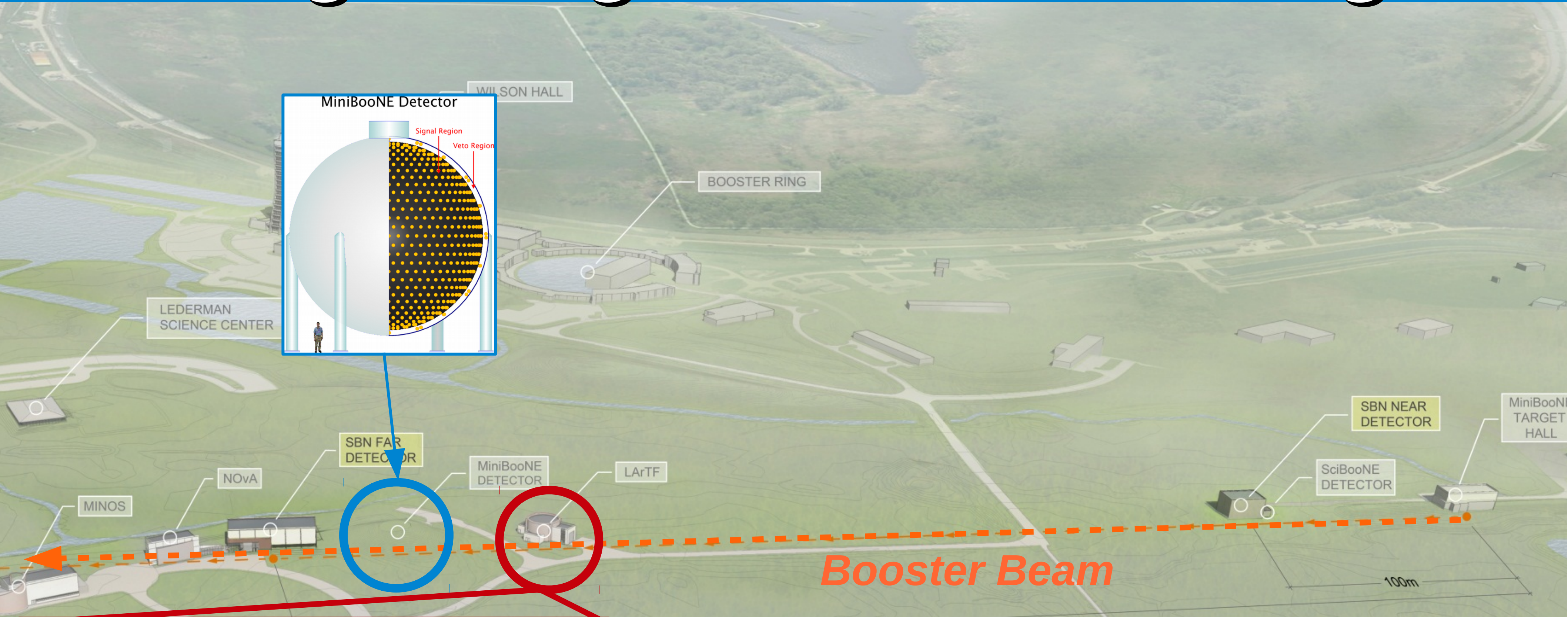


MiniBooNE $\pi^0 \rightarrow \gamma\gamma$ candidate event



What you would like is an experiment that **sees the same beam** as MiniBooNE, at (nearly) the **same distance** as MiniBooNE but with **superior electron/photon separation ability**

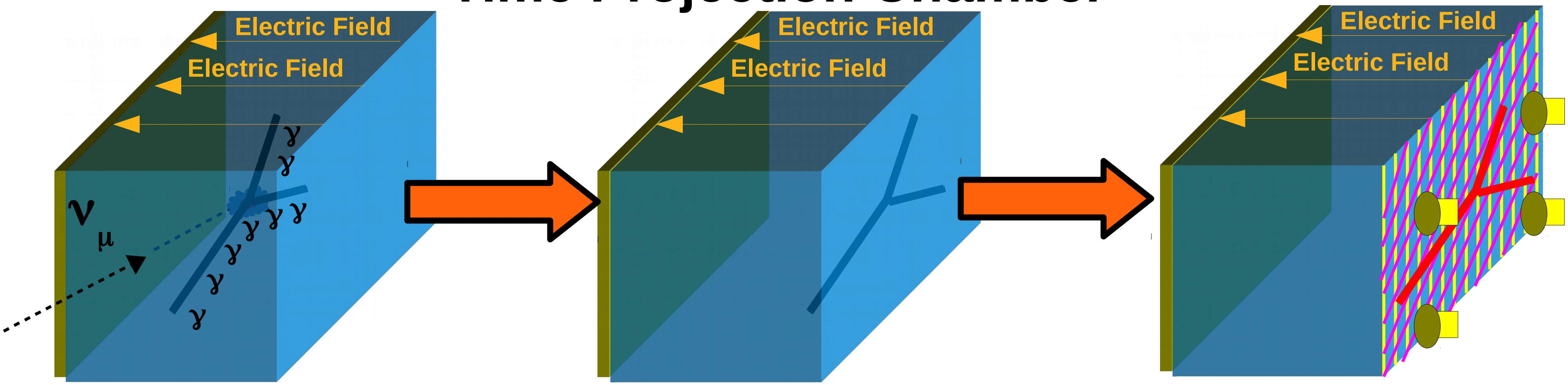
The beginning of the SBN Program



MicroBooNE is the first LArTPC detector on the short-baseline and kicks off the SBN program

LArTPC's

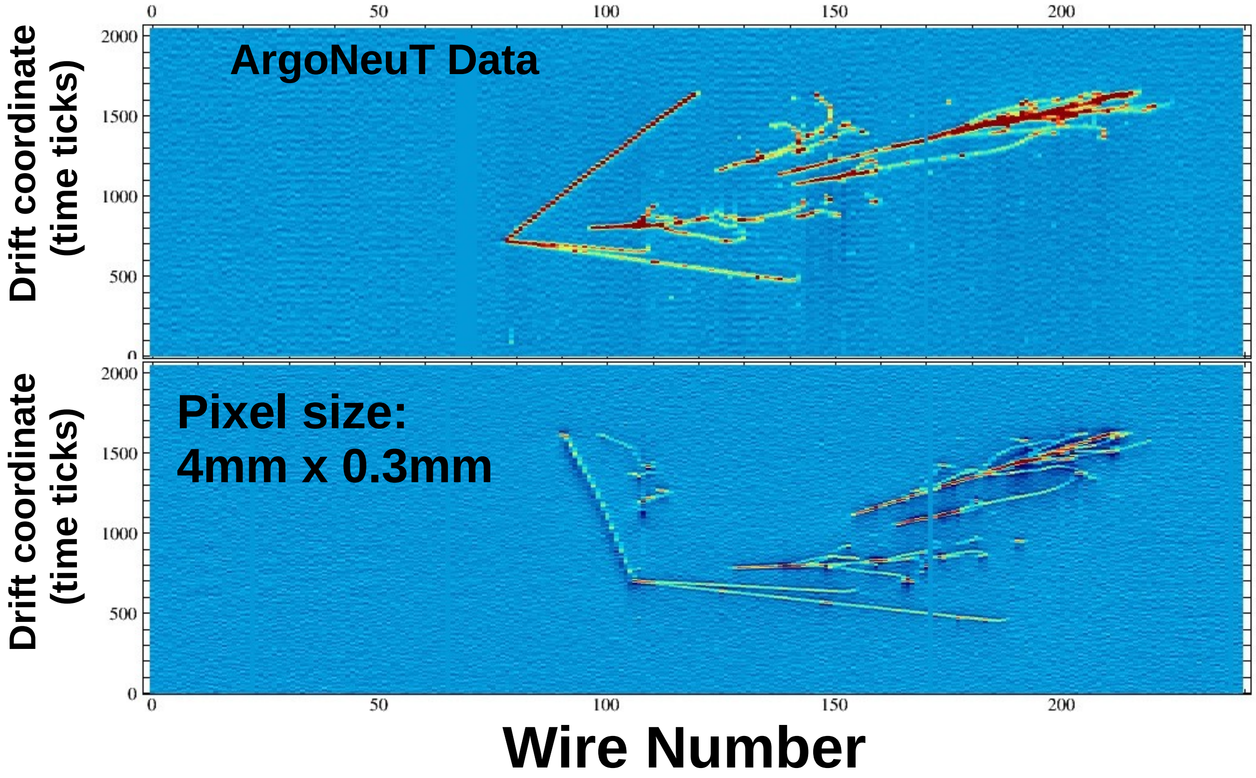
Time Projection Chamber



Neutrino interaction in LAr produces ionization and scintillation light

Drift the ionization charge in a uniform electric field

Read out charge and light produced using precision wires and PMT's

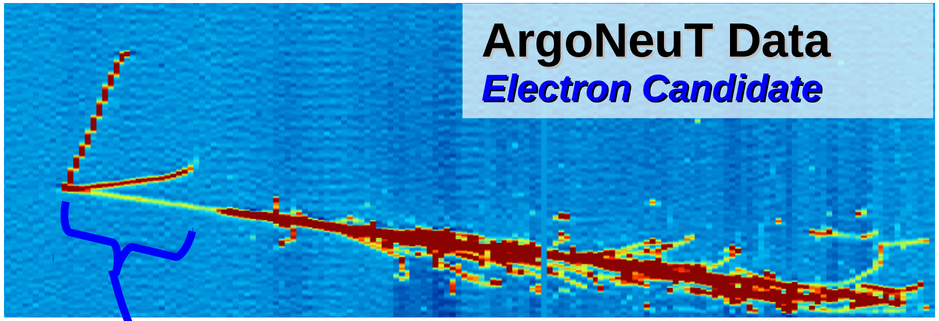


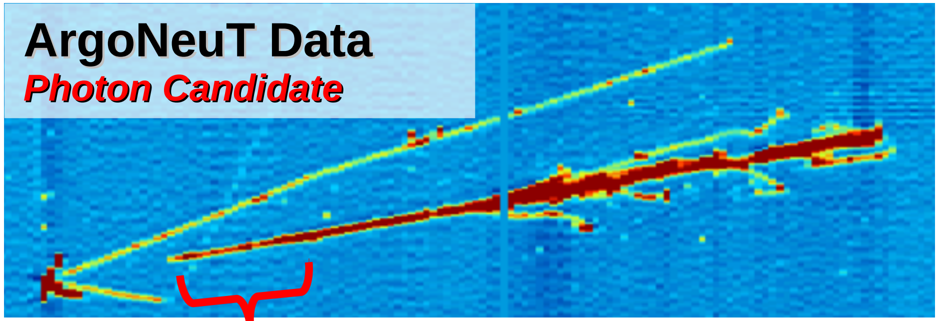
Pixel size:
4mm x 0.3mm

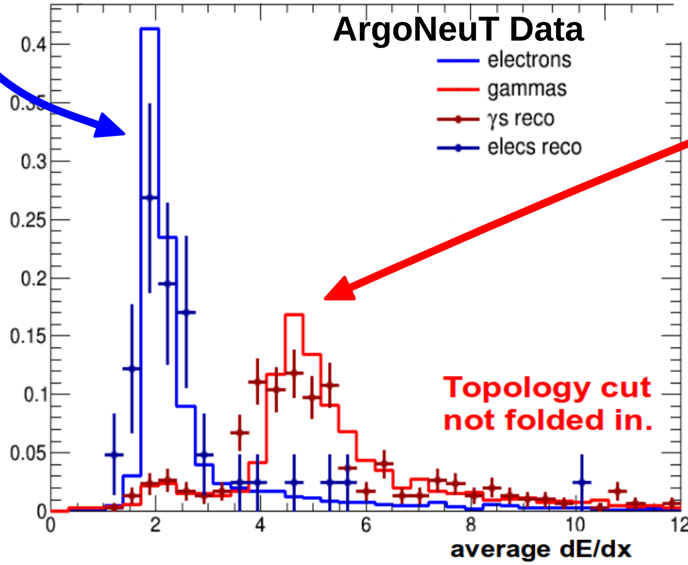
LArTPC's offer incredible fine grain tracking along with electron/photon separation

MicroBooNE

- **MicroBooNE will utilize the electron / photon discrimination power of LArTPC's to determine if the MiniBooNE excess is electron like *(from ν_e appearance)* or photon like *(unaccounted for background)***



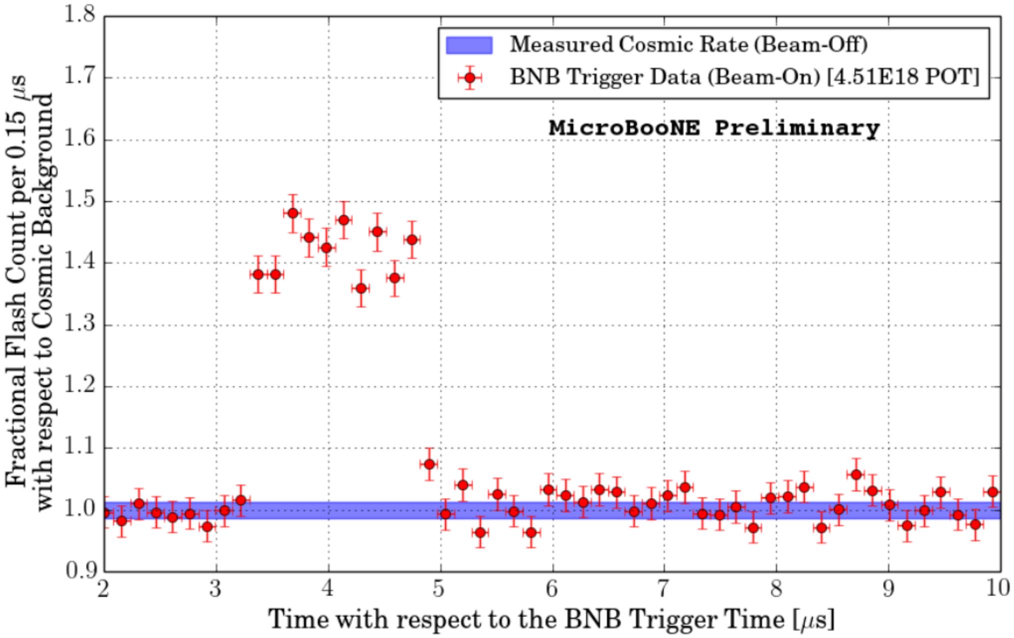


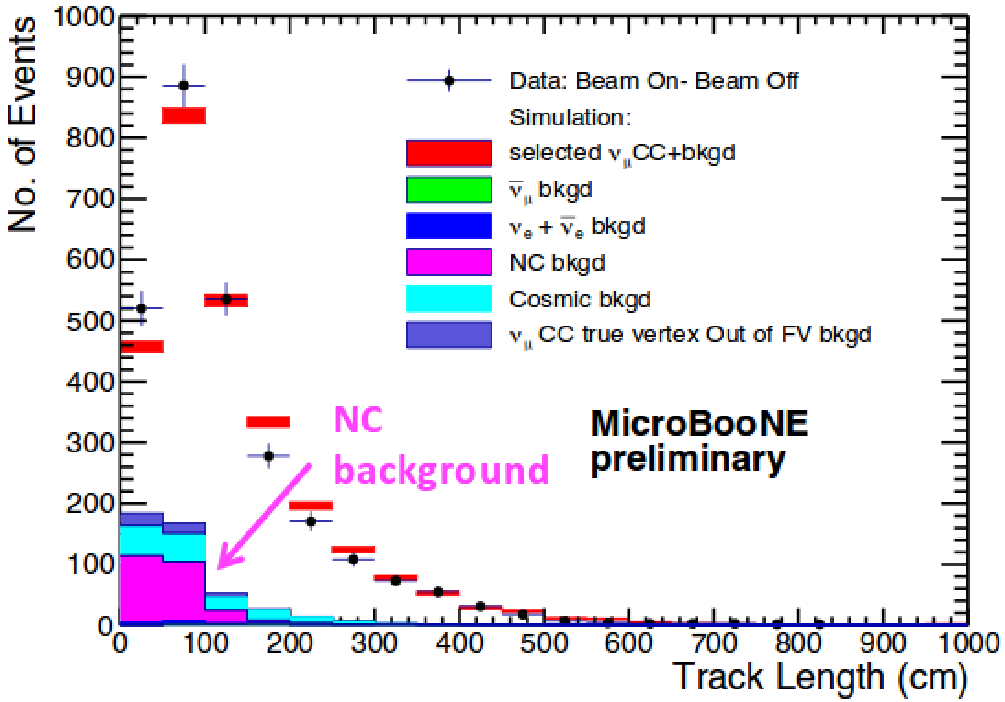


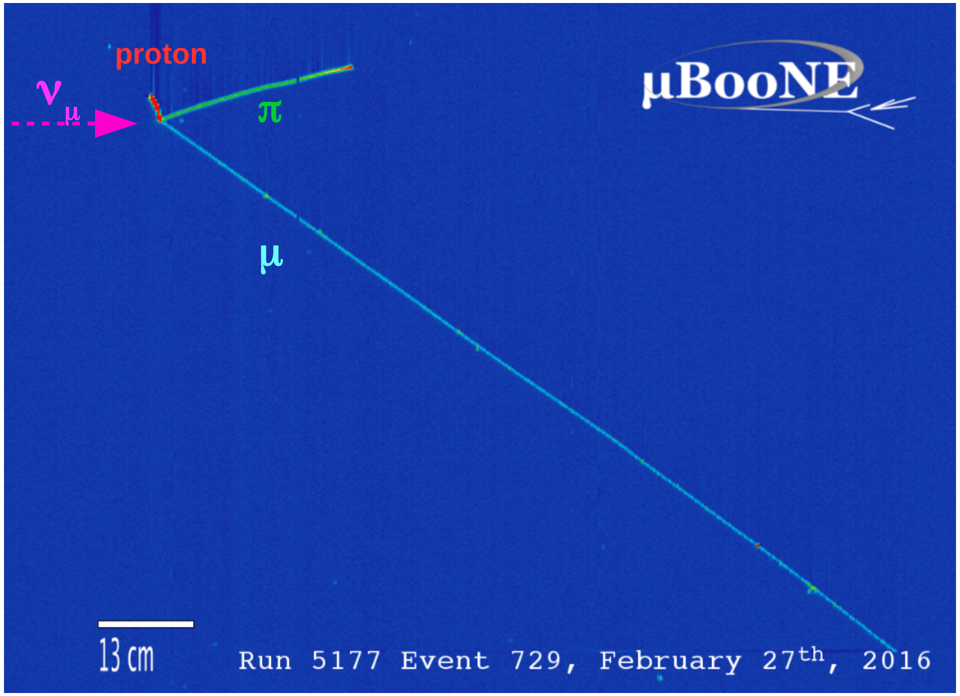
By analyzing the topology and the dE/dX of the electromagnetic shower, disentangling the MiniBooNE low energy excess becomes possible

MicroBooNE

- **MicroBooNE has been successfully recording neutrino interactions since late 2015**
  - Presented first results at NEUTRINO2016 and ICHEP2016!

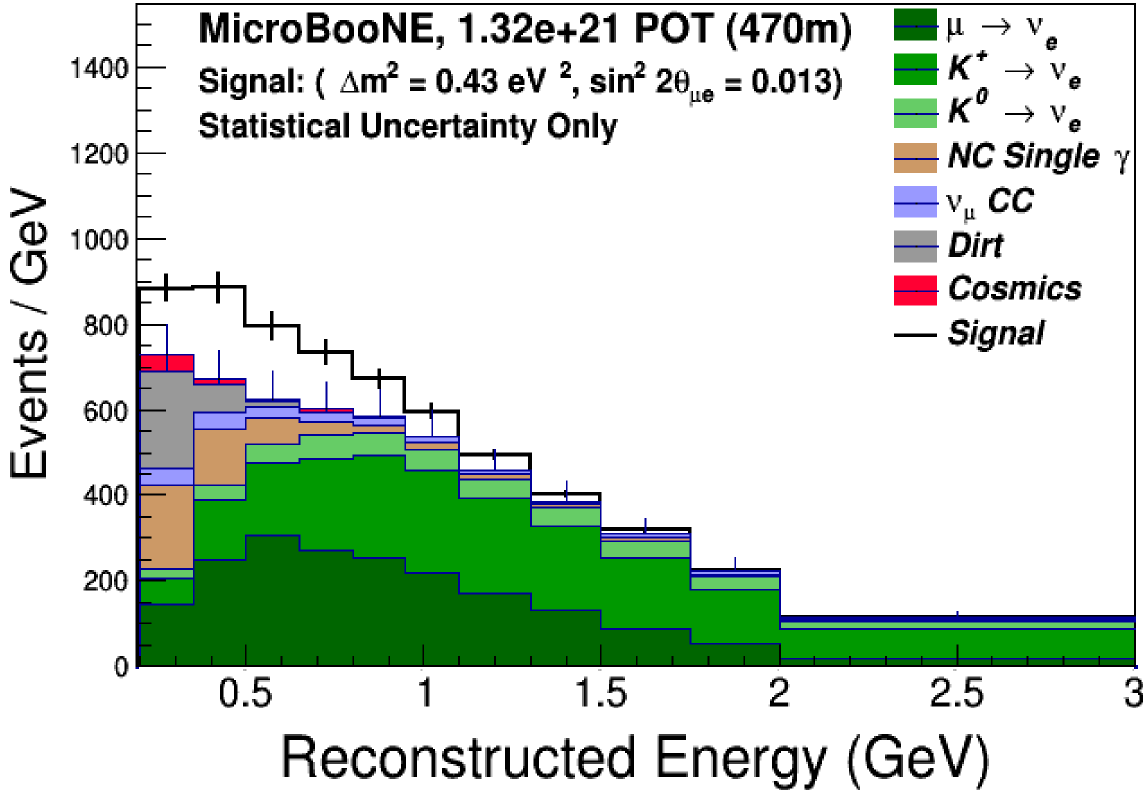






Addressing the low-energy excess of MiniBooNE

- **Oscillation Physics**
  - Utilize its e/γ separation to determine if the signal is photon-like or electron like
- **Regardless of if it is electron or photon like there is interesting physics to uncover!**
  - If it is electron-like than this is a compelling clue towards an oscillation signature
  - If it is photon like than there is a process that we are not including in our models

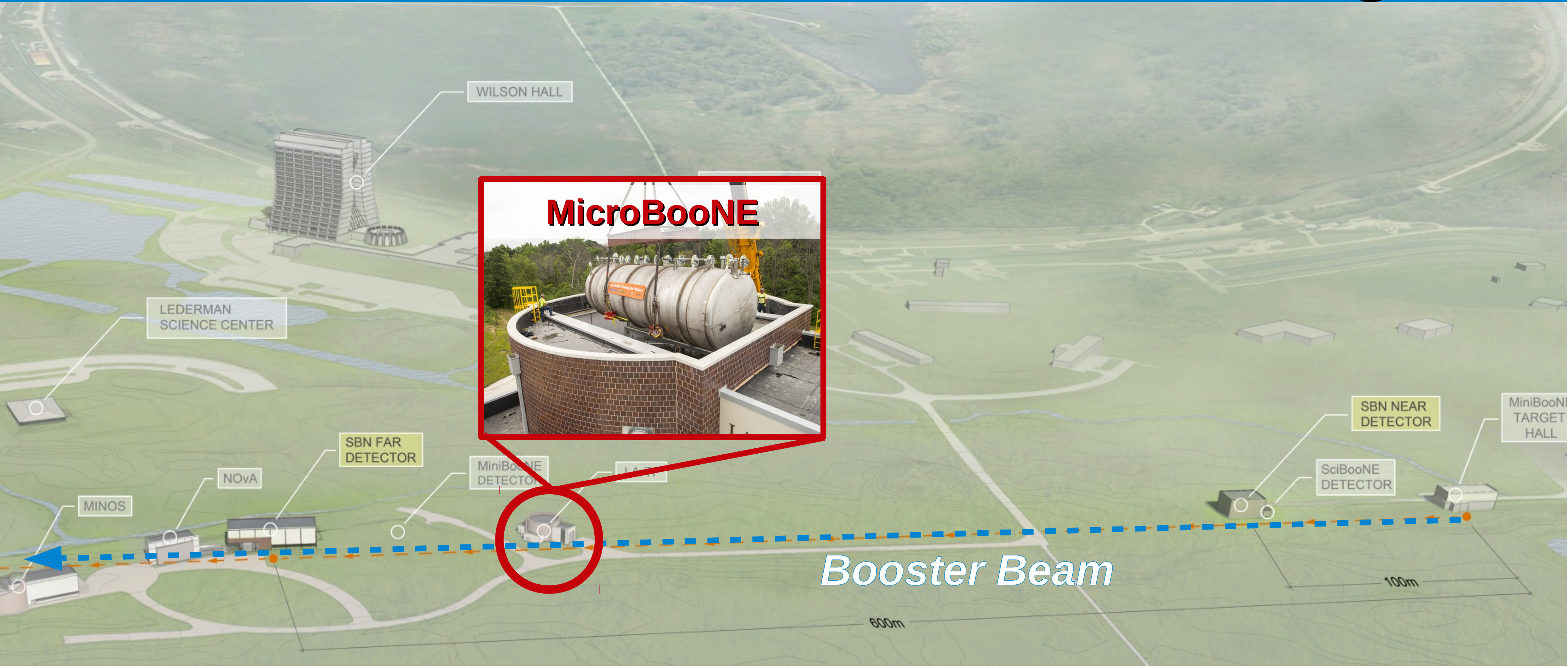


- **MicroBooNE is the largest LArTPC ever built in the U.S.**
  - 89 Tons of active mass

about this big

- **MicroBooNE also has a rich physics program planned**

The Short-Baseline Neutrino Program



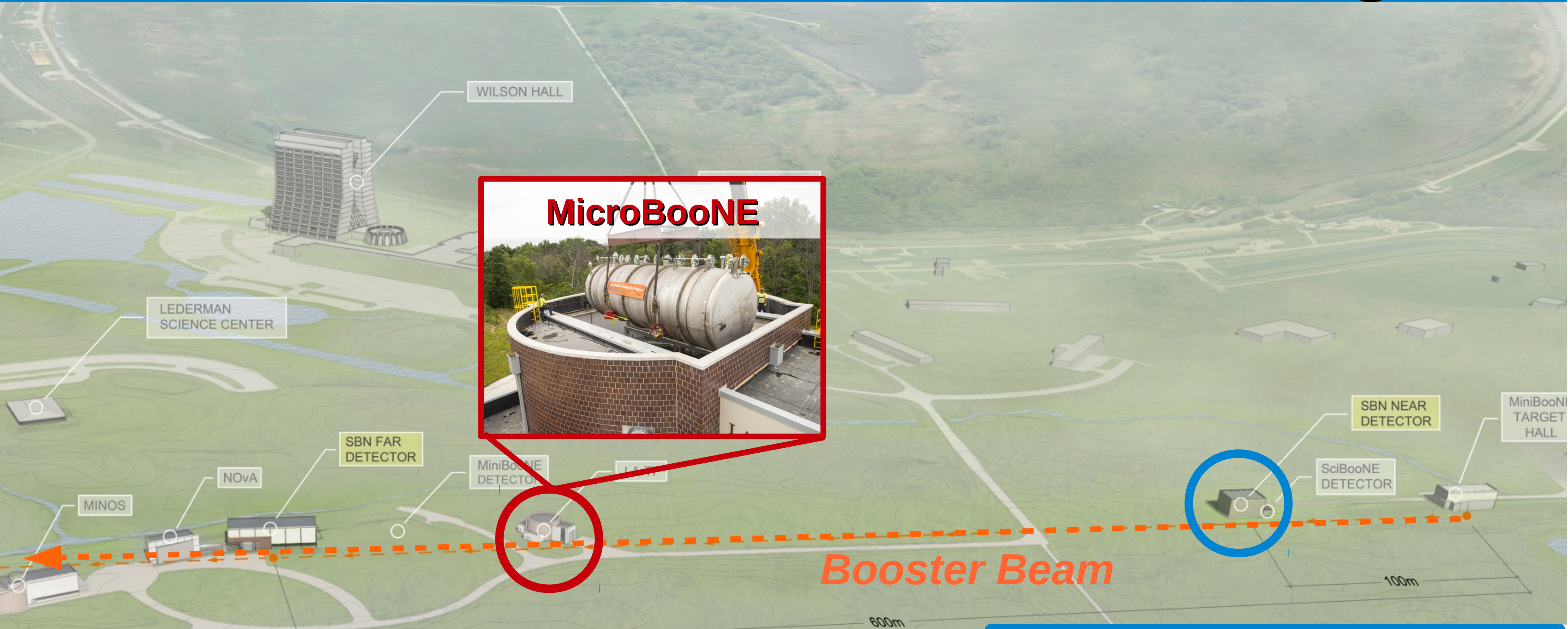
What do I need to add to the existing program (top notch neutrino beam + world class neutrino detectors) to make a definitive search eV scale for sterile neutrinos?

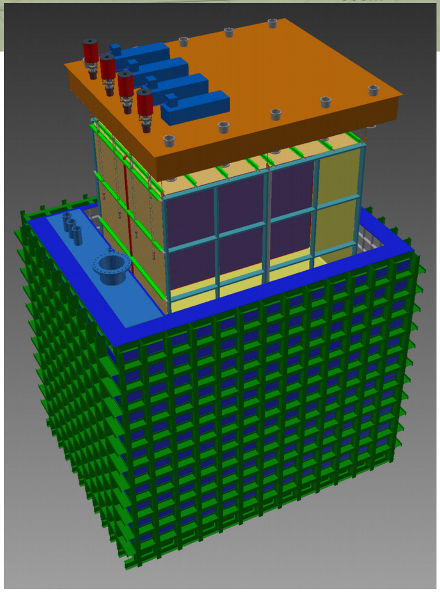
→ Normalization of the un-oscillated neutrino beam **(Near detector)**

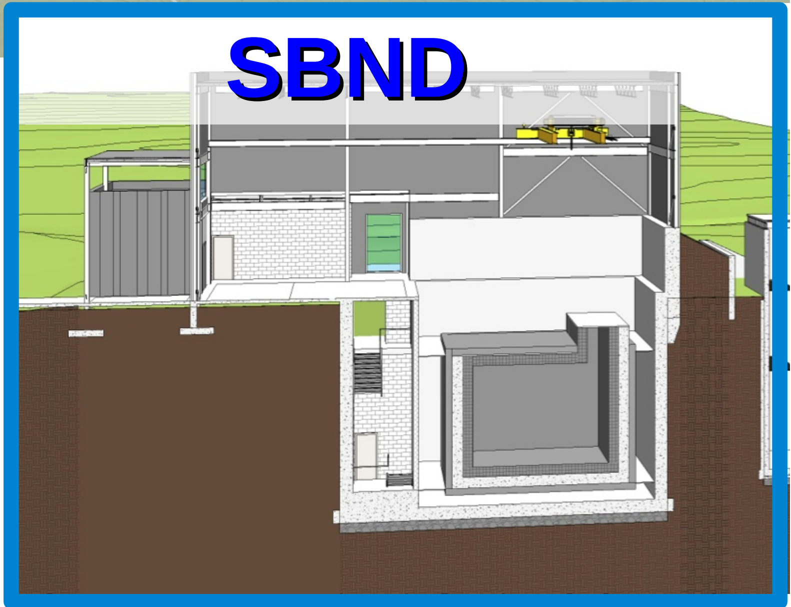
→ High statistics in the appearance channel **(large mass far detector)**

→ Look for complimentary muon disappearance **(near/far comparison)**

The Short-Baseline Neutrino Program



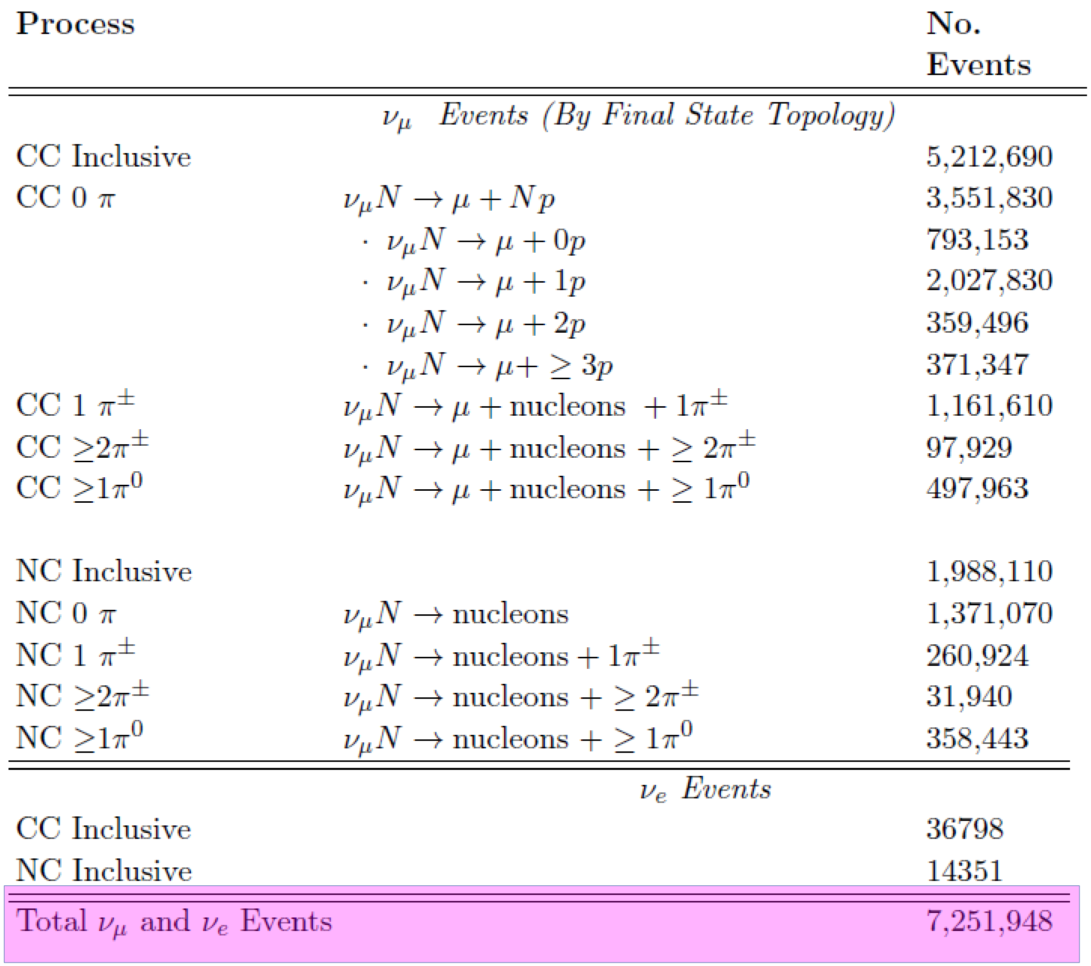




The Short-Baseline Near Detector (SBND) will be a 112 ton LArTPC located 110 meters from the target

- Characterize the beam before oscillation
- Cancel many dominant systematic

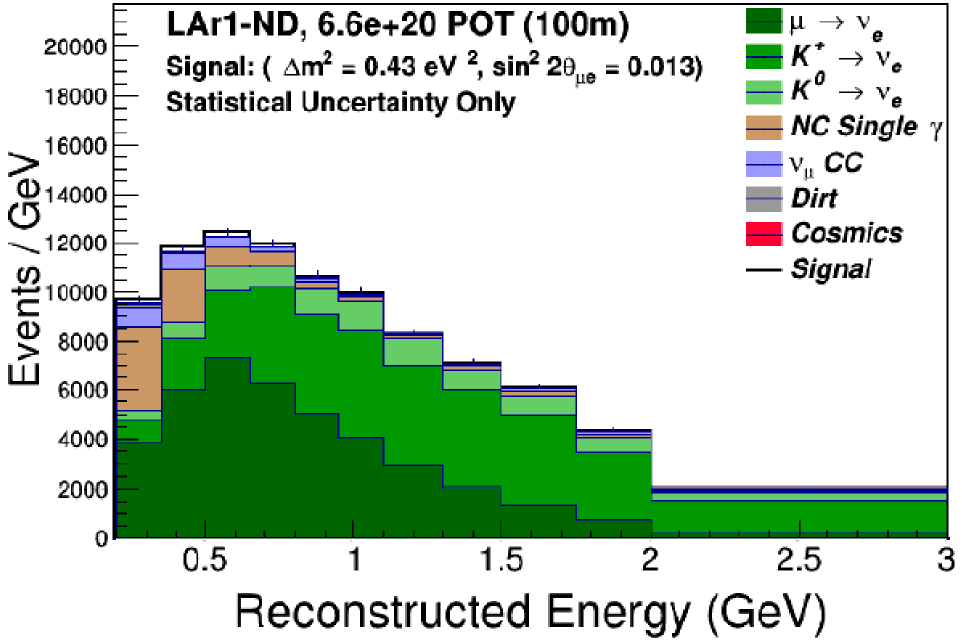
Short Baseline Near Detector (SBND)



Process		No. Events
	ν_μ Events (By Final State Topology)	
CC Inclusive		5,212,690
CC 0 π	$\nu_\mu N \to \mu + Np$	3,551,830
	$\cdot\ \nu_\mu N \to \mu + 0p$	793,153
	$\cdot\ \nu_\mu N \to \mu + 1p$	2,027,830
	$\cdot\ \nu_\mu N \to \mu + 2p$	359,496
	$\cdot\ \nu_\mu N \to \mu + \geq 3p$	371,347
CC 1 $\pi^\pm$	$\nu_\mu N \to \mu + \text{nucleons} + 1\pi^\pm$	1,161,610
CC $\geq 2\pi^\pm$	$\nu_\mu N \to \mu + \text{nucleons} + \geq 2\pi^\pm$	97,929
CC $\geq 1\pi^0$	$\nu_\mu N \to \mu + \text{nucleons} + \geq 1\pi^0$	497,963
NC Inclusive		1,988,110
NC 0 π	$\nu_\mu N \to \text{nucleons}$	1,371,070
NC 1 $\pi^\pm$	$\nu_\mu N \to \text{nucleons} + 1\pi^\pm$	260,924
NC $\geq 2\pi^\pm$	$\nu_\mu N \to \text{nucleons} + \geq 2\pi^\pm$	31,940
NC $\geq 1\pi^0$	$\nu_\mu N \to \text{nucleons} + \geq 1\pi^0$	358,443
	ν_e Events	
CC Inclusive		36798
NC Inclusive		14351
Total ν_μ and ν_e Events		7,251,948

- **Provides an un-oscillated spectrum for the electron neutrino appearance search**

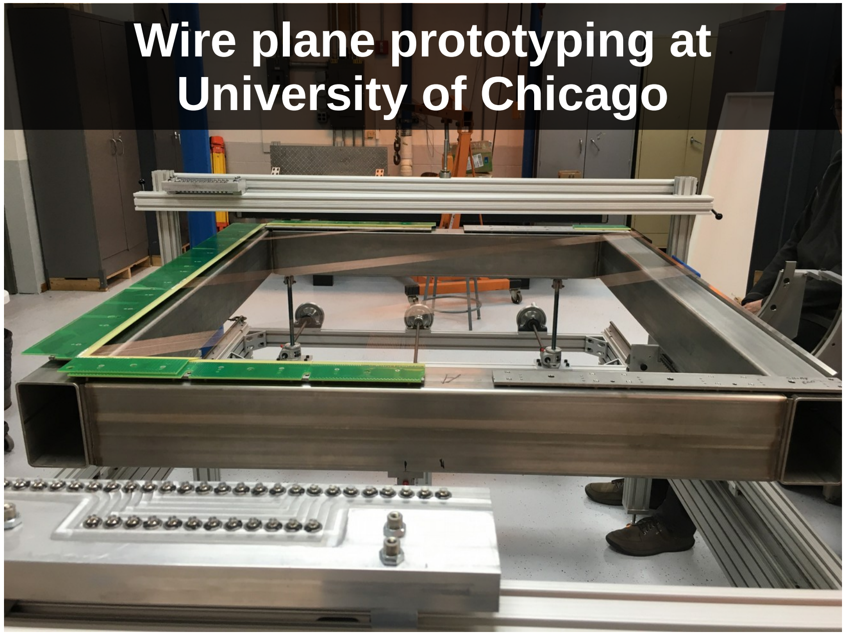
- **SBND will collect millions of neutrino interactions**
  - High statistics, precision neutrino cross-sections measurements



Short Baseline Near Detector (SBND)

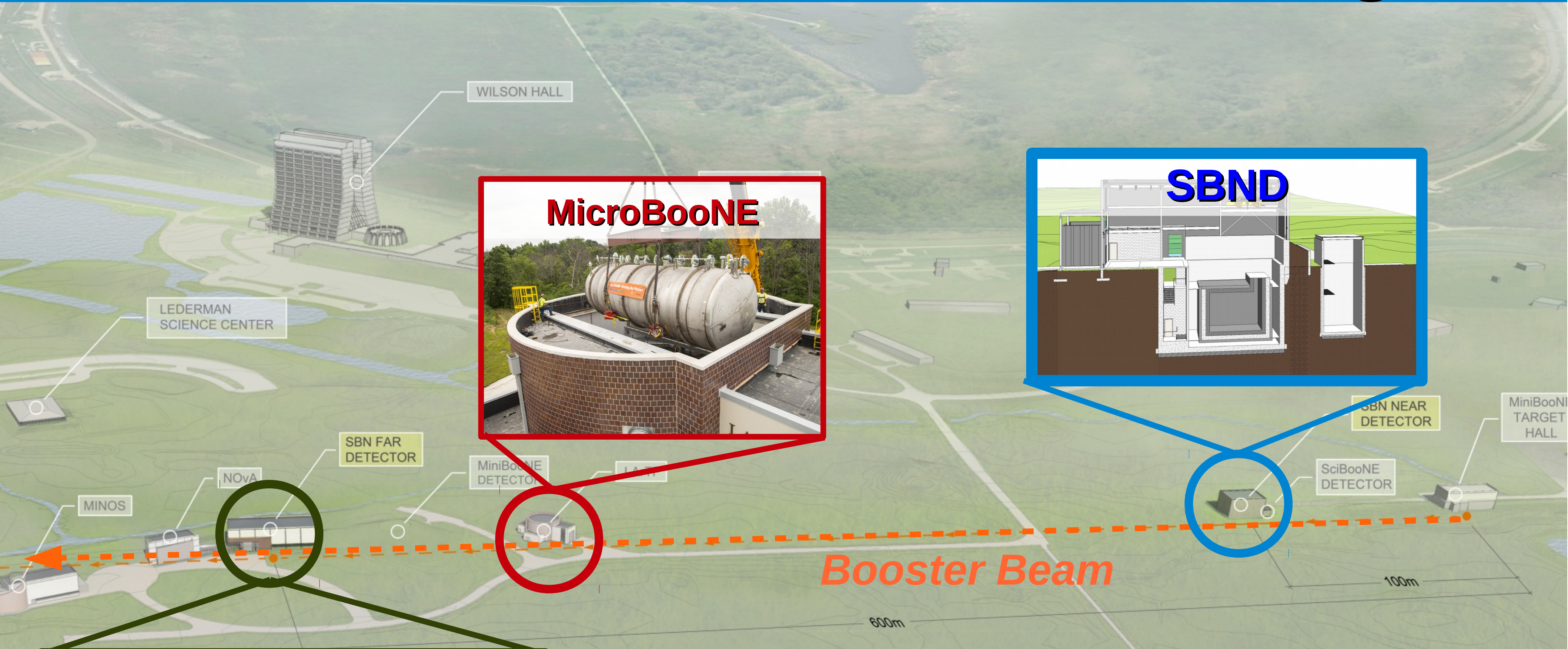
- **Major components of the SBND detector are currently being fabricated in both the US and UK**
  - Wire frames being made by both US and UK collaborators
  - Civil construction of the building proceeding on schedule
- **Expect to start detector assembly and installation in late 2017/ early 2018**

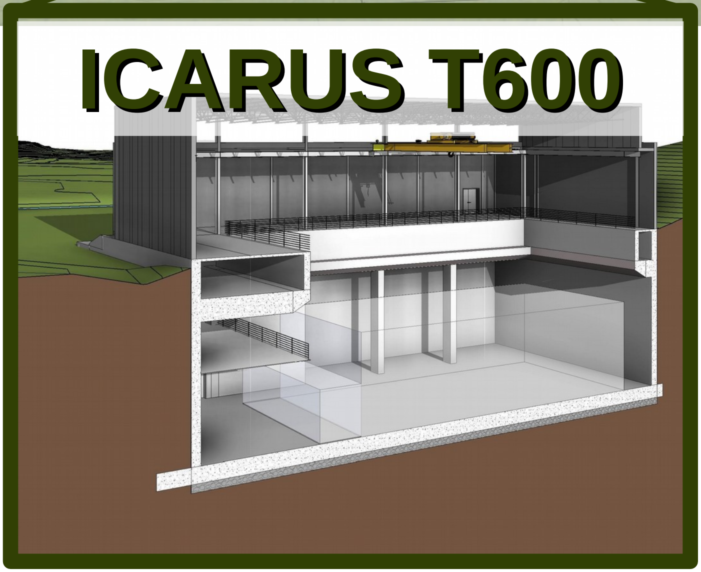
Wire plane prototyping at University of Chicago



Detector building at Fermilab as of July 2016

The Short-Baseline Neutrino Program

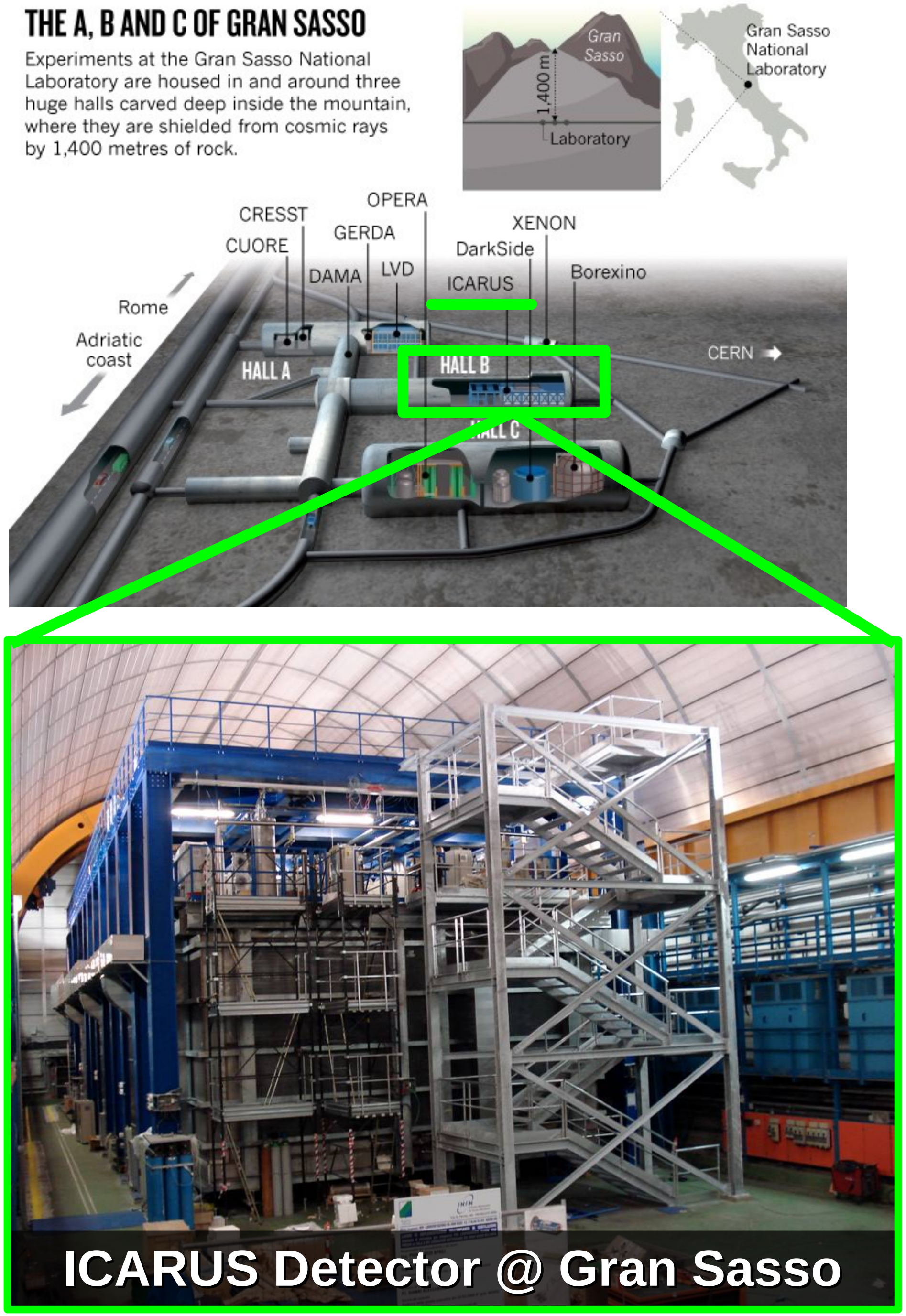




The ICARUS detector is the largest LArTPC ever built

- Adding the large mass allows for precision oscillation search

ICARUS T600



ICARUS Detector @ Gran Sasso

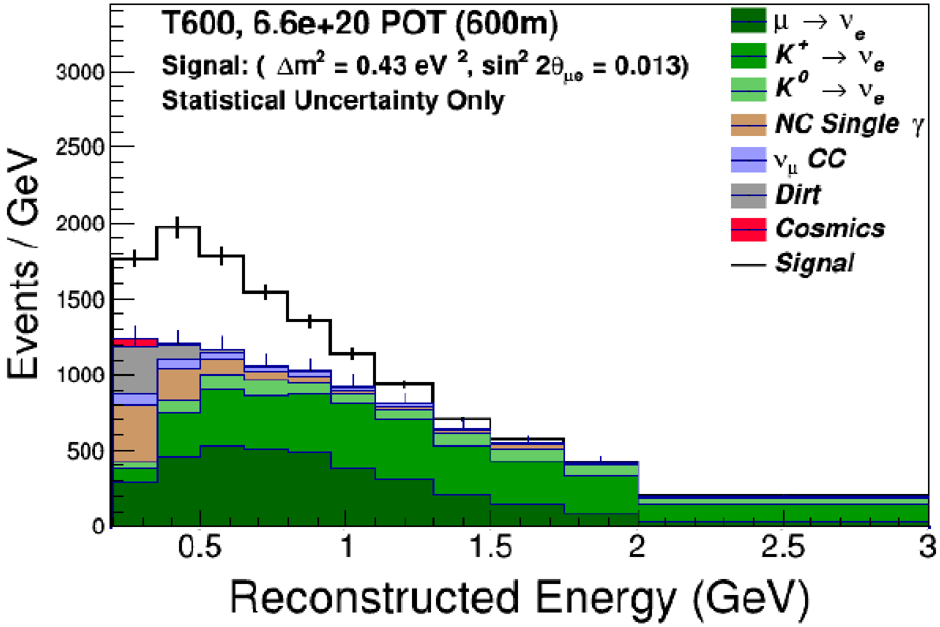
- **ICARUS was the first large scale LArTPC to run in a neutrino beam line**
  - Ran in the CNGS beam from CERN to Gran Sasso Labrotory from 2010 – 2013
- **After completing a successful neutrino run demonstrating the power of the LArTPC technology in an underground laboratory the detector has been moved from Gran Sasso to CERN**

ICARUS T600

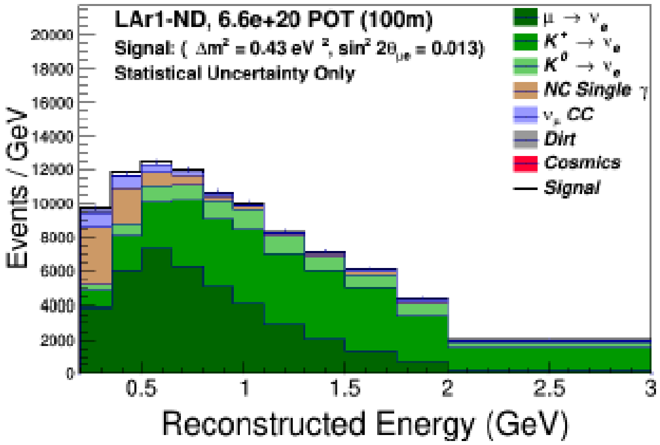

ICARUS TPC @ CERN

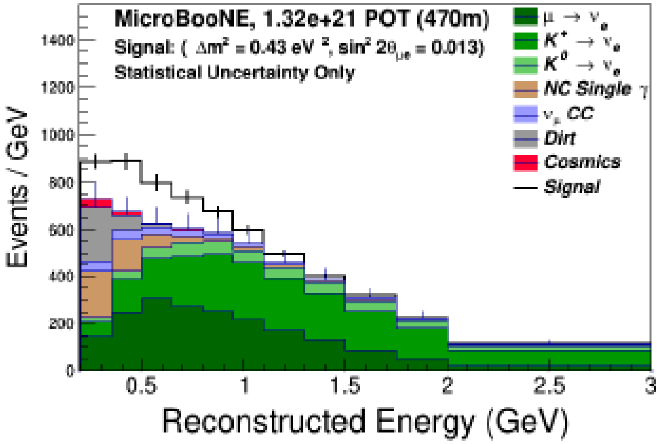
- **The ICARUS detector is at CERN for refurbishment before it is shipped to Fermilab**
  - The detector is expected to be finished in 2016 and move to FNAL in 2017
- **This large mass detector will provide increased sensitivity to the electron neutrino appearance search**

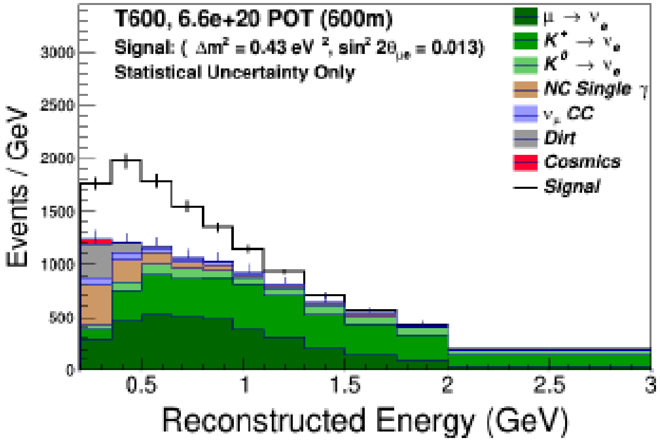
Far Detector Building



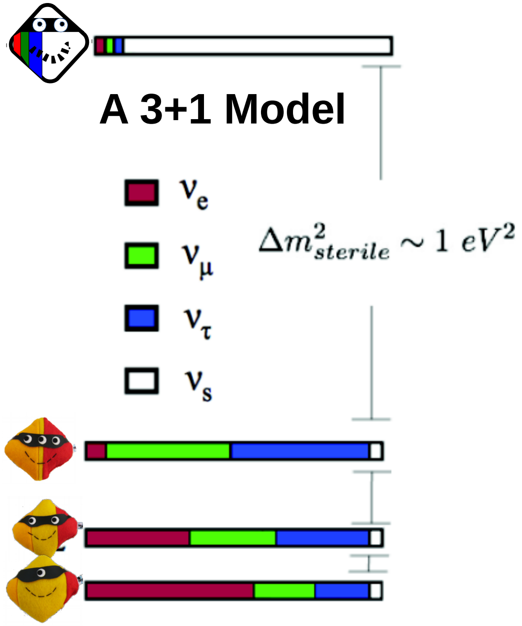
The SBN Program

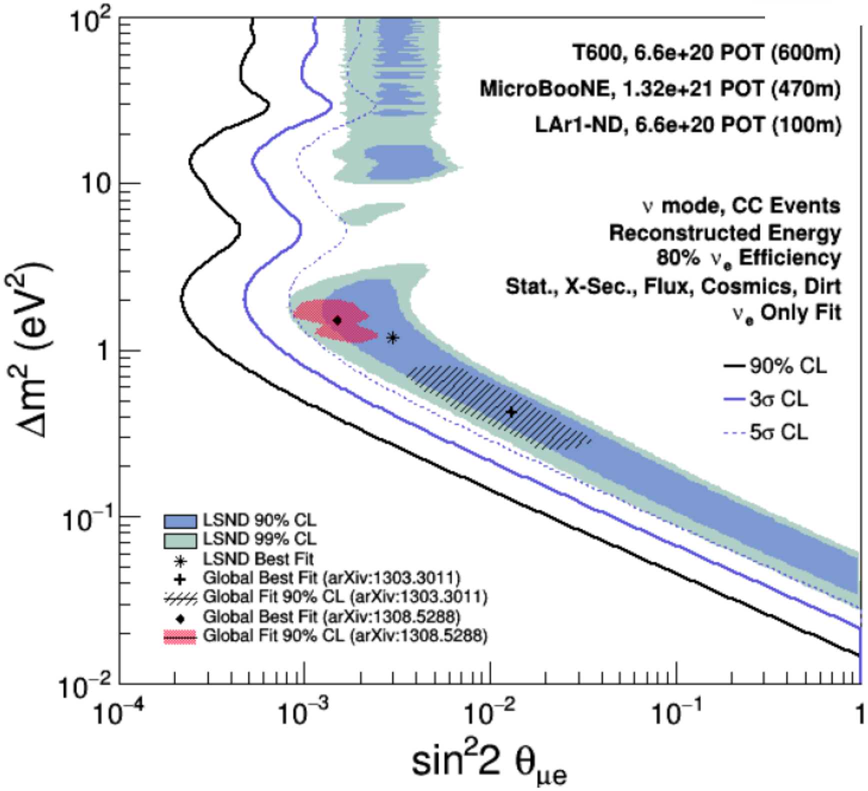




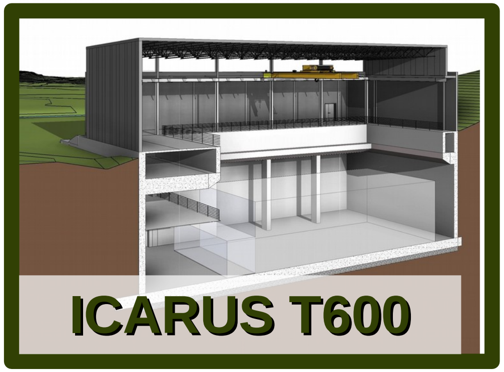


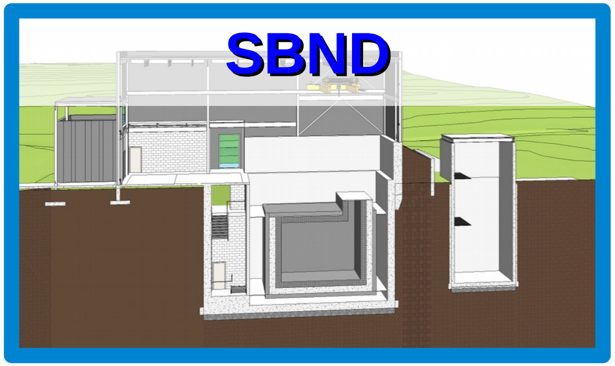
Utilizing three similar detectors at three different distances along the same neutrino beam allows for a **definitive measurement** of the allowed sterile neutrino parameter space

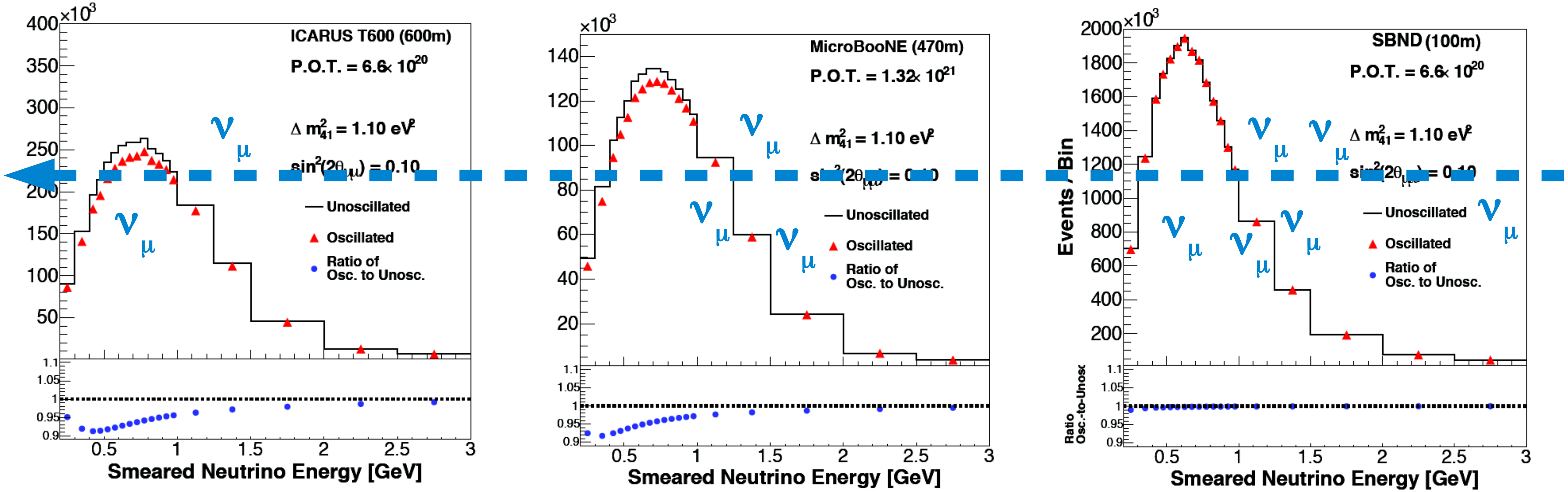




The SBN Program







- **The three detector configuration also allows you to search for the muon neutrino disappearance channel as well**
  - Complimentary to the electron neutrino appearance search

Conclusions

- **Fermilab stands at the dawn of the next generation of precision neutrino experiments**
- **The MicroBooNE experiment is taking neutrino data now!**
  - This turns the key on the launch of the short-baseline experiment at Fermilab
- **Ground breaking on the buildings for the near and far detector will occur this summer**
  - Planning and design work on the near detector is moving ahead at full speed
  - The refurbishment of the ICARUS detector is ongoing at CERN and is expected to be complete in 2016