The Fastest Trip between Fermilab and Minnesota

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Fermilab

Between Fermilab and Northern Minnesota

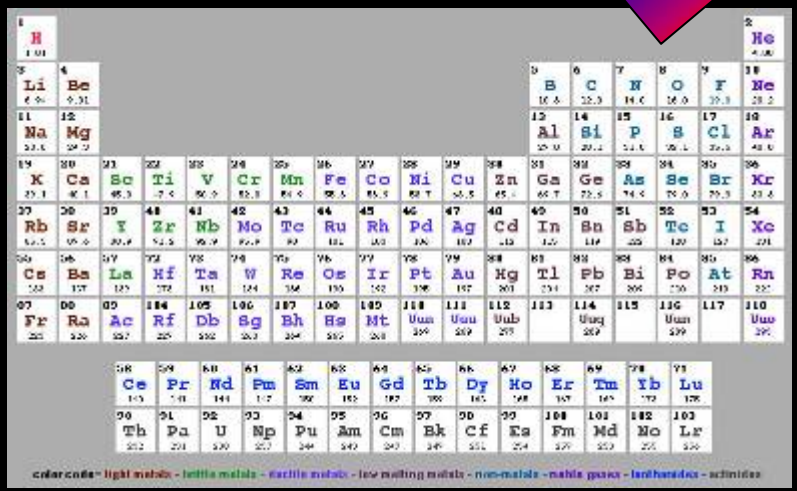
- By Plane: 3 hours
- By Car: 10 hours
- By Phone: 1/10 second
- By Neutrino: 1/400 of a second

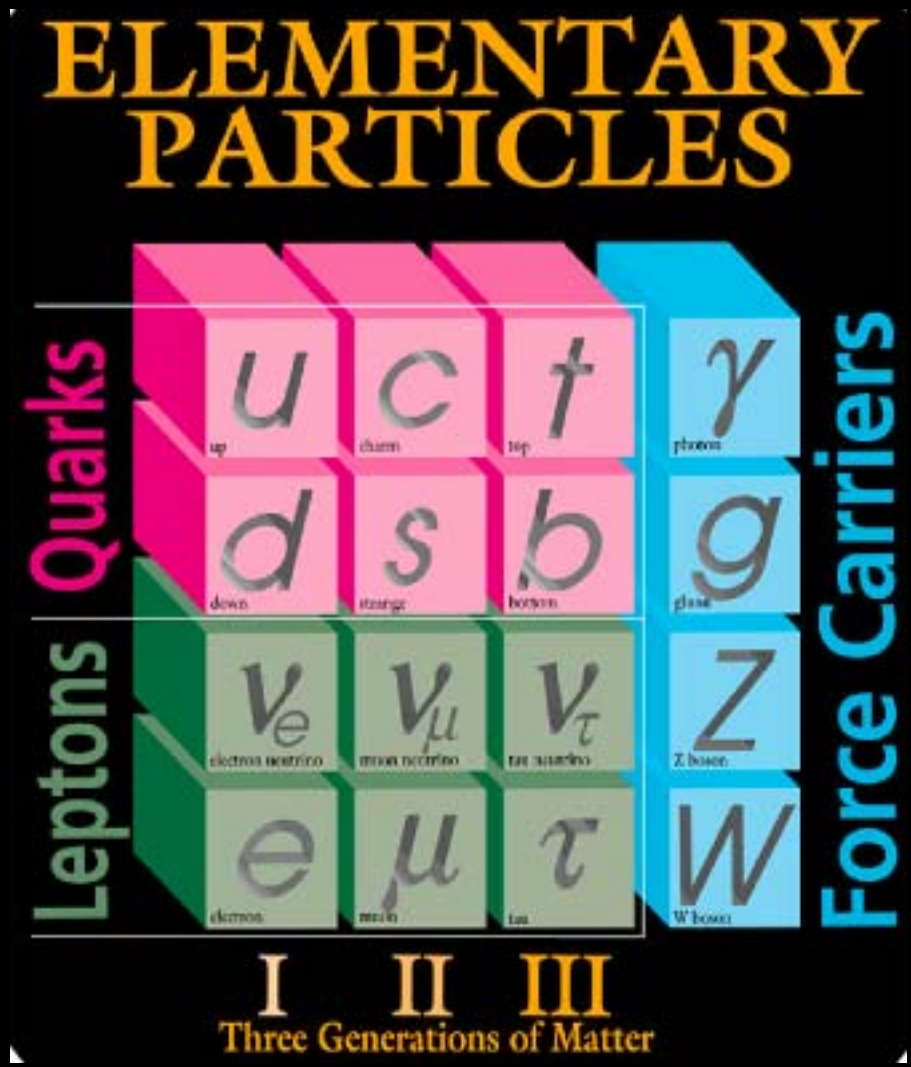
What is a Neutrino?

- Breakfast Cereal
- Japanese rhythm and blues band
- Penny-sized jumping spider
- Tiny neutral particles
  - Weigh almost nothing
  - Almost never interact
  - Named by an Italian (Fermi)
  - Symbolized by a Greek (ν)

How do neutrinos fit in?

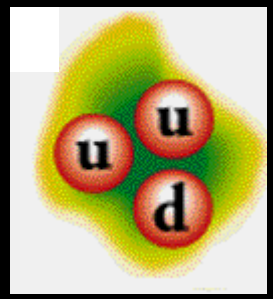
- What is the world made of?
- Molecules
- Atoms
  - Protons
  - Neutrons
  - Electrons



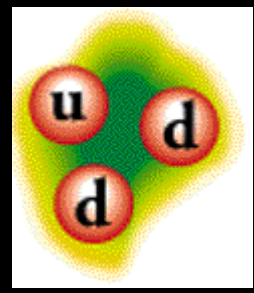


From neutrons to protons

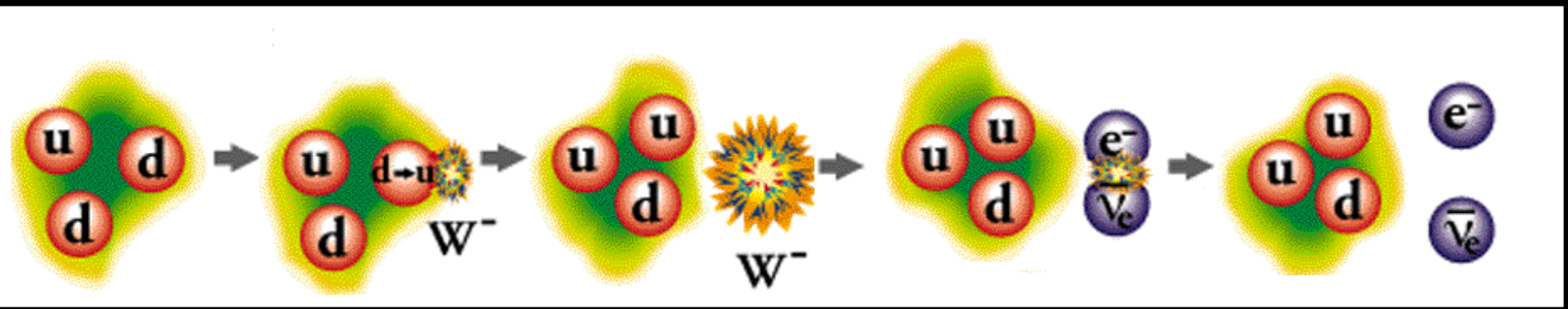
- Proton



- Neutron



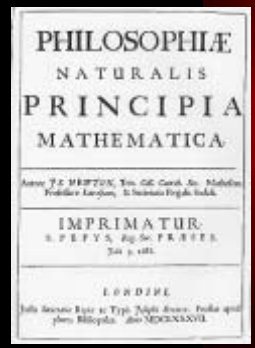
Neutrinos get you from neutron to proton, or from down to up

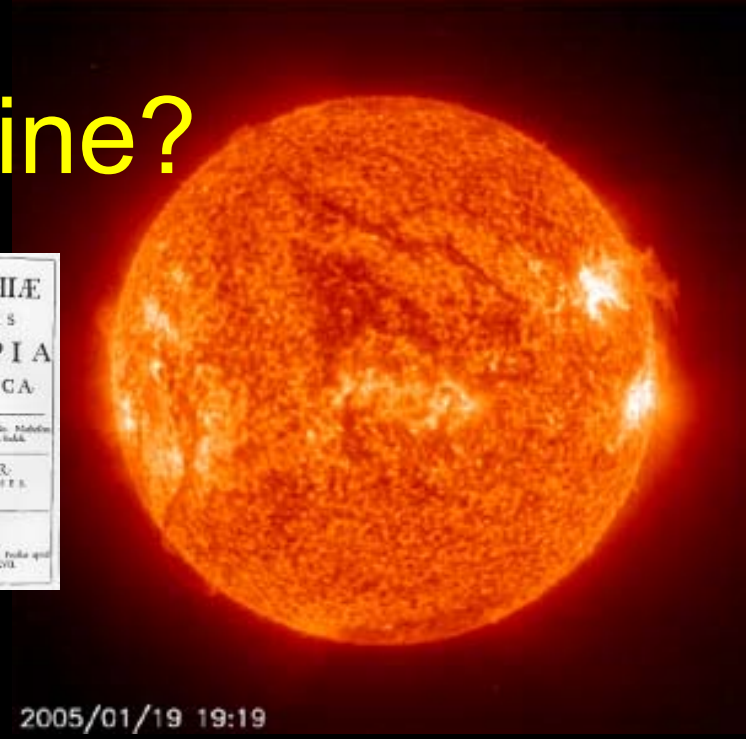


$$n \rightarrow p\ e^{-}\ \bar{\nu}_e$$

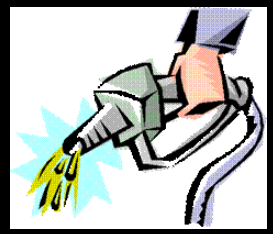
See www.Particleadventure.org

What makes the sun shine?



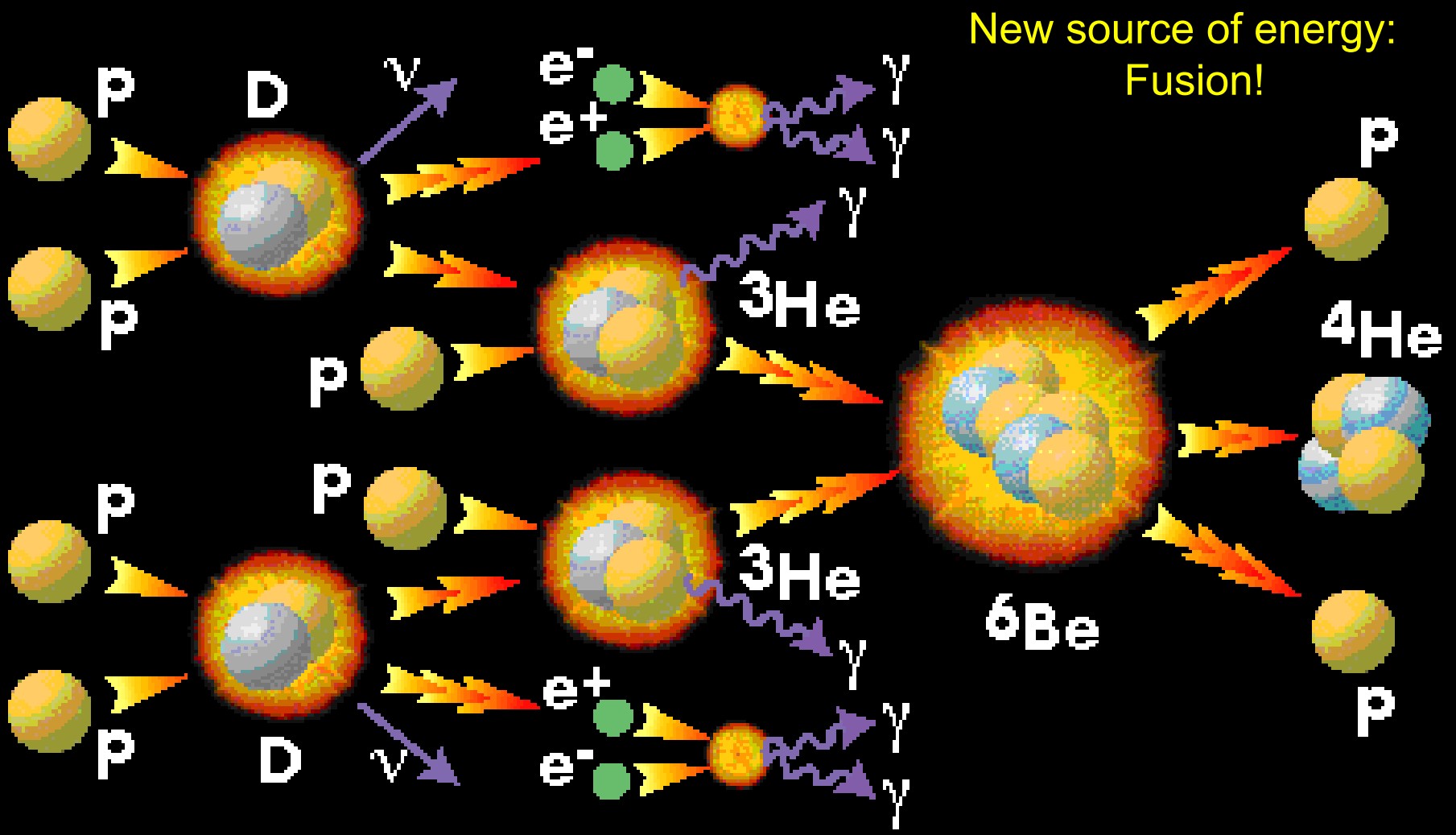


- Newton (1700's): sun weighs 2 million trillion trillion kilograms (2×10^{30}kg)



- We get about a million Joules for a kg of fuel
- We know how bright the sun is (4×10^{26} Joules/second)
- Calculation: the sun will only burn 2 centuries…
- There are buildings older than that…how can this be?

You guessed it: Neutrinos

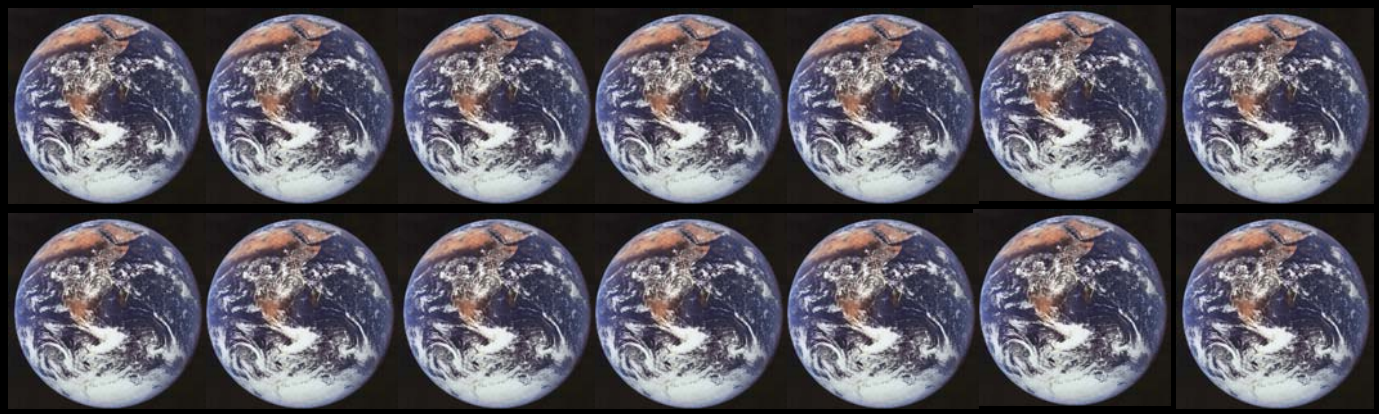


What do you mean neutrinos weigh almost nothing?

- Protons and neutrons: ~1GeV (a trillion trillion per sunflower seed)

- Electrons: 2,000 per proton
- Neutrinos: >1,000,000 per electron

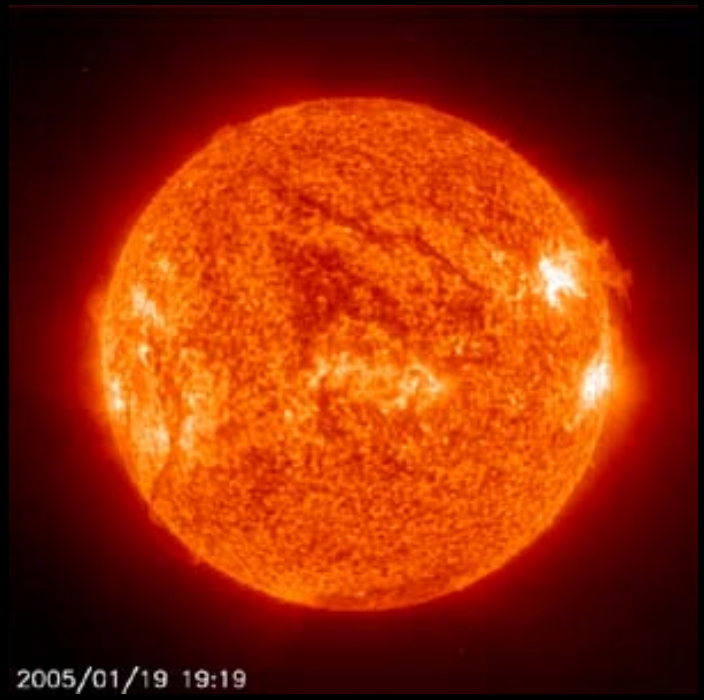
What do you mean neutrinos almost never interact?

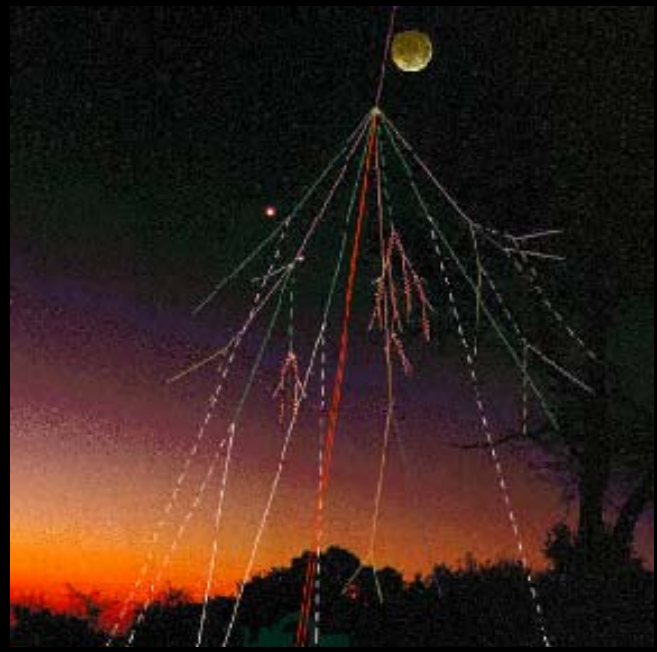


- ν has a good chance of traveling through 200 earths without interacting

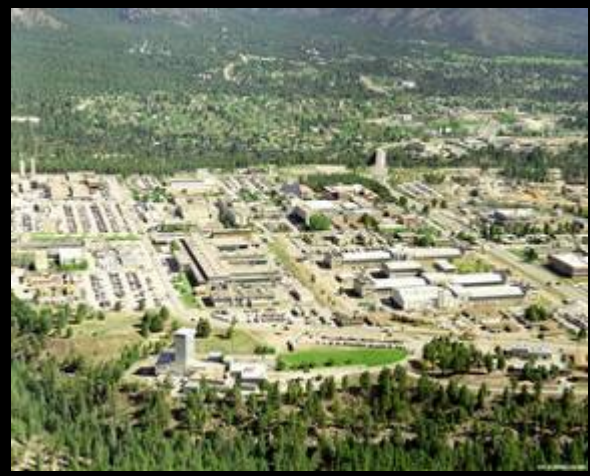
- 100 billion neutrinos from the sun pas through your thumbnail every second

The Case of the Missing Neutrinos



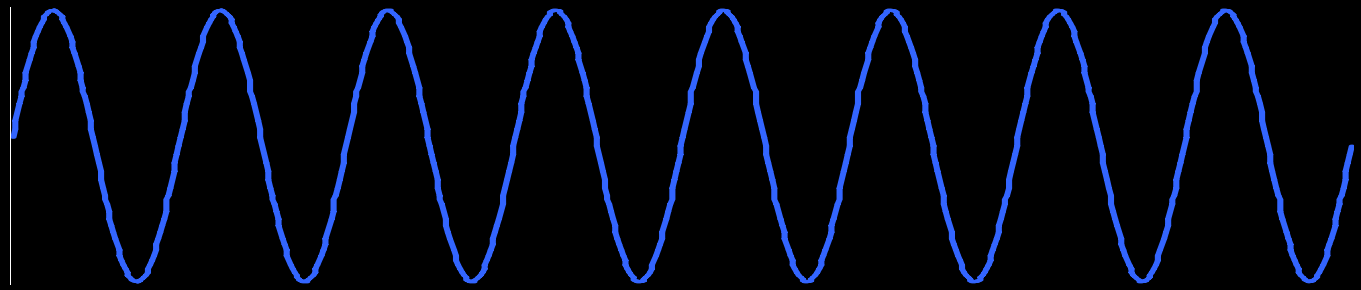


- Neutrinos from the sun:
  ~1/3 the number expected (brr….)
- Atmospheric neutrinos:
  ~1/2 the number expected were observed
- Neutrinos from Los Alamos:
  5X as many electron-type neutrinos as expected

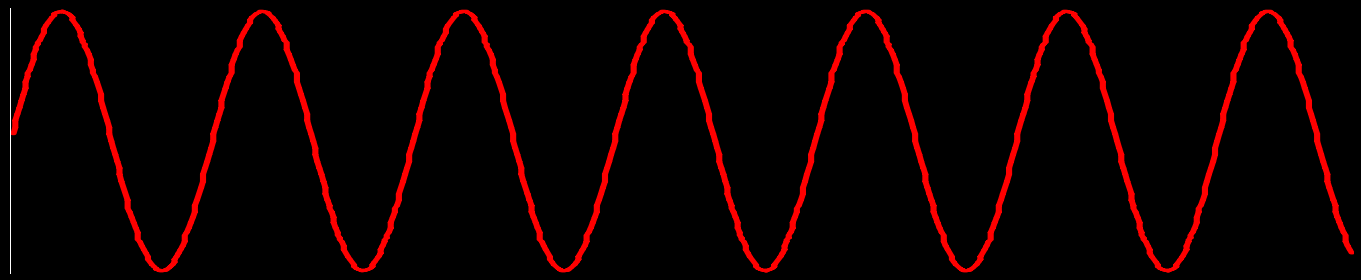


How can something become nothing?

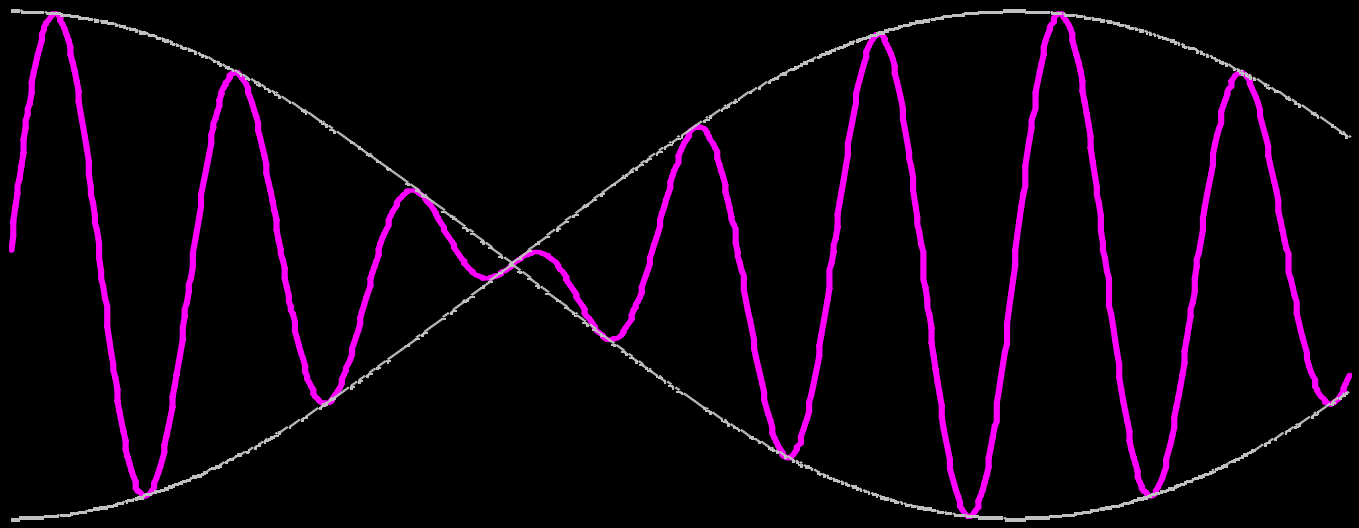
wave 1



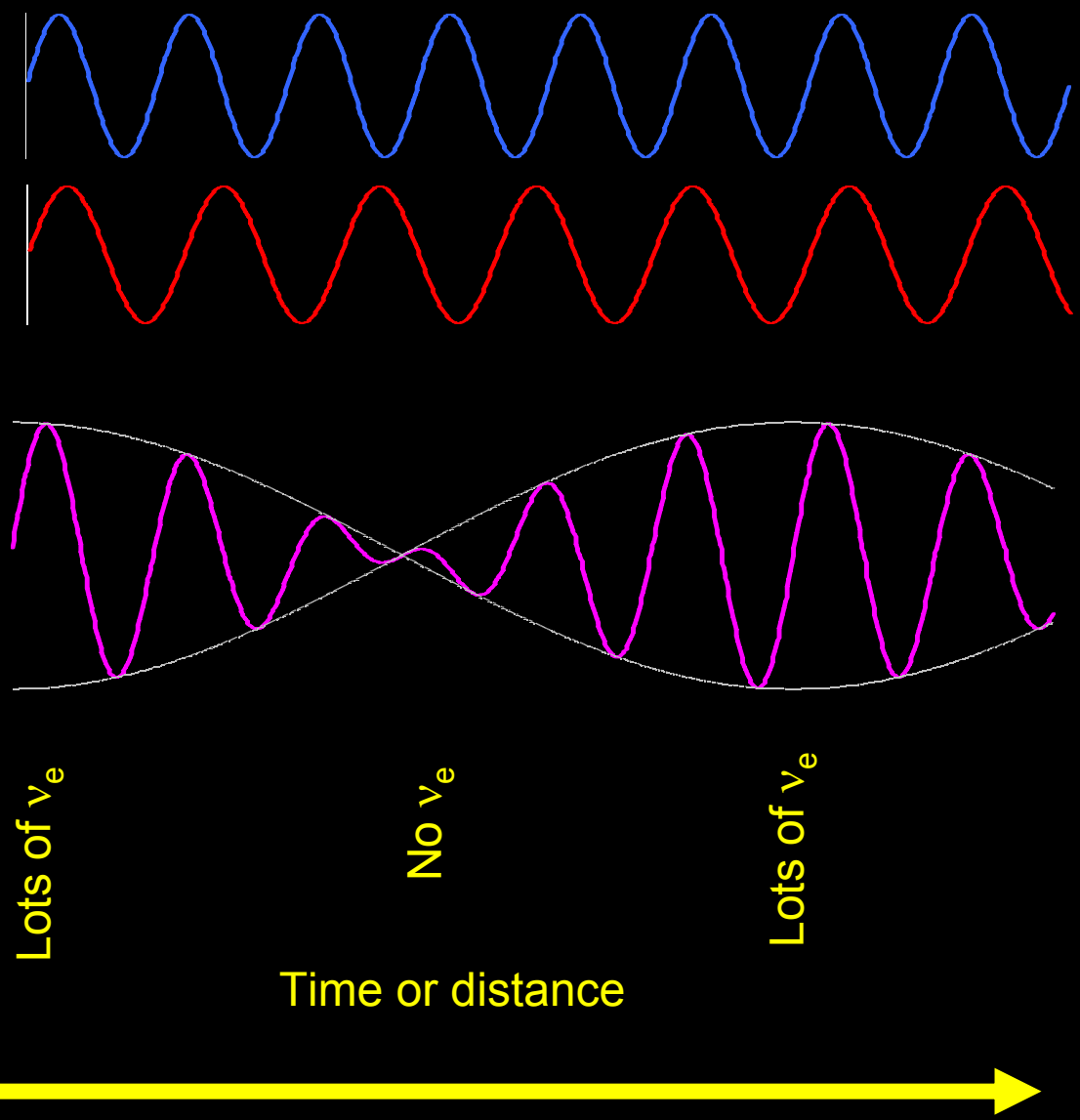
wave 2



wave 1
+ wave 2



Neutrino Oscillations



If neutrinos are waves of slightly different frequencies:

Over time, they disappear and reappear

The bigger the frequency difference, the faster the disappearance

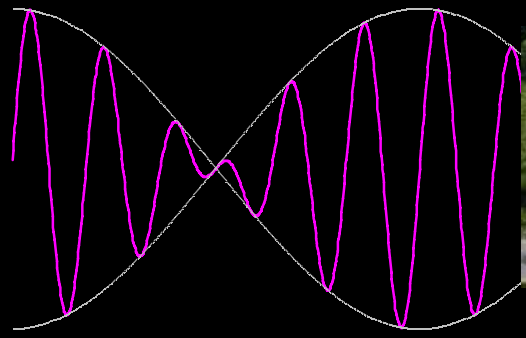
Particles are like waves particle mass determines its frequency

Measuring neutrinos oscillating: Measuring mass differences

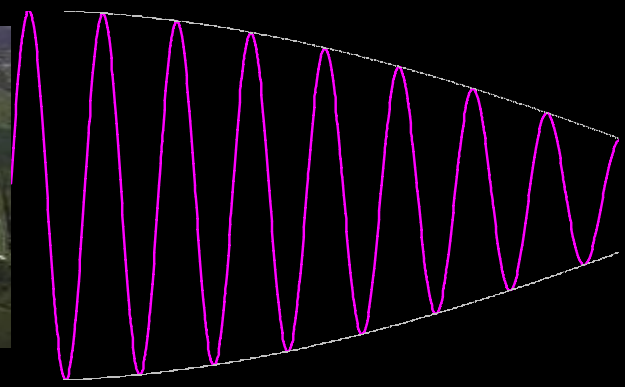
If one kind of neutrino disappears, another kind must appear

What are we doing with neutrinos at Fermilab?

- Studying how neutrinos change from one flavor to another
  - MiniBooNE: short distance oscillations (Kane County)

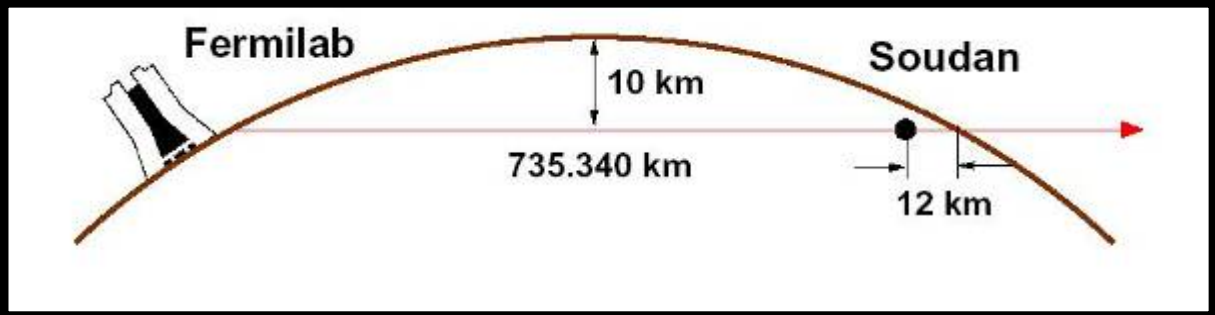


  - MINOS: long distance oscillations: (from here to Minnesota)



Why Minnesota?

- The state with the most saunas per capita in the US
- They have the best iron mines
- Measurements of neutrinos from atmosphere:
  - Neutrinos from above don't change flavors
  - Neutrinos from below change a lot
  - Neutrinos have to go at least a few hundred miles to change at all
  - So we have to send a beam of neutrinos far enough through the earth so that they will have had at least that much time to change…



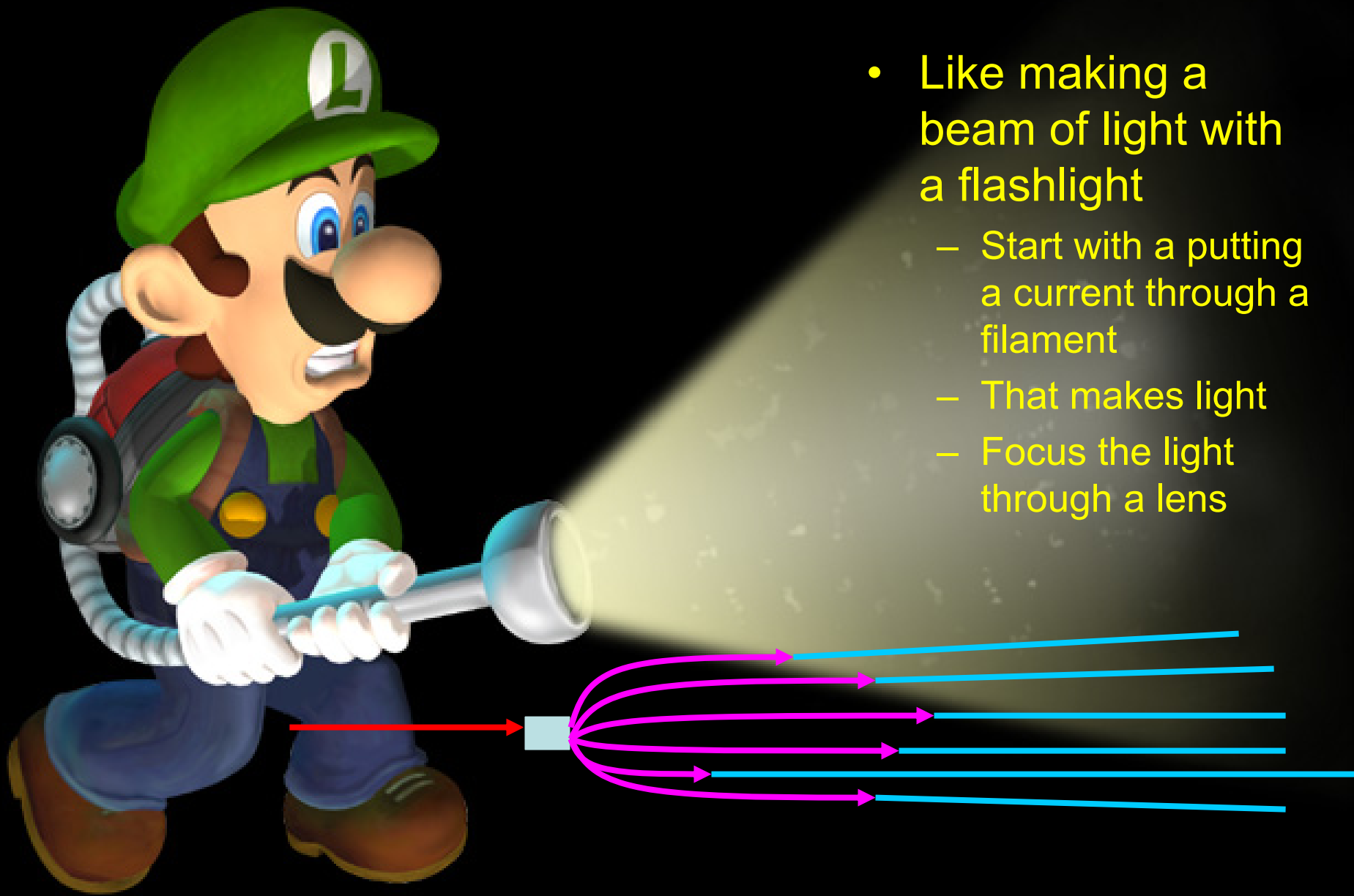
How do you get neutrinos from here to Minnesota?

- Just shoot them!
- Don't need a tunnel all the way there

$\nu\rightarrow$  .....

- The catch:
  - Need lots of neutrinos
  - Need lots of detector

How can you make a beam of neutrinos?

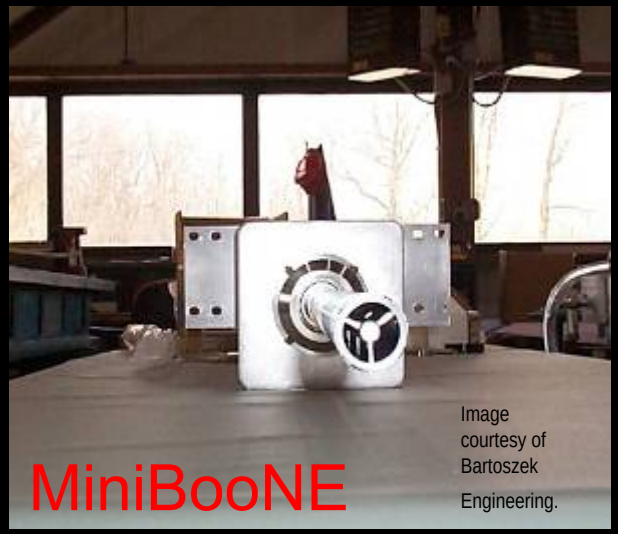


- Like making a beam of light with a flashlight
  - Start with a putting a current through a filament
  - That makes light
  - Focus the light through a lens

protons→target→unstable particles→neutrinos

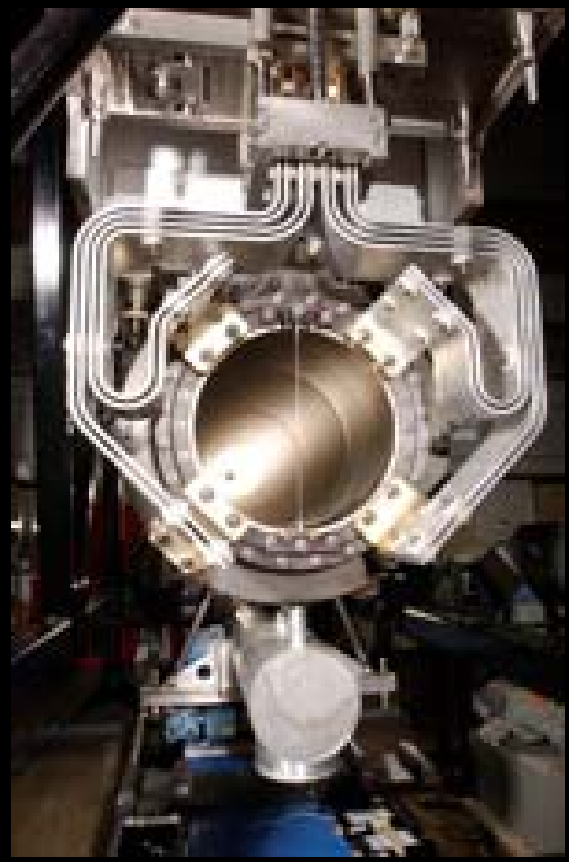

Booster


Main Injector



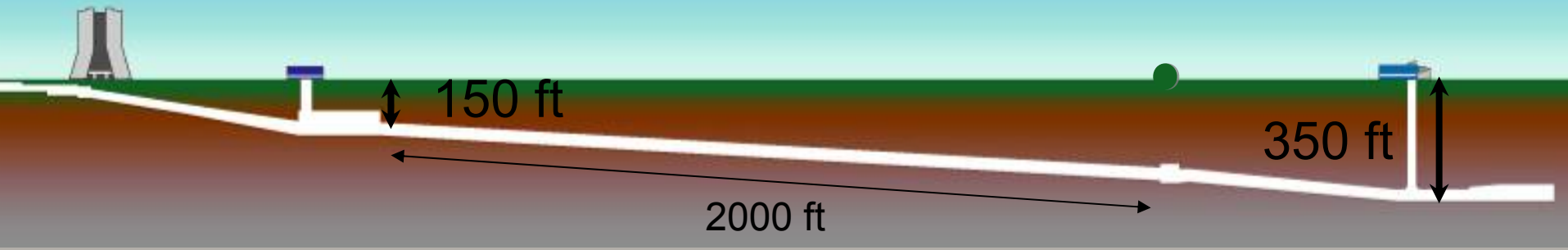
These targets see 10's' of trillions of Particles:
How can you keep something cool when you keep pumping energy into it?

MiniBooNE power: 50 kWatts
MINOS power: 200kWatts
Hair Dryer: 1500Watts



- MiniBooNE Horn:
  - Has pulsed >100 million times
  - 5 times a second!
- MINOS Horns
  - 10 million pulses
  - Once every 2 seconds
- Horn Currents: ~200,000 Amps
- 200,000 toasters!

Beamline for MINOS



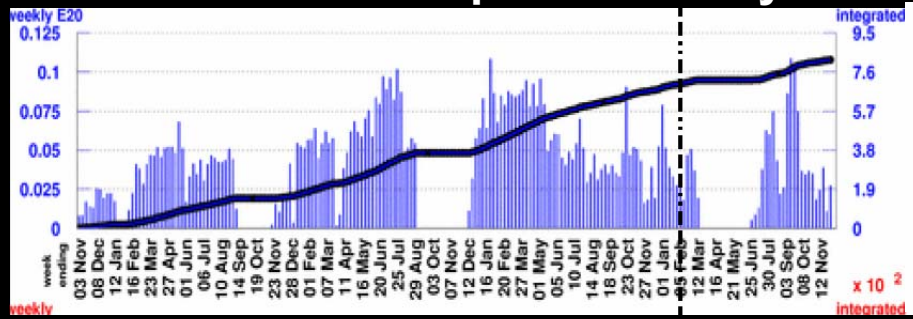
- Miners excavated a mile of underground tunnels
- Inserted 6’ tall pipe
- Filled the rest back up with concrete: 3000 cement trucks’ worth of cement
- Two large halls
  - Target hall: filled with target, horns shielding blocks
  - Near Detector Hall: 150ft long, filled with MINOS Near detector
- 3½ year construction: longer than MINOS has been taking data


APR 17 2002

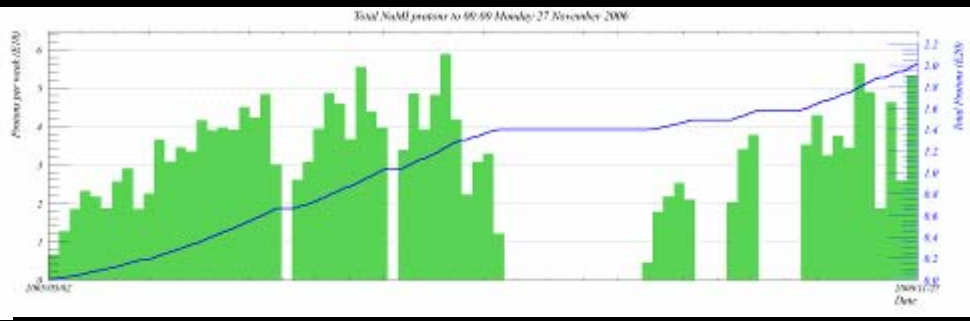
Ode to those who put the protons right on target

- In order to make neutrinos, someone has to accelerate protons
- Direct them through the beamline
- Hit the target
- And never miss!
- Like walking a mile with a glass full of milk that you cannot spill…
  - Over and over and over again for years…
- And what thanks do they get?

MiniBooNE: 9x10^{20} protons in 4 years!!!

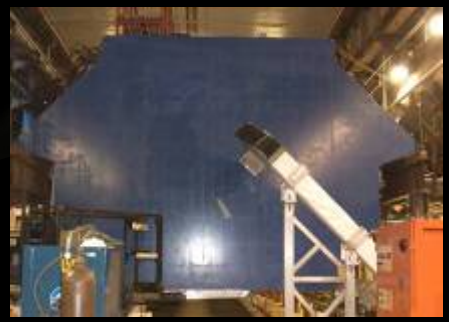


MINOS: 2x10^{20} protons in 1½ years!!!



How many detectors are there?

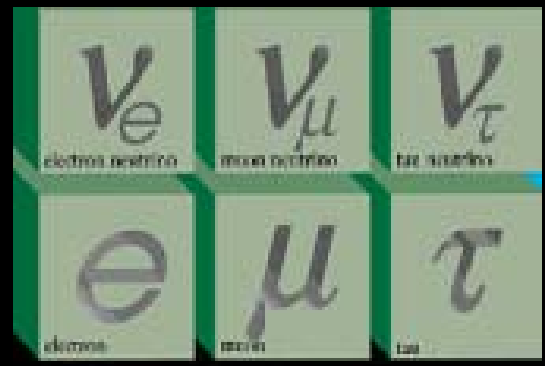
MINOS: how many muon neutrinos “DISAPPEAR”



MiniBooNE: how many electron neutrinos APPEAR

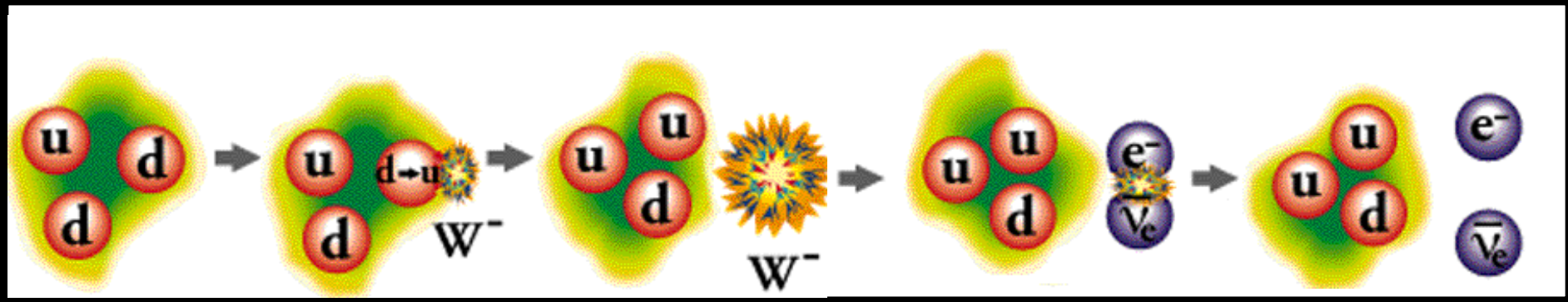
How can you see a neutrino?

- These three neutrinos (ν's) are associated with three charged particles, who are as different in size as
  - Squirrel (e: electron)
  - Lion (μ: muon)
  - Elephant (τ: tau)

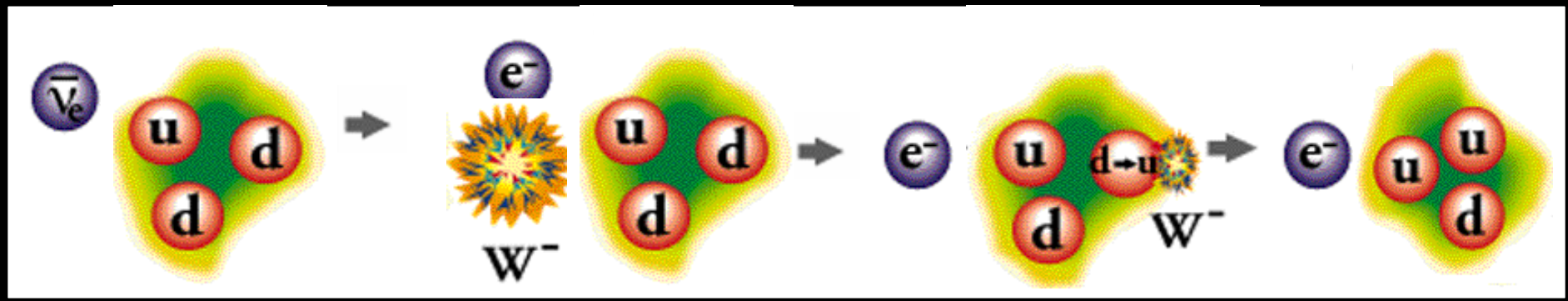


You can't see the neutrino, but you can see their partners

Remember $n \rightarrow p\ e^-\ \bar{\nu}_e$?

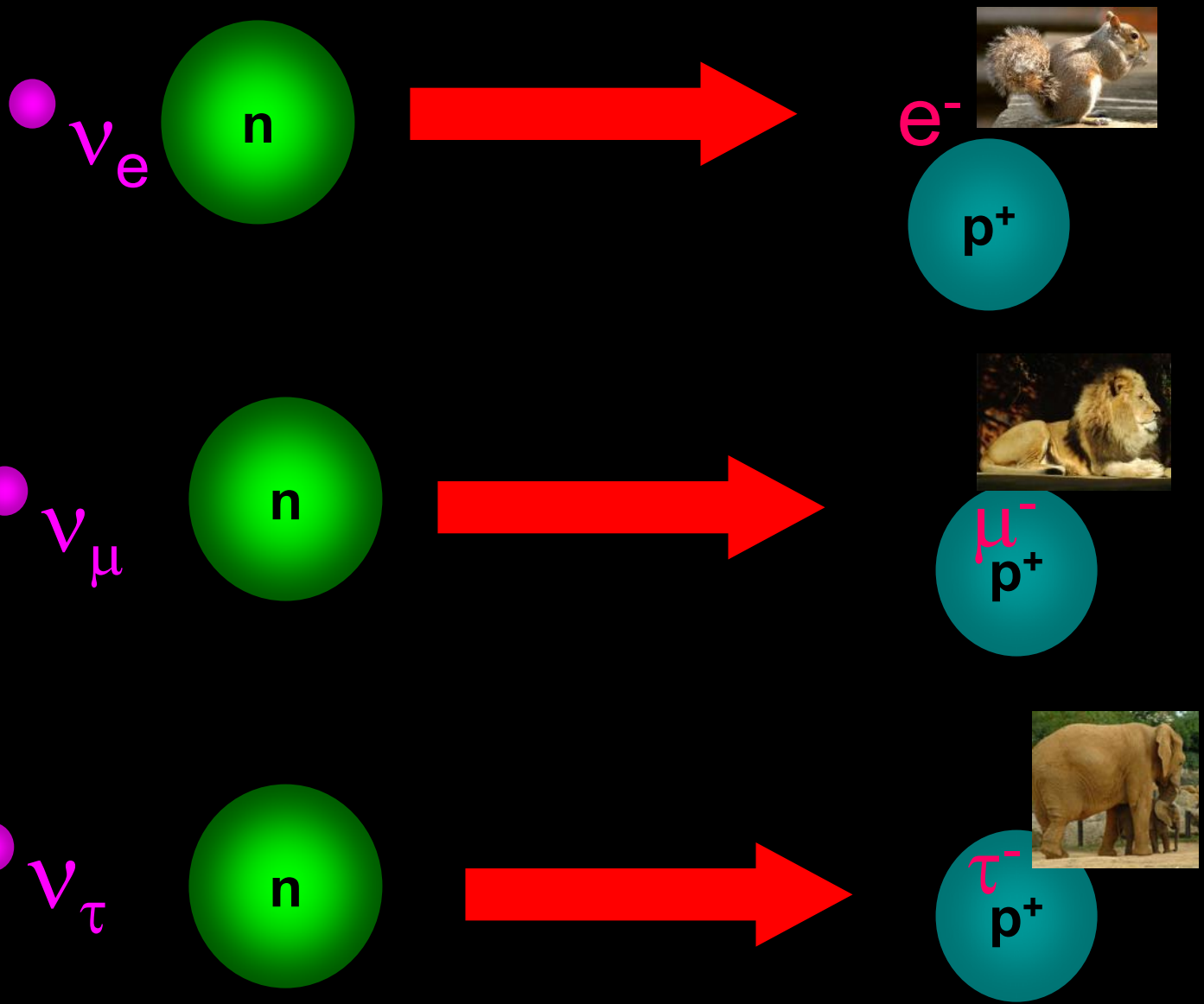


Play the neutrino part backwards…

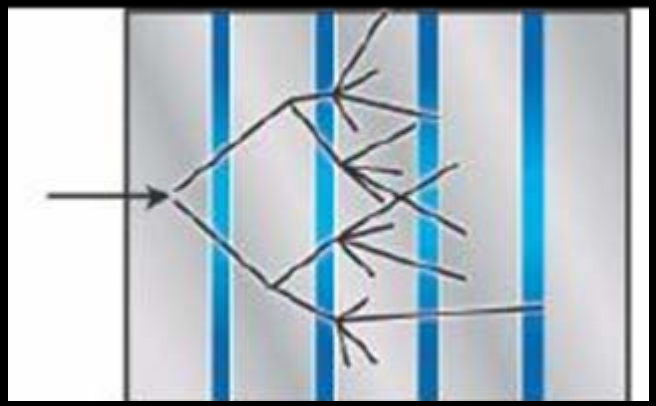


$\nu_e + n \rightarrow p\ e^-$

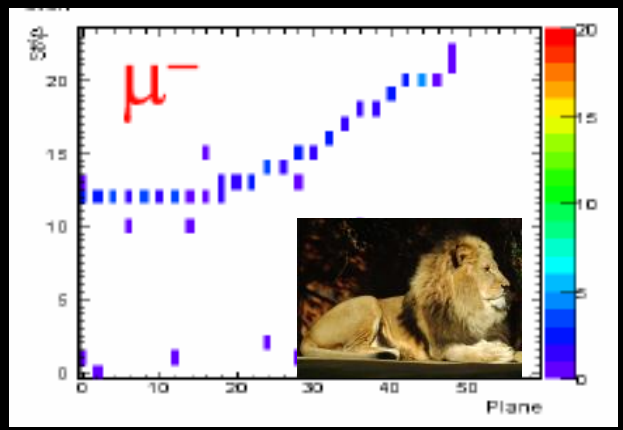
What kind of neutrino is it?

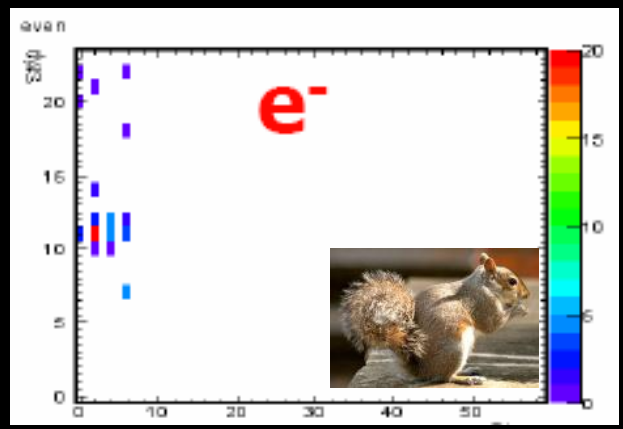


MINOS

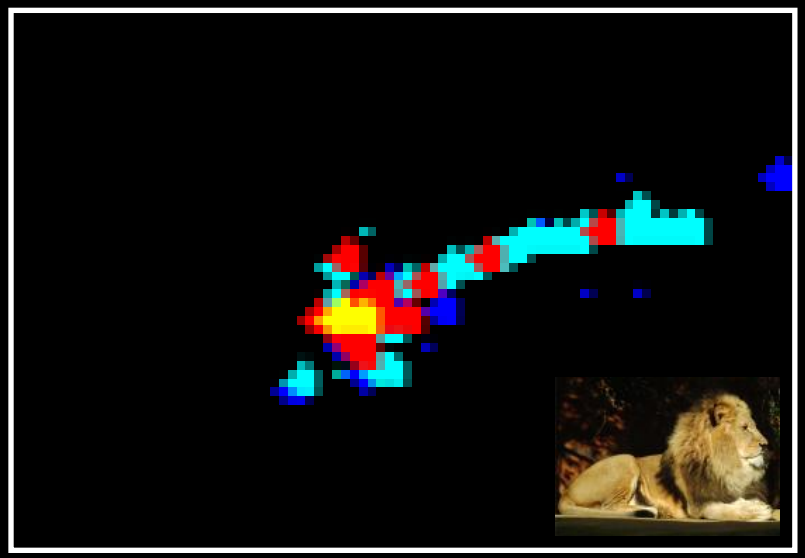


MINOS Detector:
5,400 tons of steel and plastic
Not just any plastic: it gives off light
when charged particles go through it
Collect the light: more particles, more light

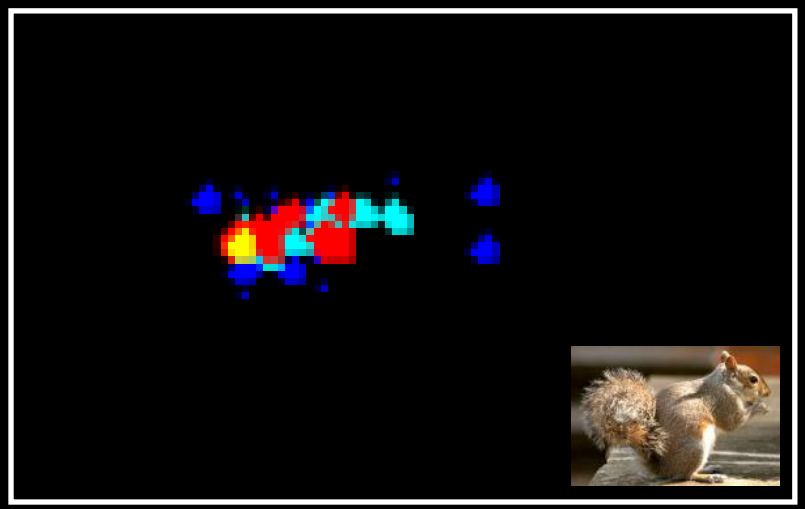




Neutrino Signals in MINOS



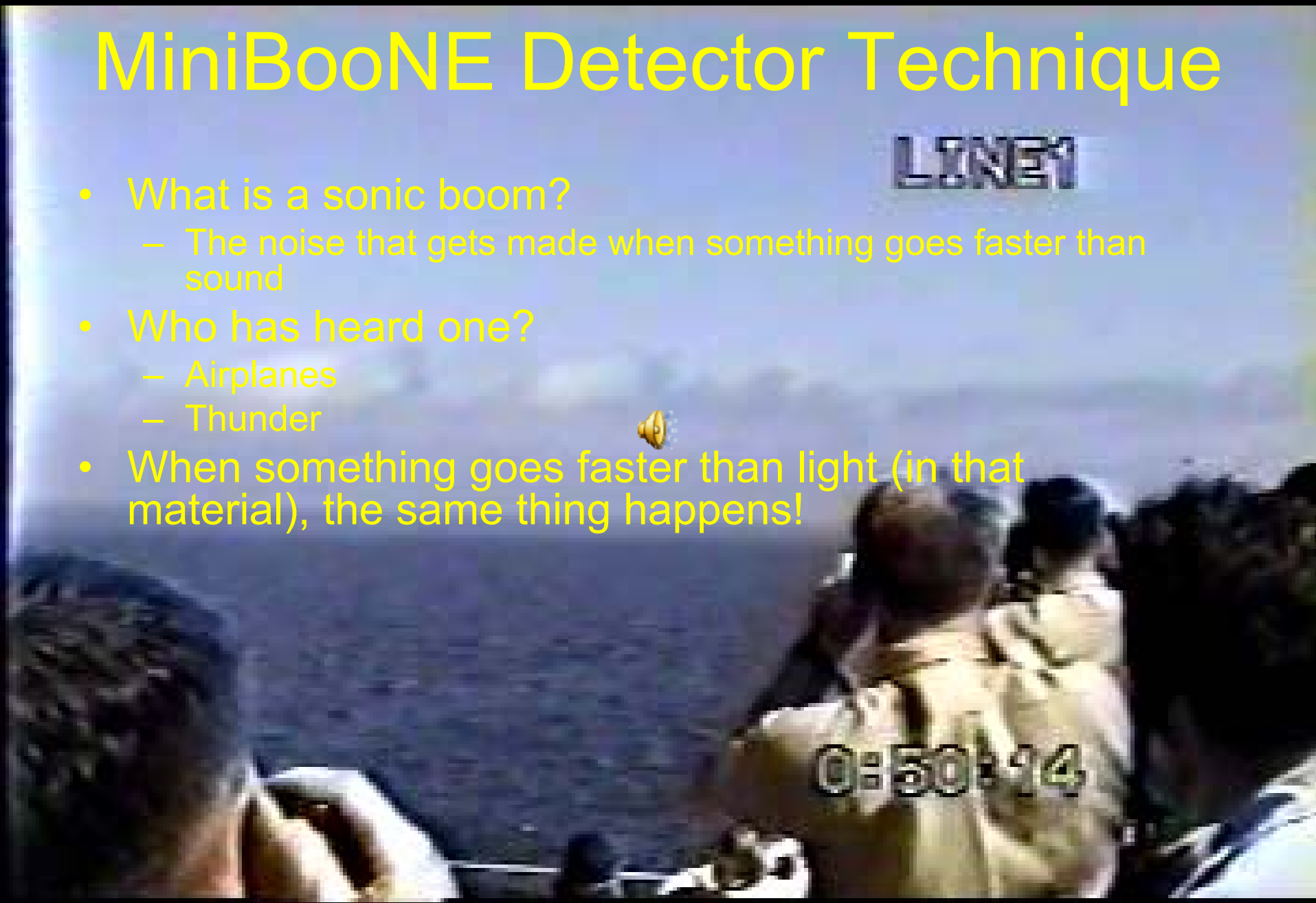
- Muon Neutrino:
  - Nothing going in
  - Muon going out
  - 1/400 second after protons hit target



- Some kind of neutrino
  - Nothing going in
  - A few particles going out, could be an electron neutrino
  - 1/400 second after protons hit target

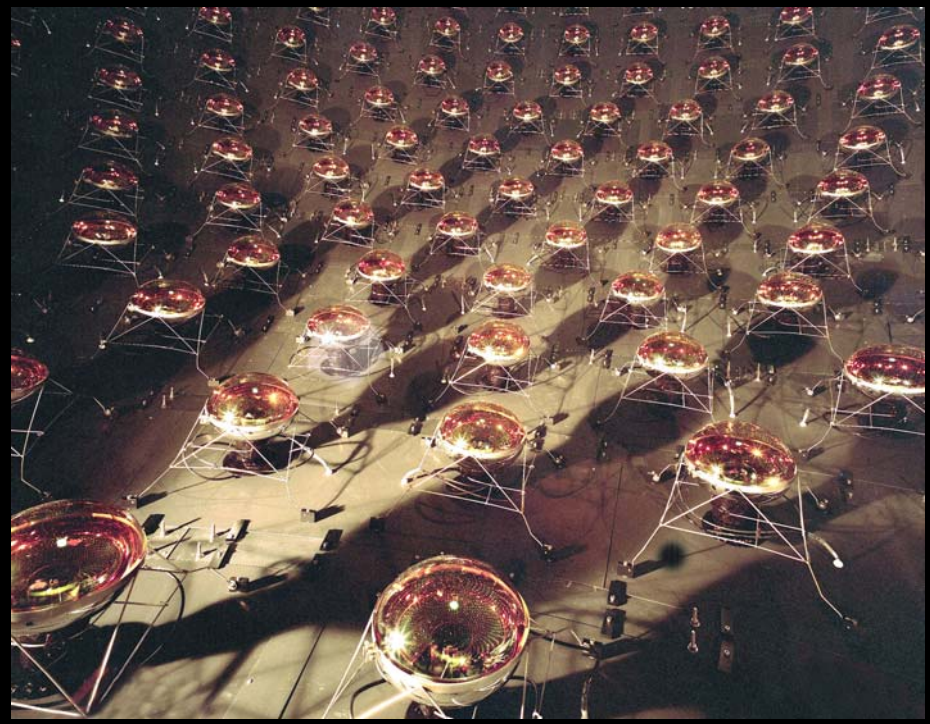
MiniBooNE Detector Technique

- What is a sonic boom?
  - The noise that gets made when something goes faster than sound
- Who has heard one?
  - Airplanes
  - Thunder
- When something goes faster than light (in that material), the same thing happens!



MiniBooNE Detector

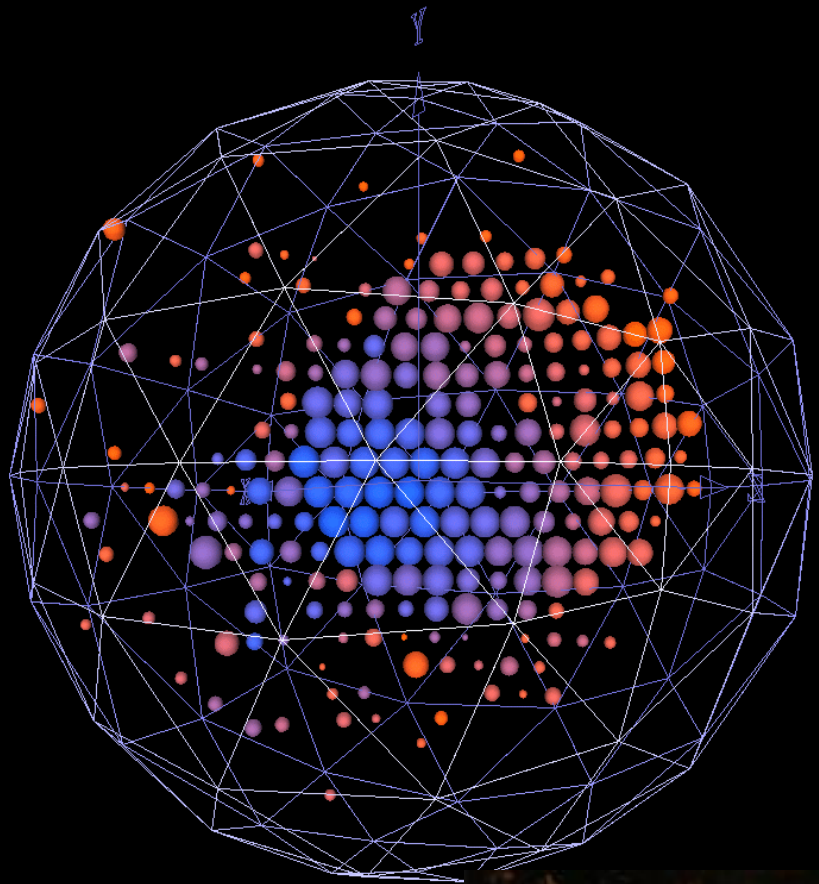
- tank contains 250,000 gallons of **mineral oil** (neutrino target)
  - 44 tanker trucks worth
  - 800 tons
- lined w/ 1520 **PHOTOTUBES** (electronic "eyes" of the detector)

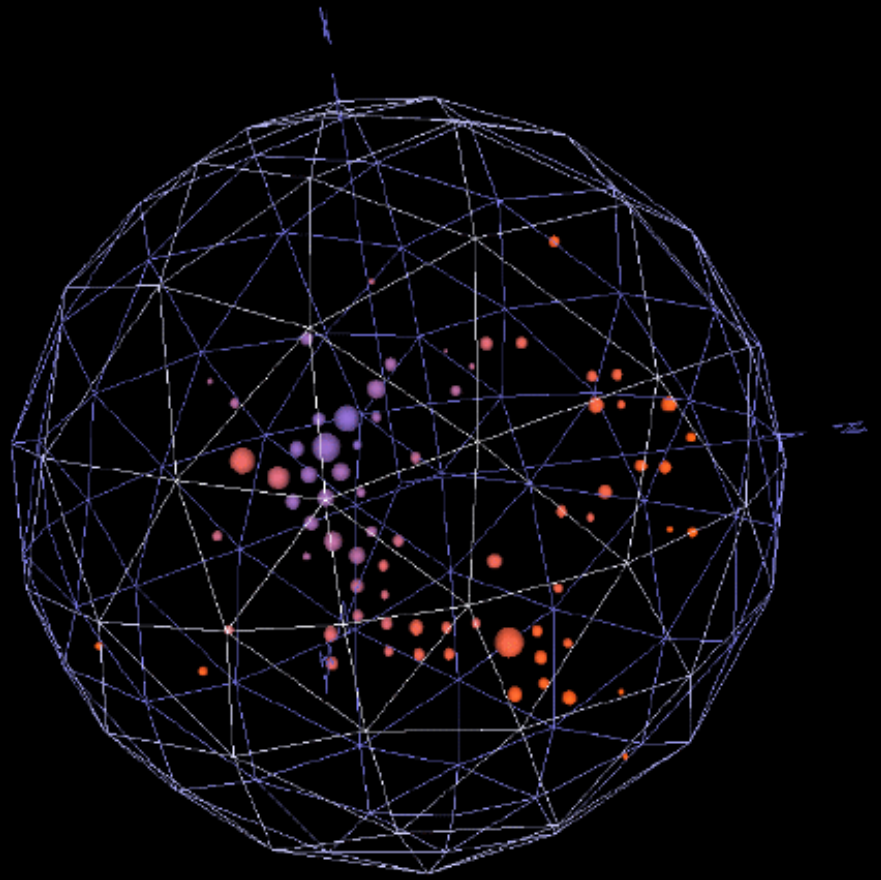


Phototubes work like inverse light bulbs

- produce an electrical signal whenever light strikes them

Neutrino Patterns in MiniBooNE



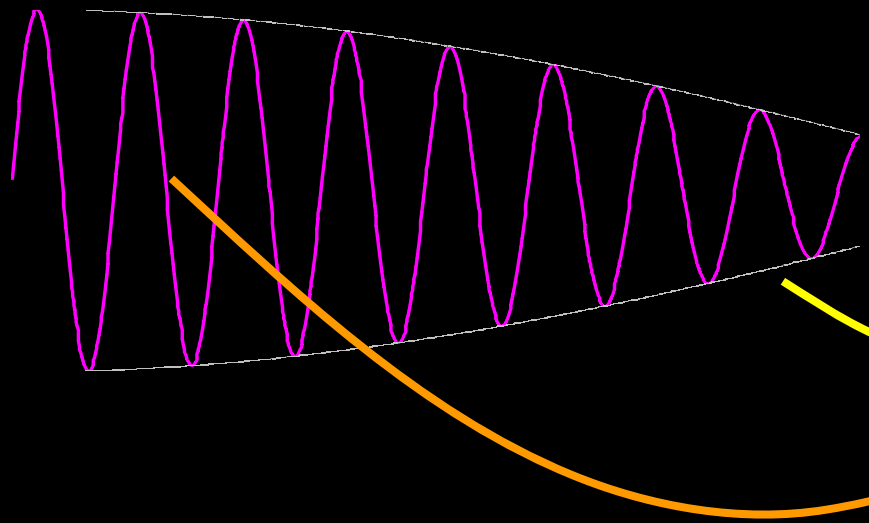


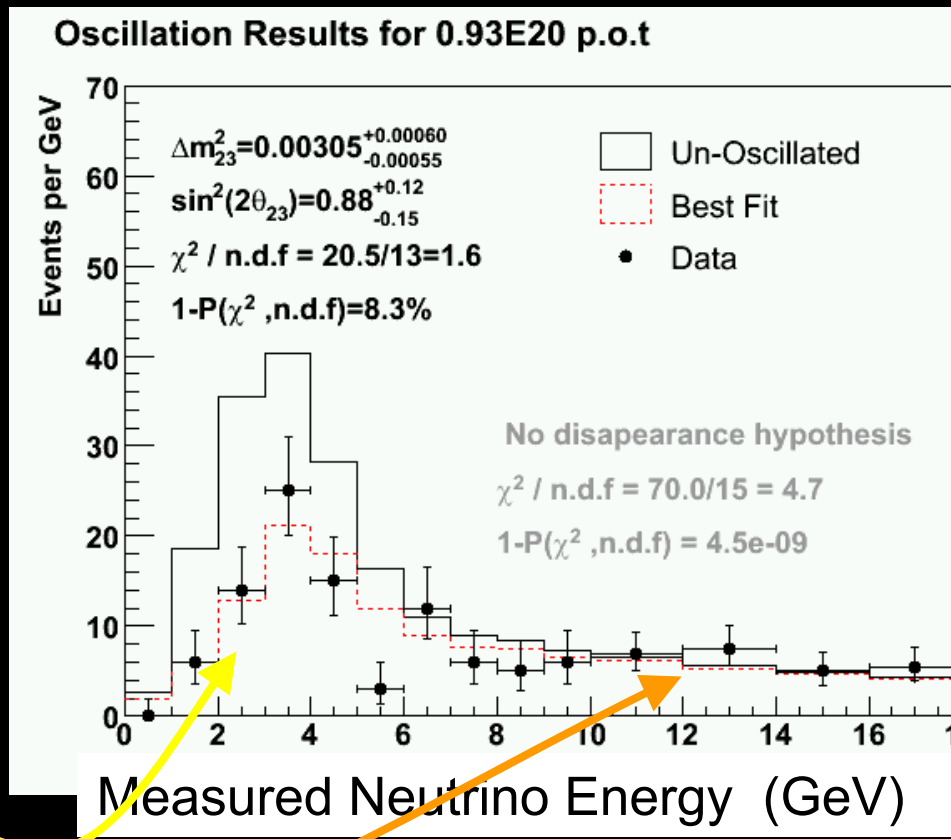
muon

electron

First Results from MINOS

- March 30, 2006:
  - Auditorium was packed
  - 204 ν_μ events seen
  - Expect 50% more if no oscillations!



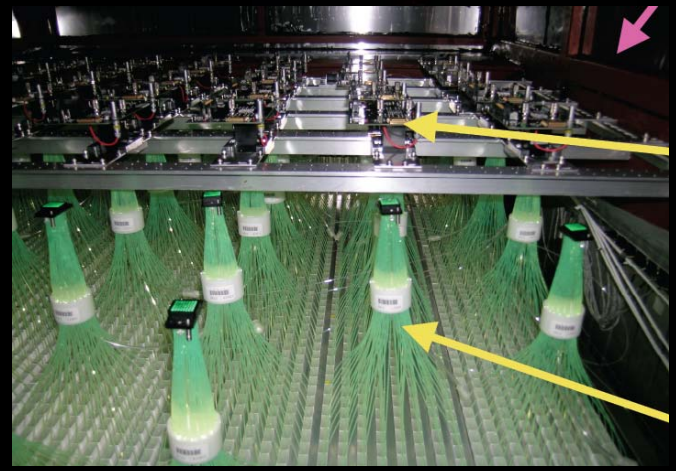


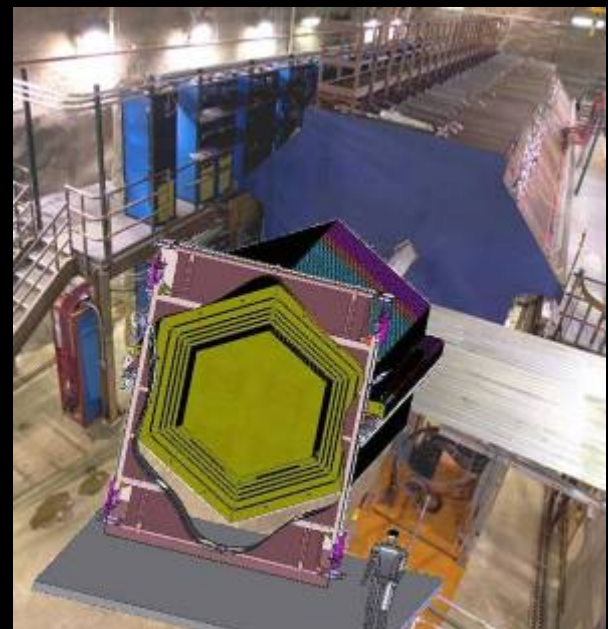
- The auditorium will be packed again soon for MiniBooNE…

What's Next?

Just Around the Corner:

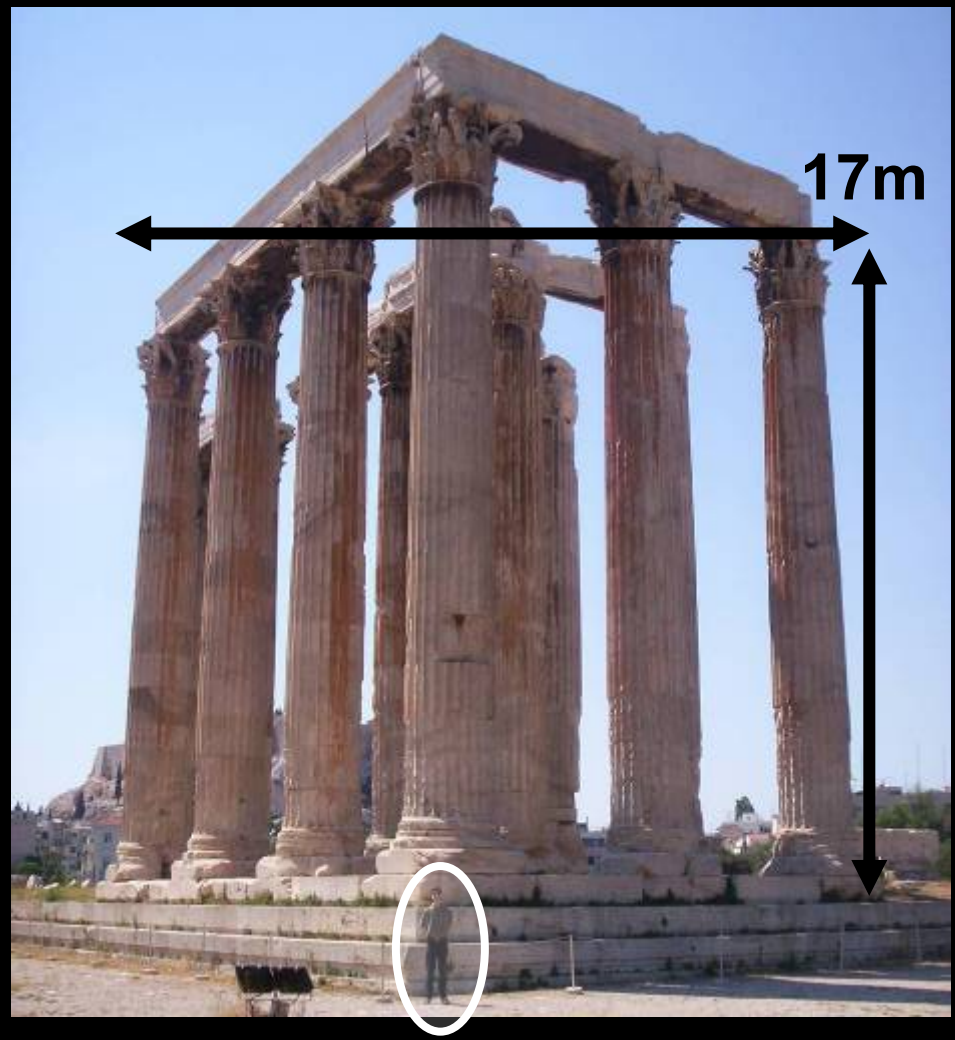
- SciBooNE:
  - detector from Japan
  - Same beam as MiniBooNE
- MINERvA:
  - New detector
  - New community of nuclear physicists
  - Same beam as MINOS
- Both: new eyes on the way neutrinos interact
- Both: will help next generation of oscillation experiments





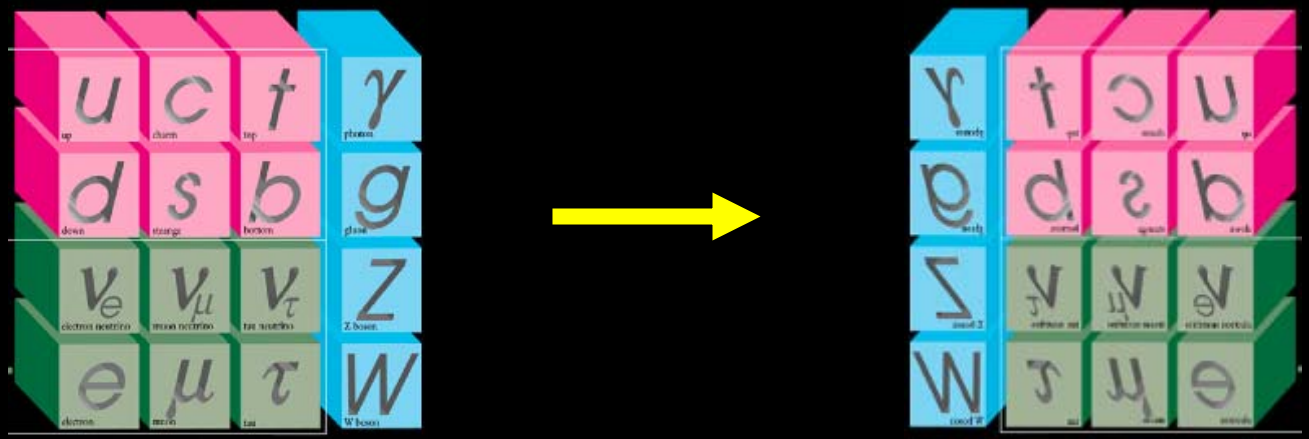
What's next for Oscillations?

- Just around two corners: NOvA
  - Will use the same neutrino beamline as MINOS
  - Brand new HUGE detector in northern Minnesota: better able to distinguish electrons (squirrels) from anything else
  - Best chance for seeing neutrino anti-neutrino differences!



Why Neutrinos and Anti-Neutrinos?

- Every fundamental particle has an anti-matter partner



- When they meet, they annihilate into pure energy
- Alternatively, energy can become matter plus anti-matter

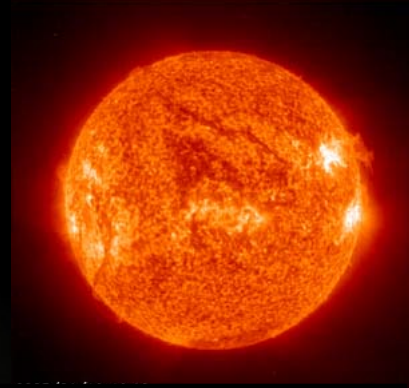
So you might ask…

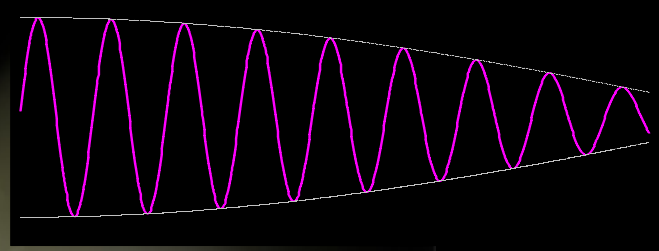
- The early Universe had a lot of energy. Where is the anti-matter in the Universe?
- Good question… how do we know it isn't around today?
  - look for annihilations.
  - As far away as we can tell, today there aren't big matter and anti-matter collisions

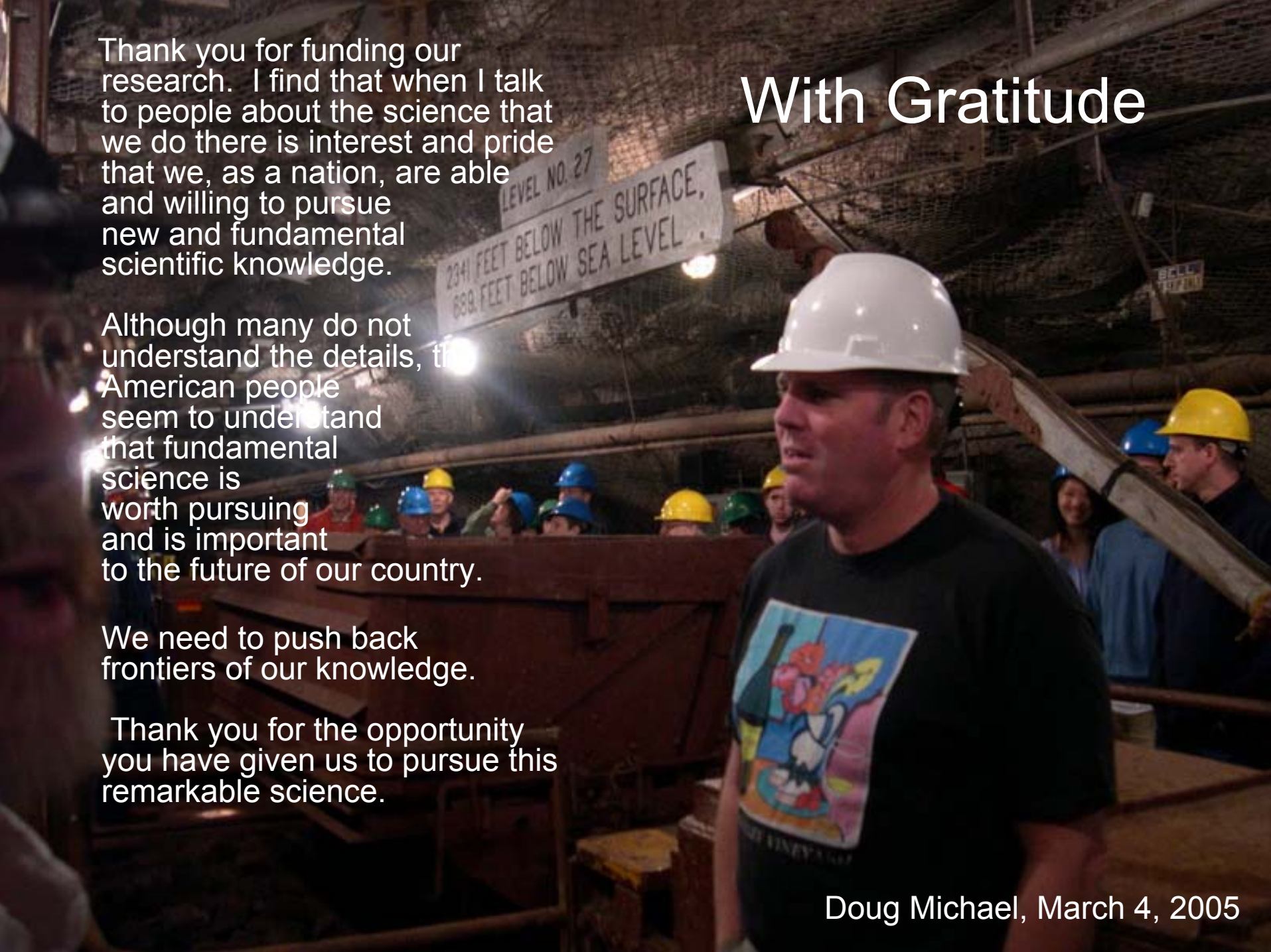


  - Maybe it's the neutrinos which are different from anti-neutrinos! Stay tuned…

Conclusions







With Gratitude

Thank you for funding our research. I find that when I talk to people about the science that we do there is interest and pride that we, as a nation, are able and willing to pursue new and fundamental scientific knowledge.

Although many do not understand the details, the American people seem to understand that fundamental science is worth pursuing and is important to the future of our country.

We need to push back frontiers of our knowledge.

Thank you for the opportunity you have given us to pursue this remarkable science.

Doug Michael, March 4, 2005