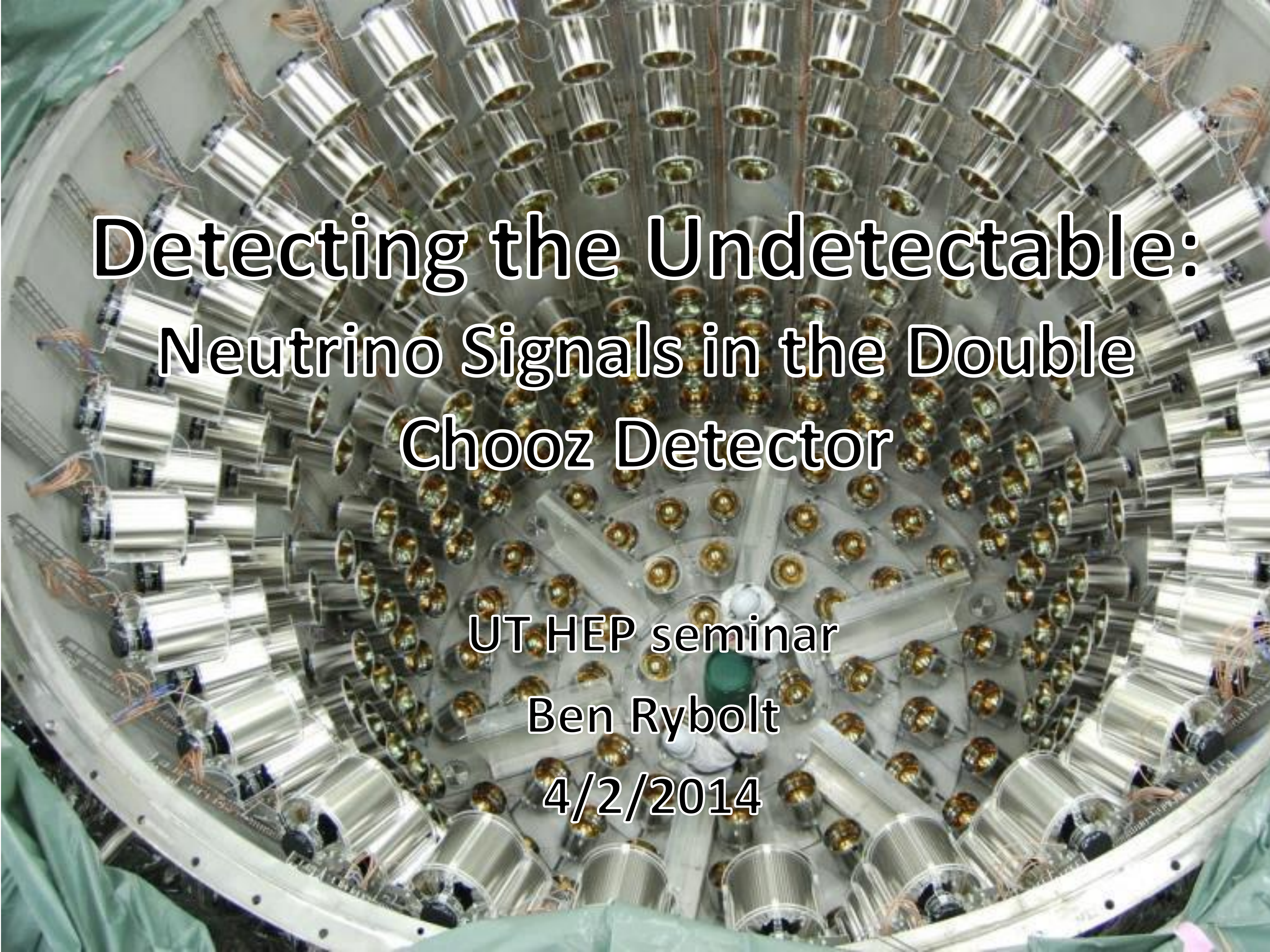


Detecting the Undetectable: Neutrino Signals in the Double Chooz Detector

UT HEP seminar

Ben Rybolt

4/2/2014

Outline

- What is a neutrino? Why do we want to study them?
- Building a detector to detect the undetectable
- What does a neutrino detector see?
- How do you seperate a neutrino signal from the background?

Neutrinos

"I have done a terrible thing, I have postulated a particle that cannot be detected."
–Wolfgang Pauli (1930)

Why measure them?

- Most numerous particle in the Universe
- Fundamental Science
    - Neutrino Oscillation
    - Possible CP violation
        - Could account for matter/anti-matter asymmetries
- Neutrino behavior must be correctly modeled for astrophysics and cosmology
    - Supernova
    - Big Bang
- Nuclear Reactor Detector/Monitor
    - Nuclear Non-Proliferation

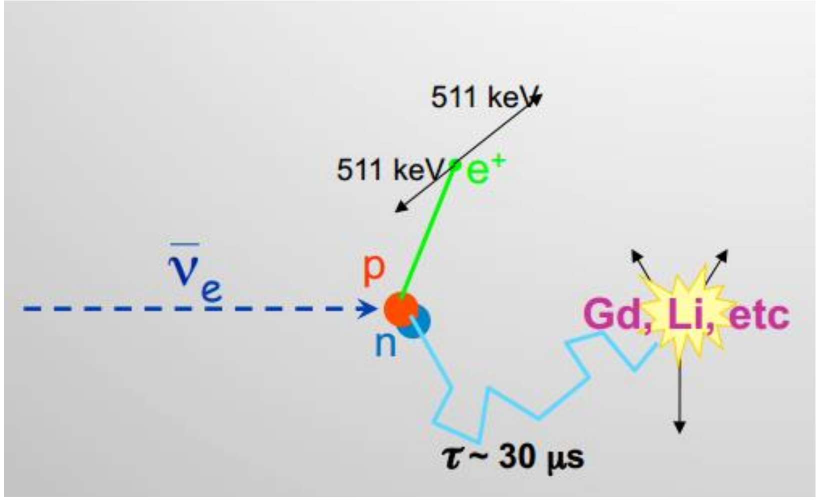
Why are they difficult to observe?

- Light Particle
    - Mass of $\nu_e < 2.2\ eV$
    - 250,000 times lighter than electron
- Neutral Charge
- Interact only though the weak force
- Small Cross section

$\sigma = 10^{-18}\ barns$ at reactor energies

One trillion trillion times smaller than a Uranium Nuclei!

Detection Mechanism



- Inverse Beta Decay (IBD)
  - Produces:
    - Positron
      - Energy Depends on Neutrino Energy
      - Minimum Signal -> 1.02MeV
    - Neutron
      - Low Energy
      - Thermalizes with random walk
      - Captured on nuclei
- Conservation of Energy determines threshold of interaction

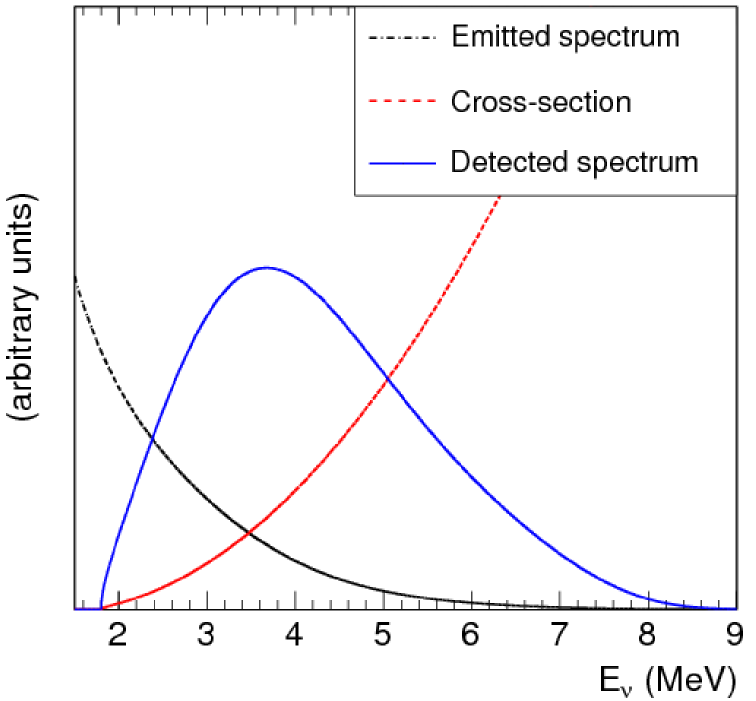
$$E_{\bar{\nu}_e} + E_p = E_{e^+} + E_n$$

$$E_{\bar{\nu}_e} = E_{e^+} + E_n - E_p$$

$$= 0.511 + 939.565 - 938.272$$

$$= 1.804\ MeV$$

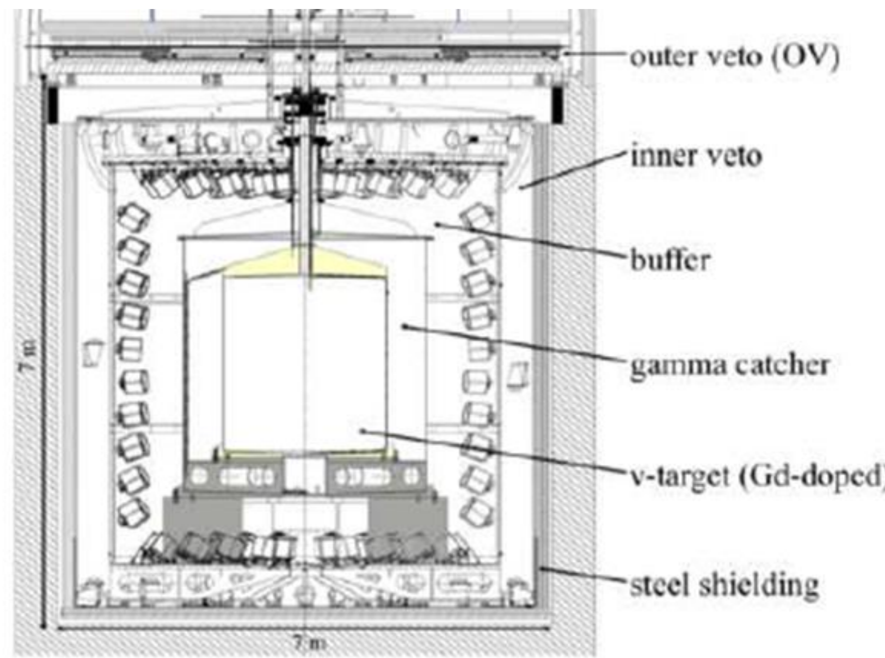
Reactor Neutrino Spectrum



Double Chooz Detector

- Neutrinos generated in two nuclear reactors

- Four Separate Volumes
  - Inner Veto
    - Scintillator
    - Optically separated
    - PMTs
  - Buffer
    - Transparent Mineral Oil
    - PMTs
  - Gamma Catcher
    - Scintillator
  - Target
    - Gadolinium doped Scintillator
    - Gadolinium has high neutron capture cross section
    - Relatively high energy gamma rays associated with neutron Capture (~8MeV)
    - Very Important!



Double Chooz Detector

- Neutrinos generated in two nuclear reactors
- Detected by
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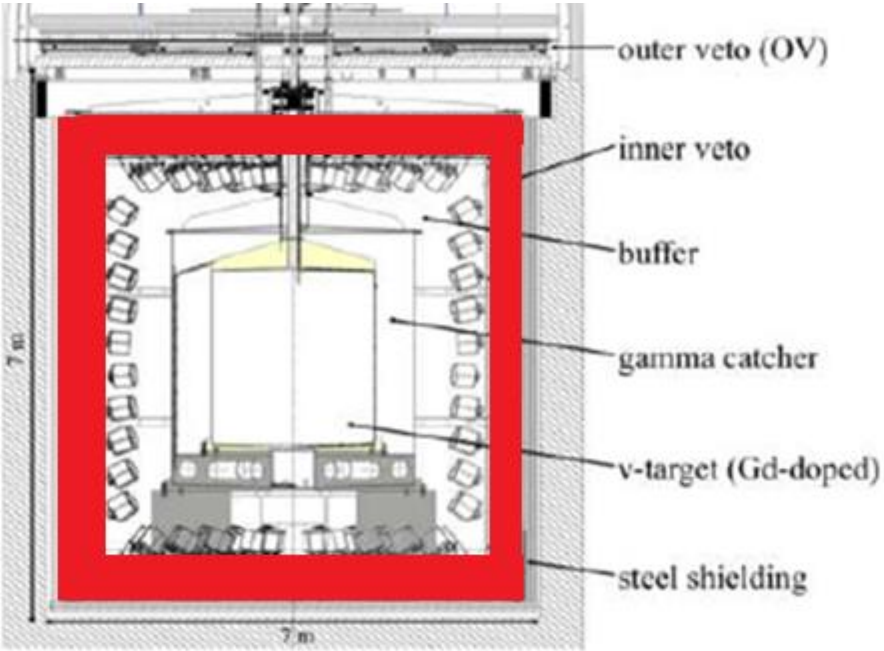

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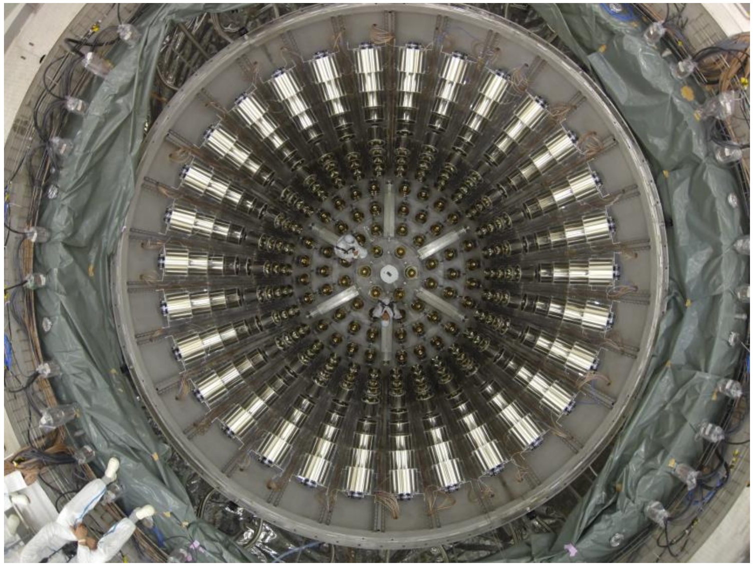

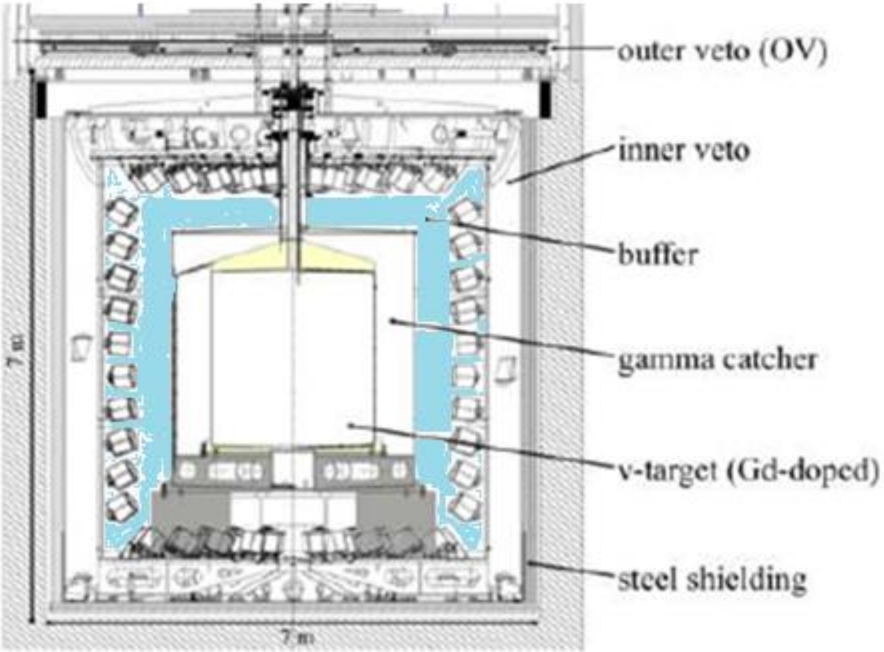

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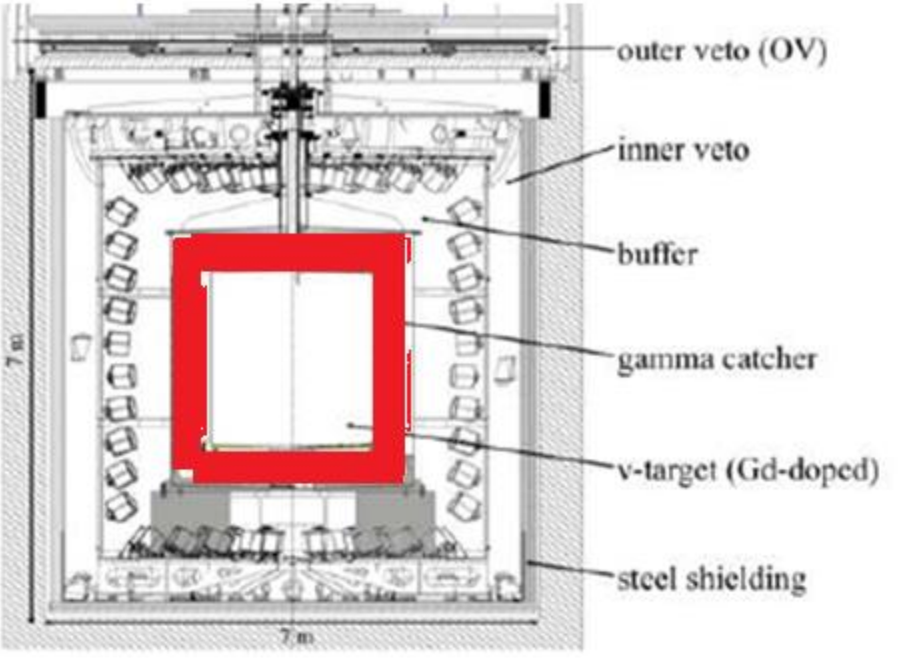

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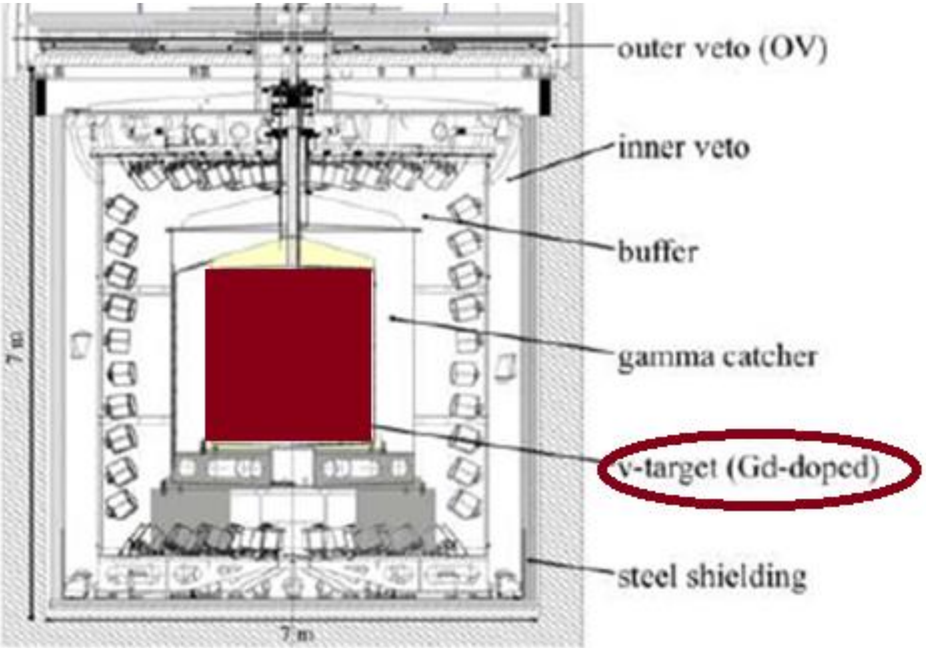
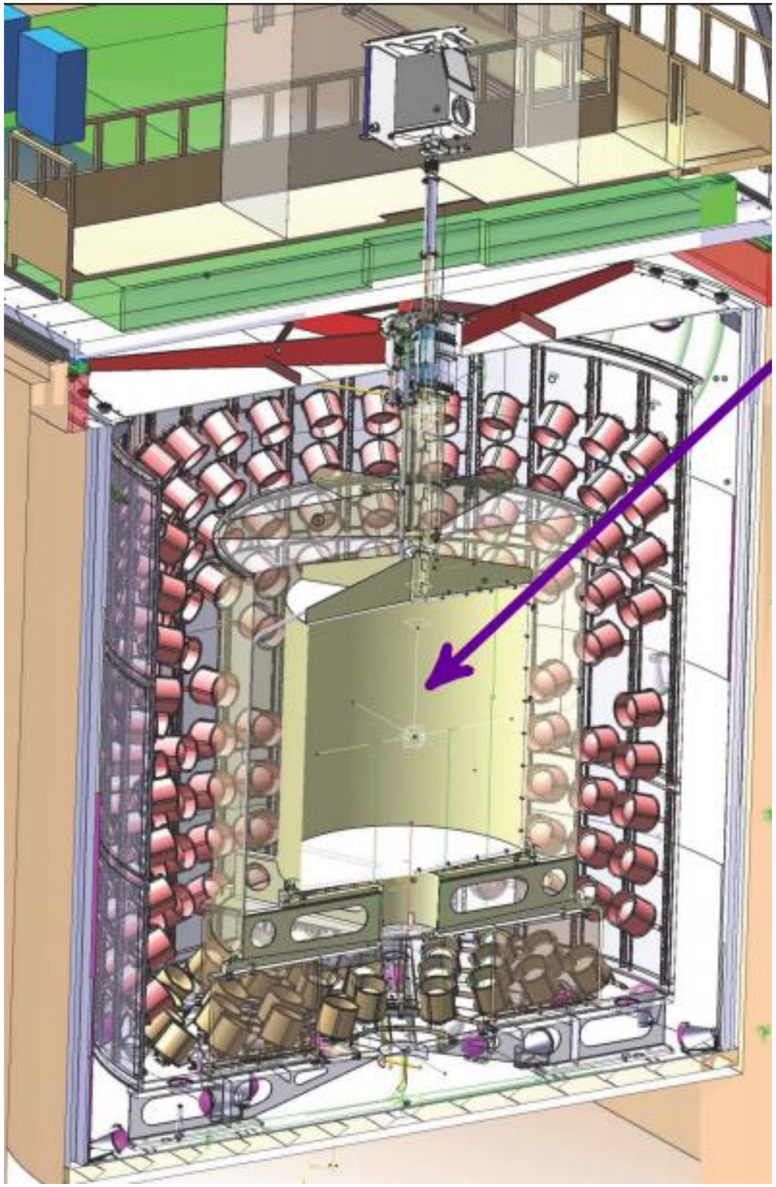
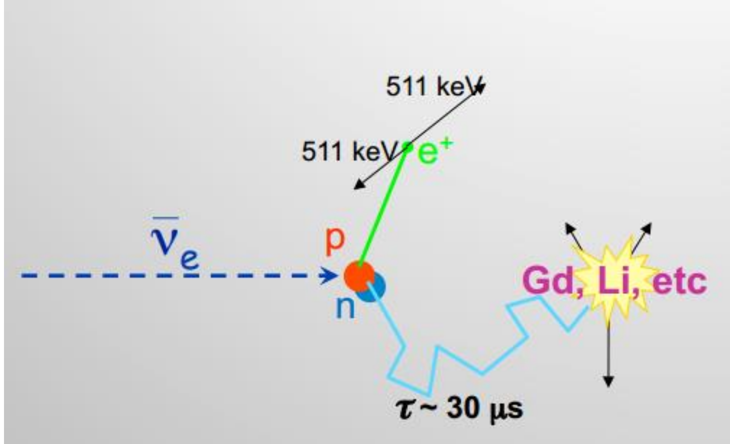


Double Chooz Detector

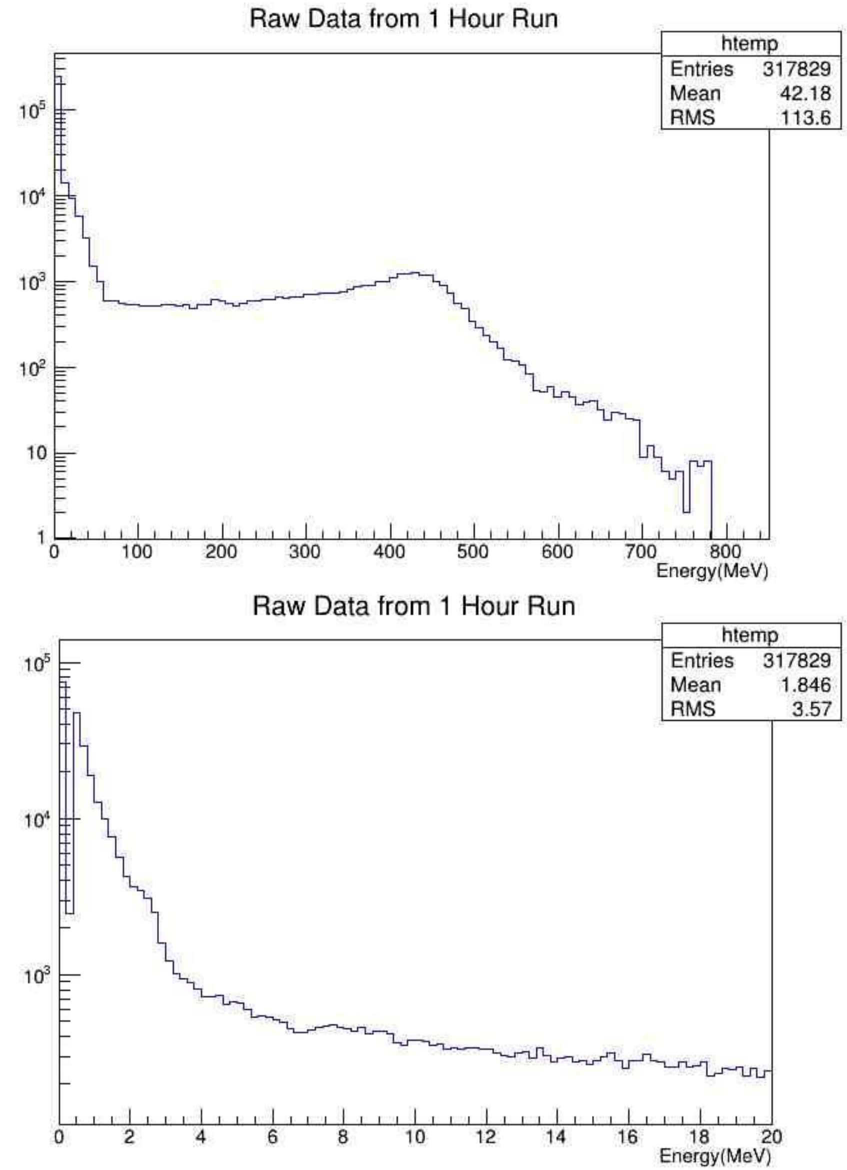
- Trigger System
  - Divide Detector PMTs into two groups
  - Sum the groups
  - Sum the Inner Veto PMTs
  - If any group has a readout value above threshold the Detector is Triggered and information from all PMTs is stored
  - 350 keV Threshold for the Inner Detector is well below the 1.02 MeV minimum neutrino signal from positron annihilation





Double Chooz Detector: What do we see?

- 317829 Events/hour = 88Hz
- Any charged particle moving through scintillator will create light
- Possible Sources of Charged Particles
  - Radioactive Decay
  - Particles from Cosmic Ray Showers
  - Positrons from neutrino IBD
  - Gammas from Nuclear Capture of Neutrons (i.e. on Gd and others)



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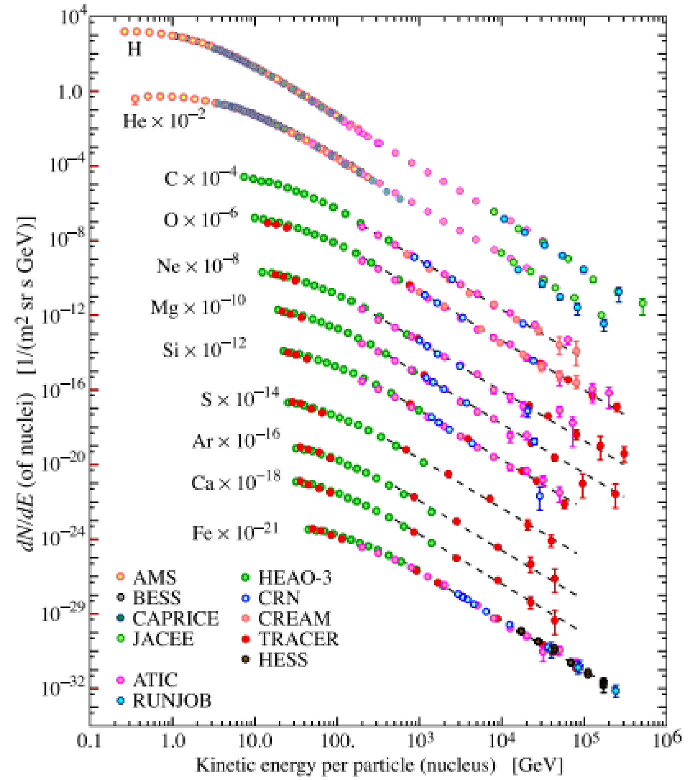
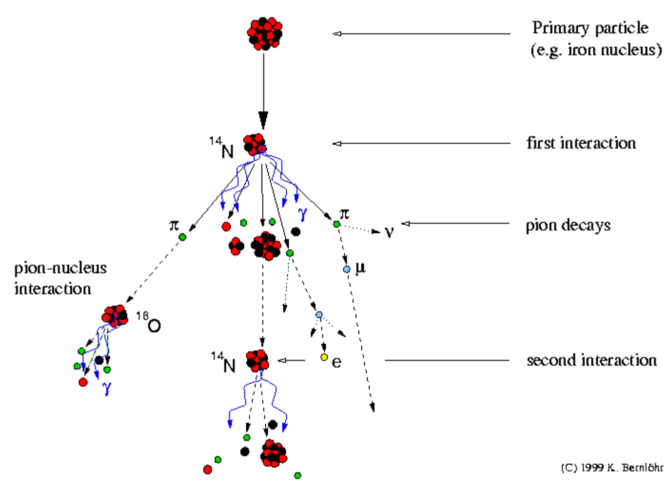
  - Gammas from Nuclear Capture of Neutrons (i.e. on Gd and others)
- Most numerous charged particles come from muons or muon induced reactions

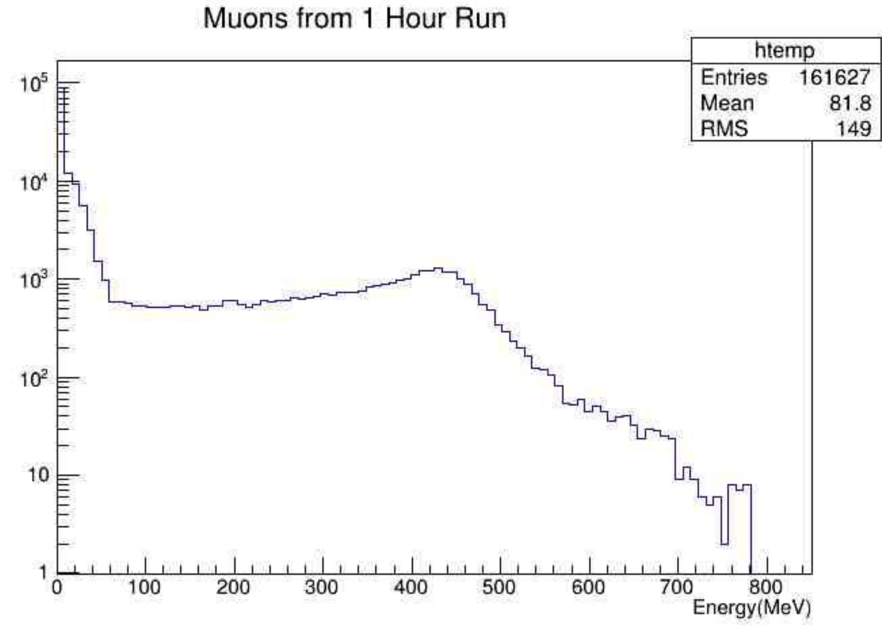


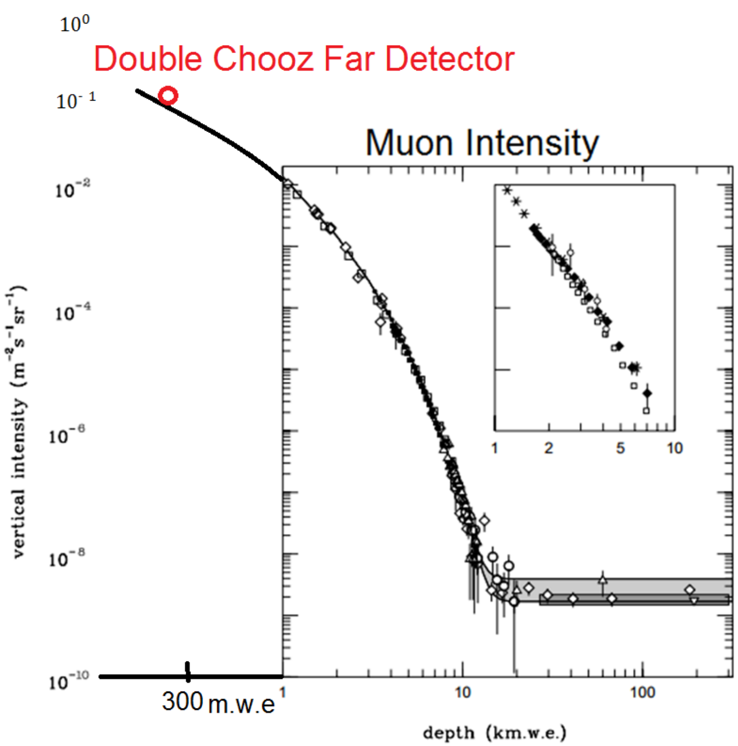
Development of cosmic-ray air showers

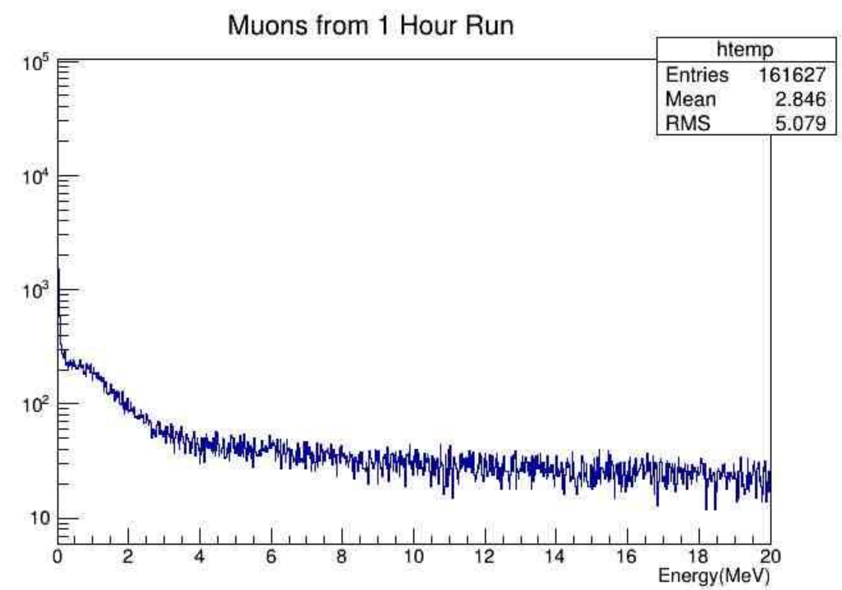


Double Chooz Detector: What do we see?

- Muons 45 (Hz)
- Double Chooz Detector Far is under 300 MWE rock overburden
  - Near Detector is only 120 MWE
- Veto Muons and 1 ms after Muons







Double Chooz Detector: What do we see?

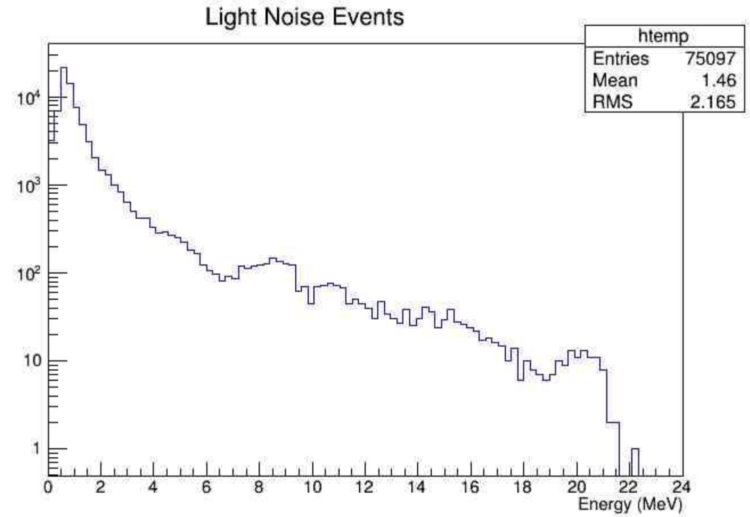
An Unexpected Background

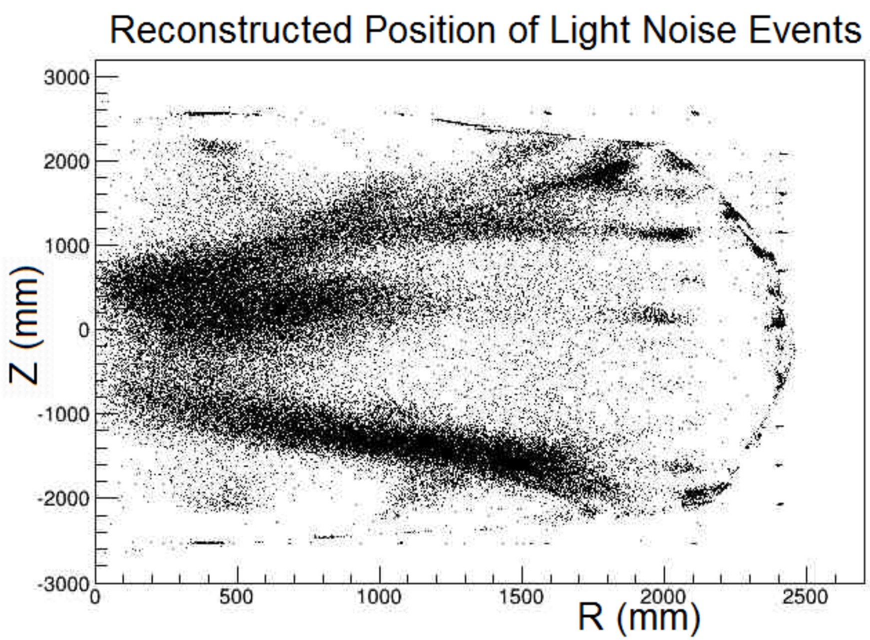
- Possible Sources of Light
  - Light Noise (20Hz)
  - Radioactive Decay
  - ~~Particles from Cosmic Ray Showers~~
  - Positrons from neutrino IBD
  - Gammas from Nuclear Capture of Neutrons (i.e. on Gd and others)
- Tagged by looking for events where >12% of charge is collected by a single PMT

OR

- When RMS of PMT start times > 40 ns
  - Events starting in center will have similar start times
  - Events localized by one PMT will have varied start times

- What is the source of these events?

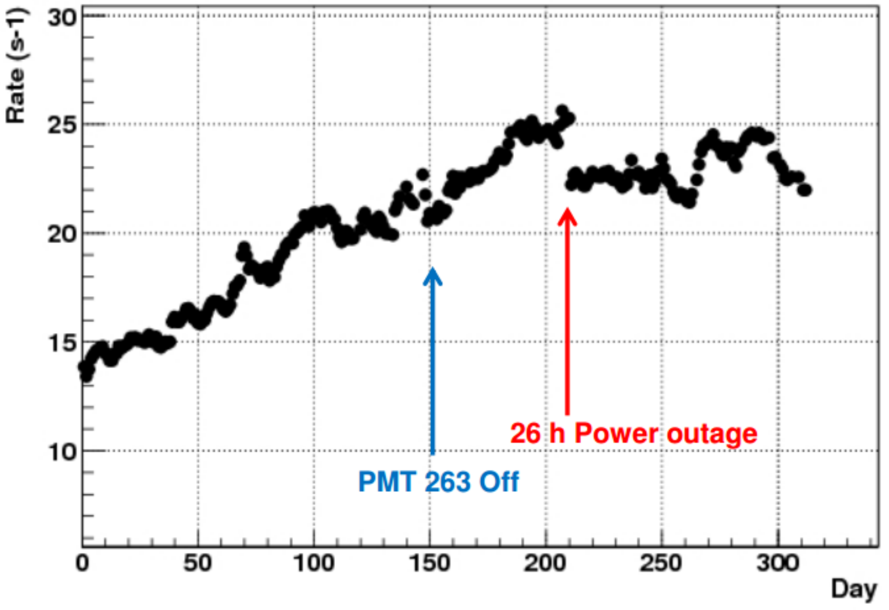


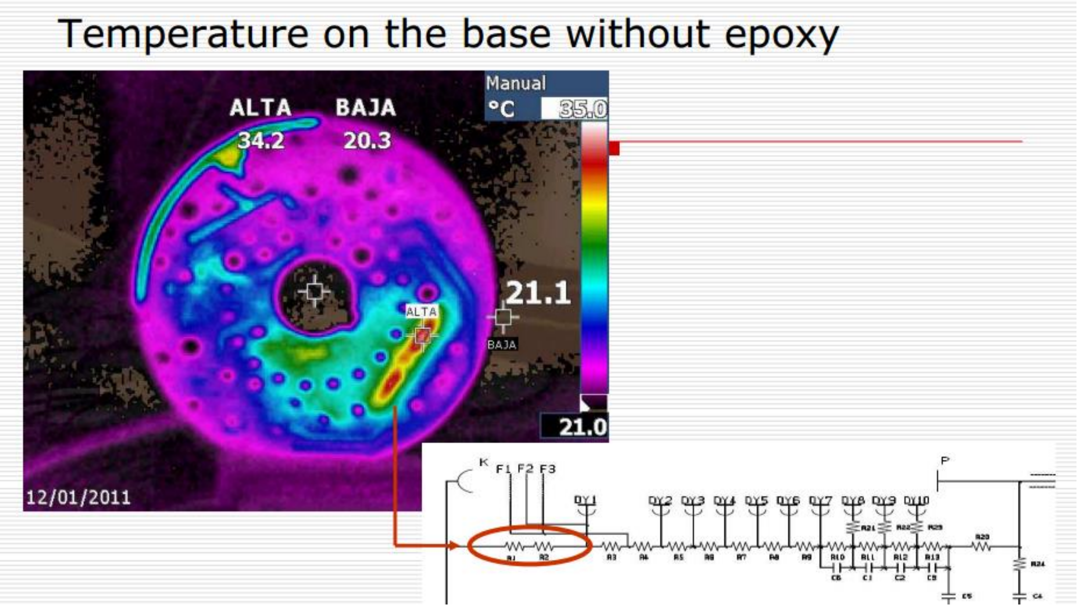


Glowing PMTs

- Voltage discharge across PMT base creates light inside the detector
- Increases with higher temperature
- Increases with higher Voltage

Light Noise Rate



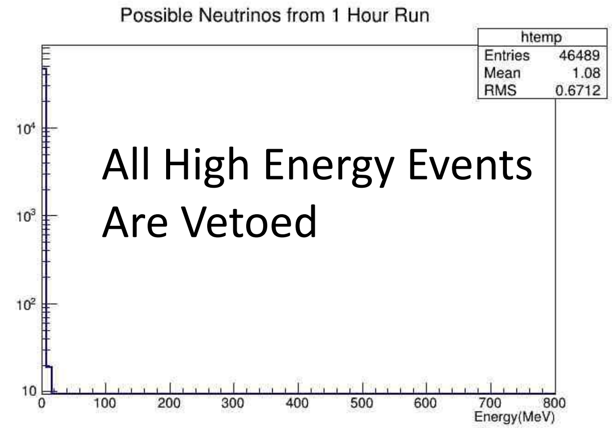


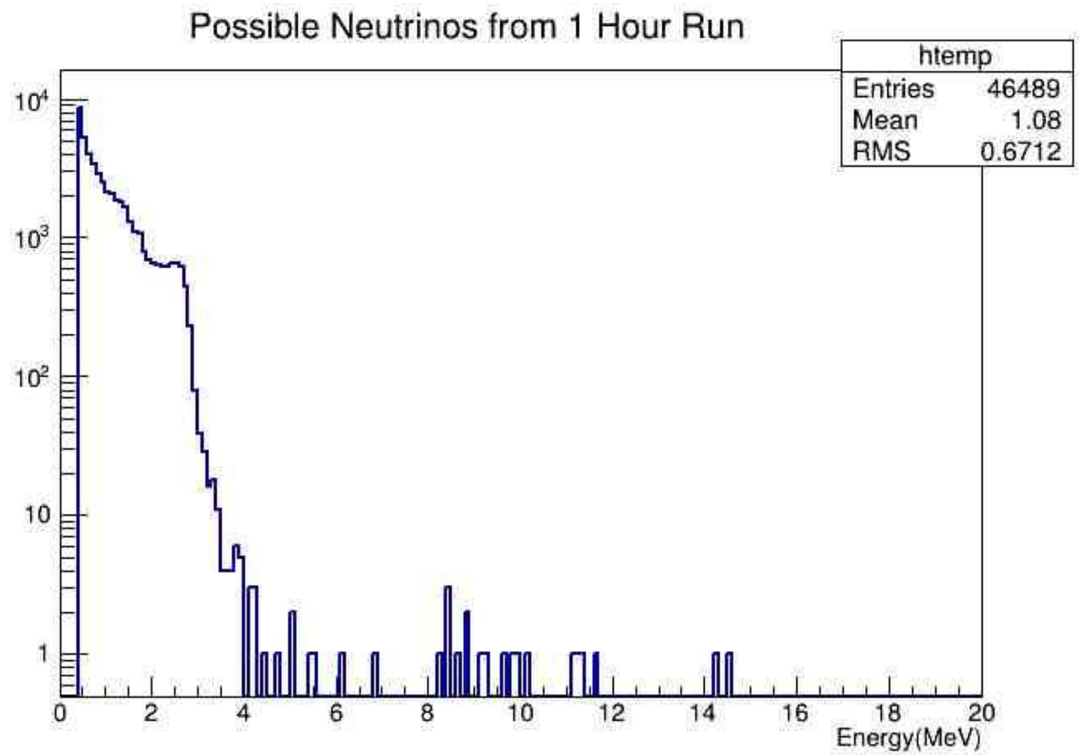
Double Chooz Detector: What do we see?

- Veto Muons and 1 ms after Muons and Veto Light Noise

- Remaining Events = **12Hz**
- Possible Sources of Light
  - Radioactive Decay
  - ~~Light noise~~
  - ~~Particles from Cosmic Ray Showers~~
  - Positrons from neutrino IBD
  - Gammas from Nuclear Capture of Neutrons (i.e. on Gd and others)

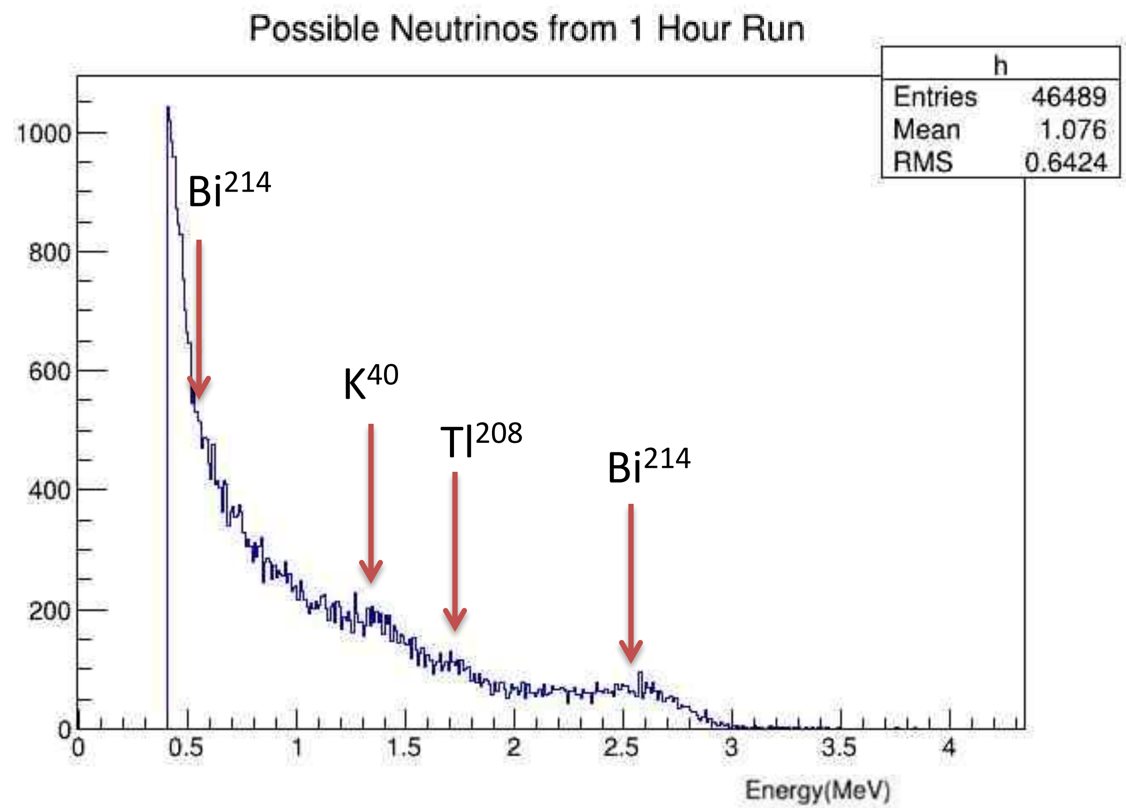
- What about low energy events?





Double Chooz Detector: What do we see?

- Possible Sources of Charged Particles
  - **Radioactive Decay**
    - K 40 -> 1.46 MeV γ 10%
    - Tl 208 -> 2.6MeV γ 99.75%
    - Bi 214 ->
      - 0.6 MeV γ 45%
      - 1.75 MeV γ 14%

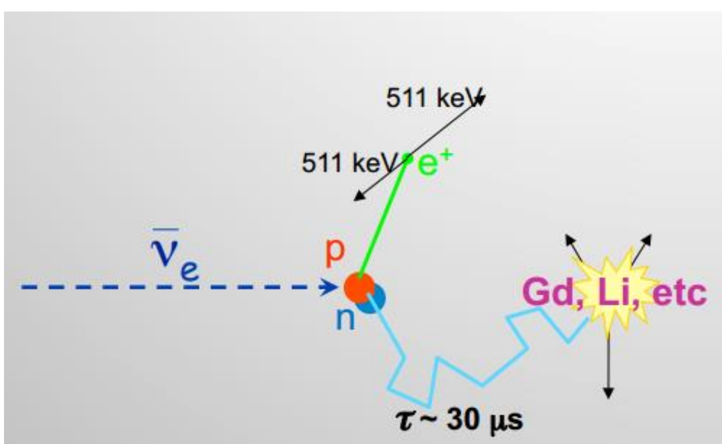


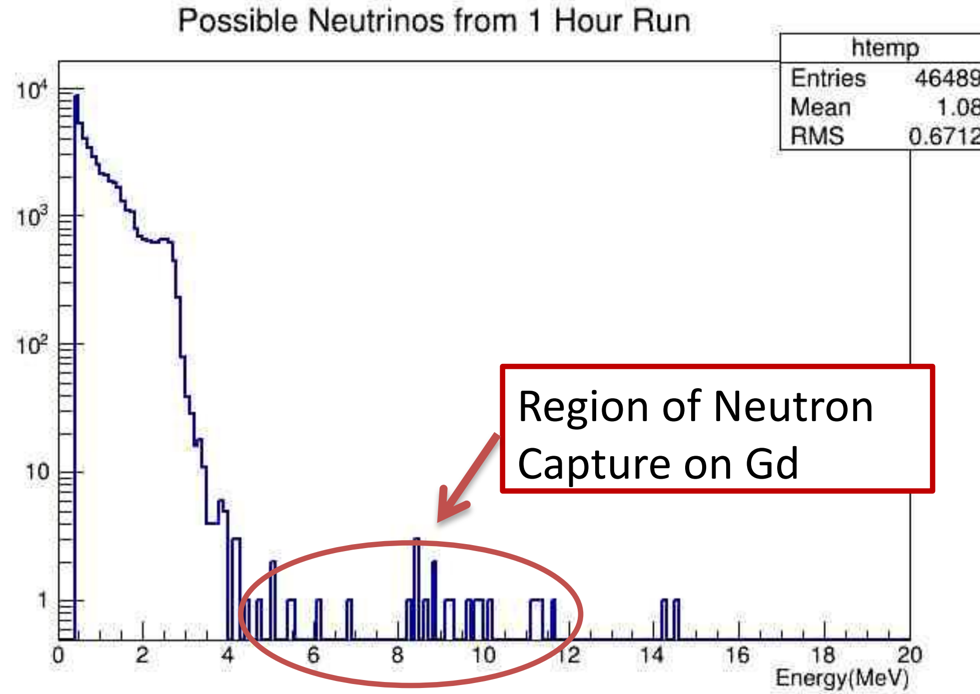
Double Chooz Detector:

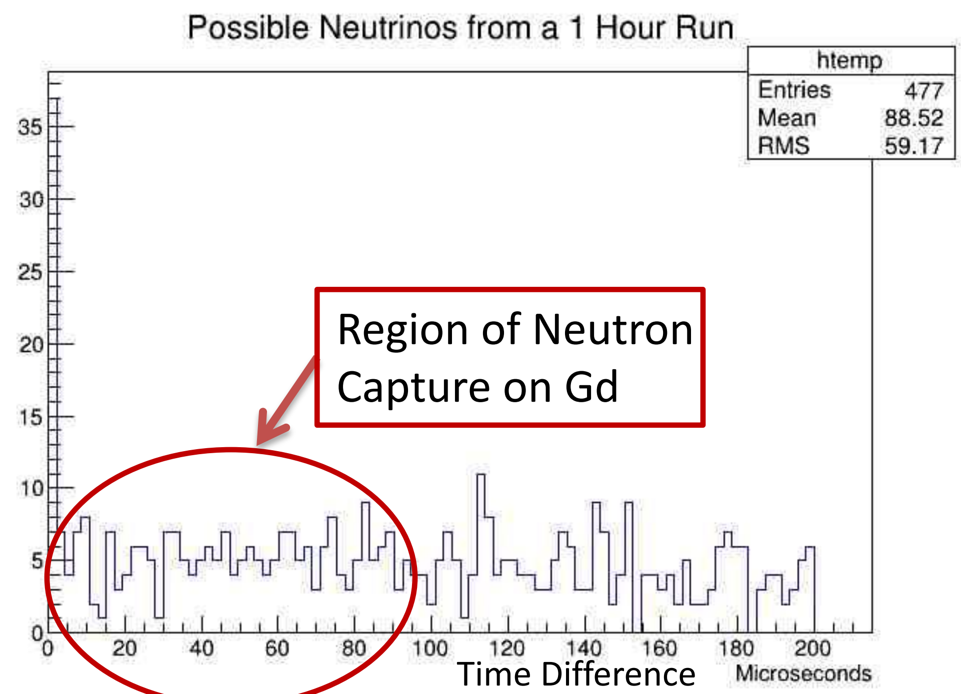
Finding a Neutrino in a Hay Stack

- ~~Radioactive Decay~~
- ~~Light noise~~
- ~~Particles from Cosmic Ray Showers~~
- Positrons from neutrino IBD
- Gammas from Nuclear Capture of Neutrons (i.e. on Gd and others)

- Neutrino Signal Coincidence
  - Prompt
    - Positron scintillation and annihilation
  - Delay
    - Neutron capture on Gd
    - ~8MeV γ
    - Delayed by ~ 30 microseconds







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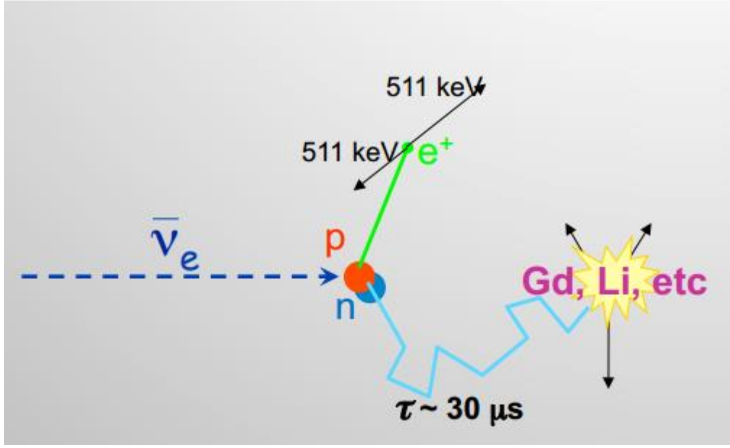
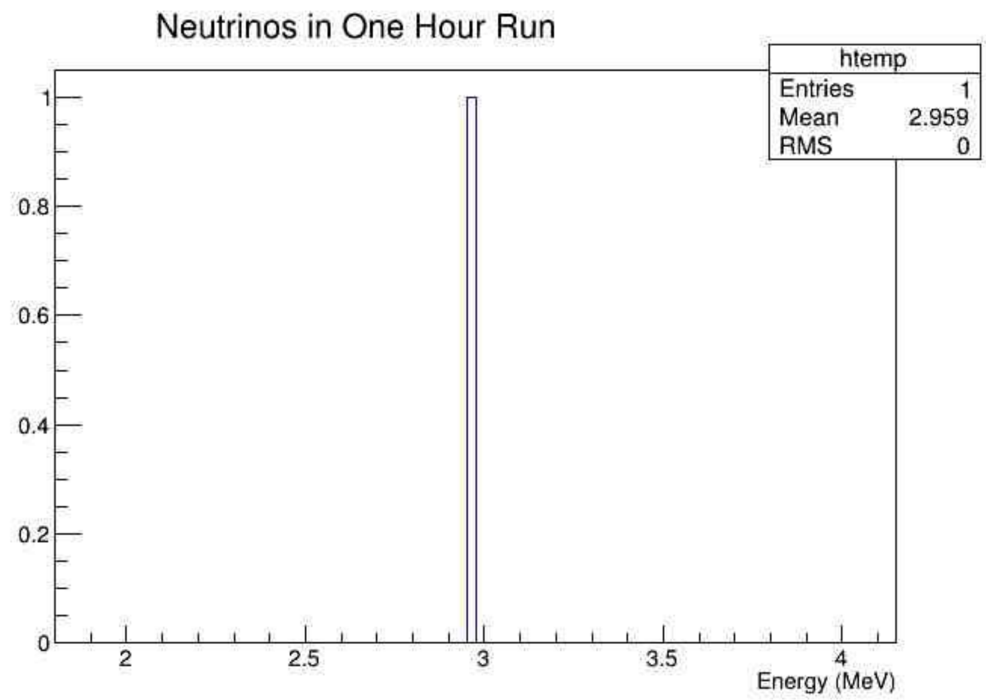




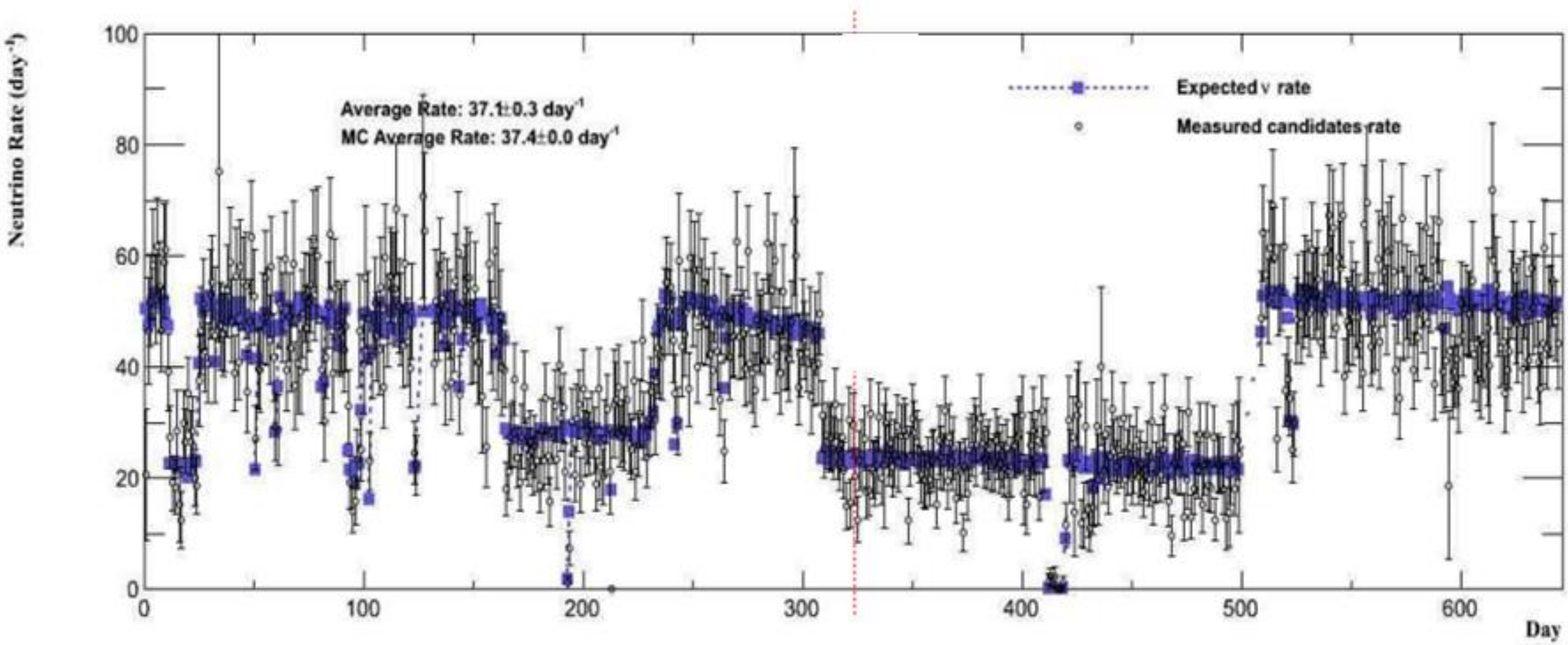
Finding Neutrinos: Summary

- 1 hour of data
  - 300,000 Triggered Events
  - 160,000 Muons
  - 75,000 Light Noise Events
  - 46,000 possible Neutrinos
  - 200 with correct time coincidence of prompt and delay Energy
  - 30 with correct Delay Energy
  - 1 Neutrino

Pauli has not done such a terrible thing

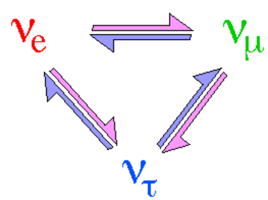
Detecting Neutrinos: Now What?

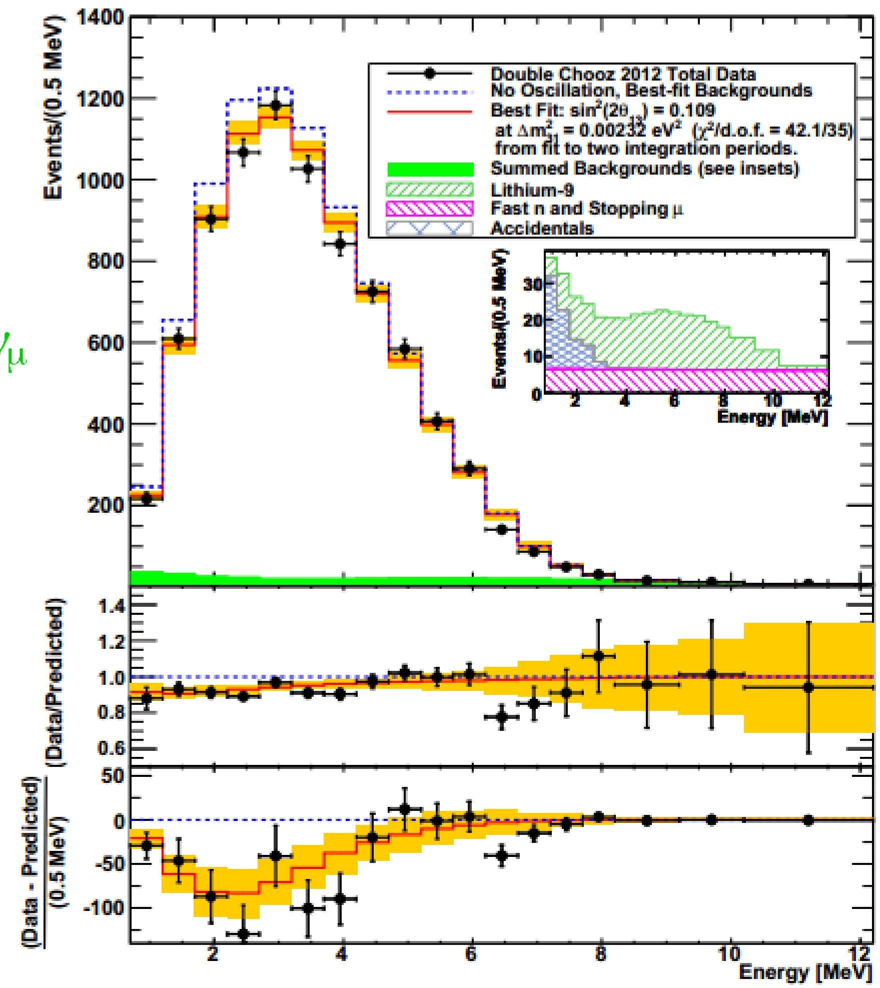
- Nuclear Reactor Monitor

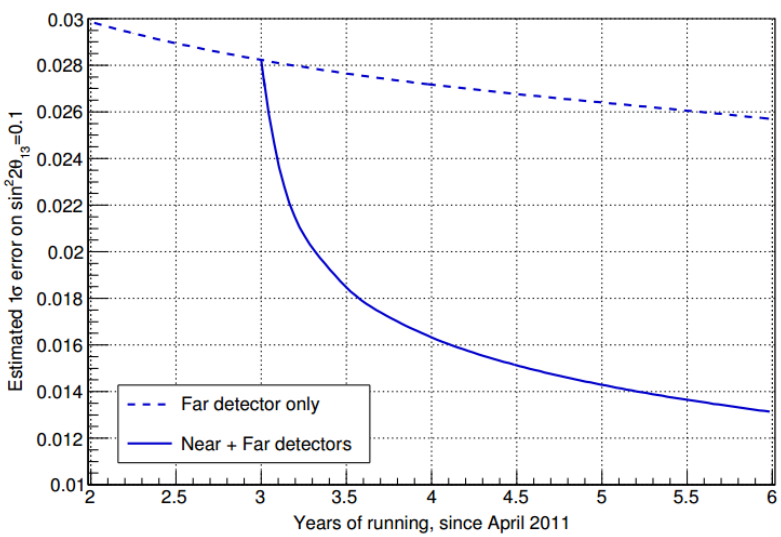


Detecting Neutrinos: Now What?

- Neutrino Oscillations
  - 10% of expected neutrinos are not detected
  - Neutrinos change Flavor as they propagate







Conclusion

- Neutrino detection has gone from an impossibility to a precision measurement in the last 80 years
- Neutrino Detectors see much more than neutrinos
- Looking for Prompt-Delay pairs is an extremely powerful tool for identifying Neutrinos
- Gd doped scintillator gives a huge background suppression