Monte Carlo Simulations for Future Geoneutrino Detectors

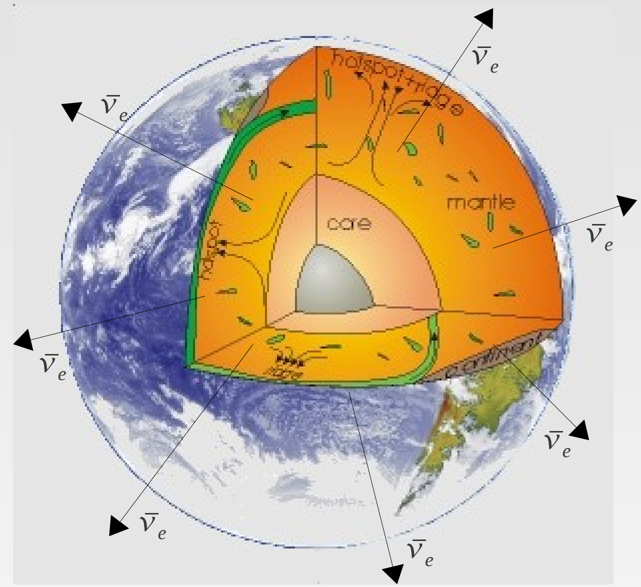
Morgan Askins
University of Washington INT REU
Center for Experimental Nuclear and Astrophysics
08/18/2010

Outline

- Neutrinos in geophysics
- Neutrino detection in liquid scintillator
- Proposed detector design
- Monte Carlo simulation of background signals

Geophysics – The Motivation

- 44 TW of heat dissipated by the earth
- Thermodynamic models suggest about 26 TW must be produced within the mantle
- Most likely origin of this heat: Decay chains from 238U, 232Th, and 40K
- Current estimates on abundances results up to 19 TW from U, Th, and K

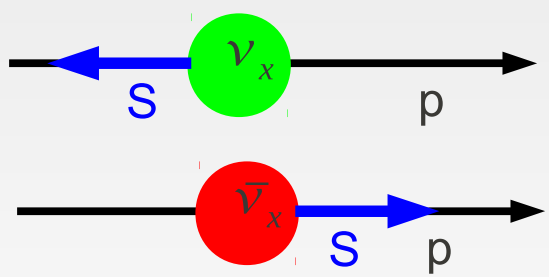


Properties of Neutrinos

- Leptons with three flavor eigenstates: ν_e, ν_μ, ν_τ
- Flavor states can mix
- Fermions (spin $\frac{1}{2}$)
- Interactions mediated by the weak nuclear force
- Neutrinos have left-handed helicity
- Anti-neutrinos have right-handed helicity
- Non-zero mass differences

Leptons		
e^-	τ^-	μ^-
ν_e	ν_τ	ν_μ

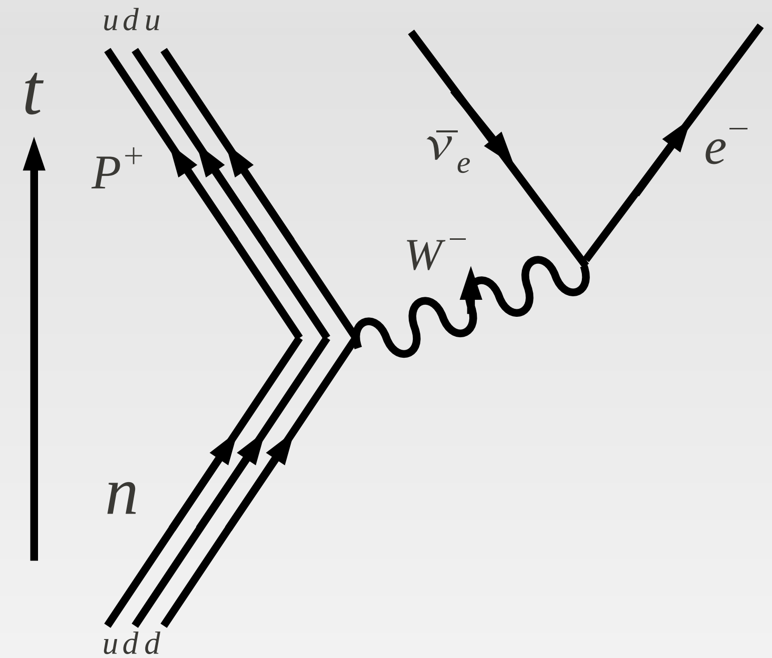
Gauge Bosons	$W^\pm$ Z^0



Geoneutrinos

- Geoneutrinos $\bar{\nu}_e$ are created during β^- decays from the 238U, 232Th and 40K decay chains
- Only $\bar{\nu}_e$ will make it to the earth's surface
- Three body decay will cause a spectrum of $\bar{\nu}_e$ energy
- Geoneutrino flux can give measurements of total 238U and 232Th within the earth (but not 40K)*

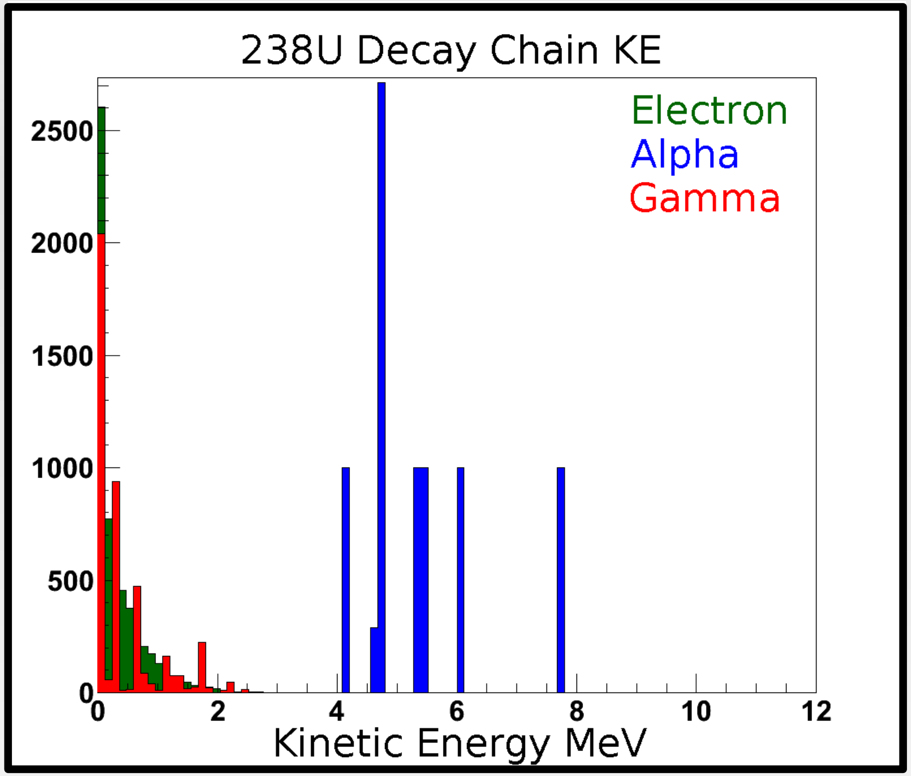
$$n \rightarrow p^+ + e^- + \bar{\nu}_e$$

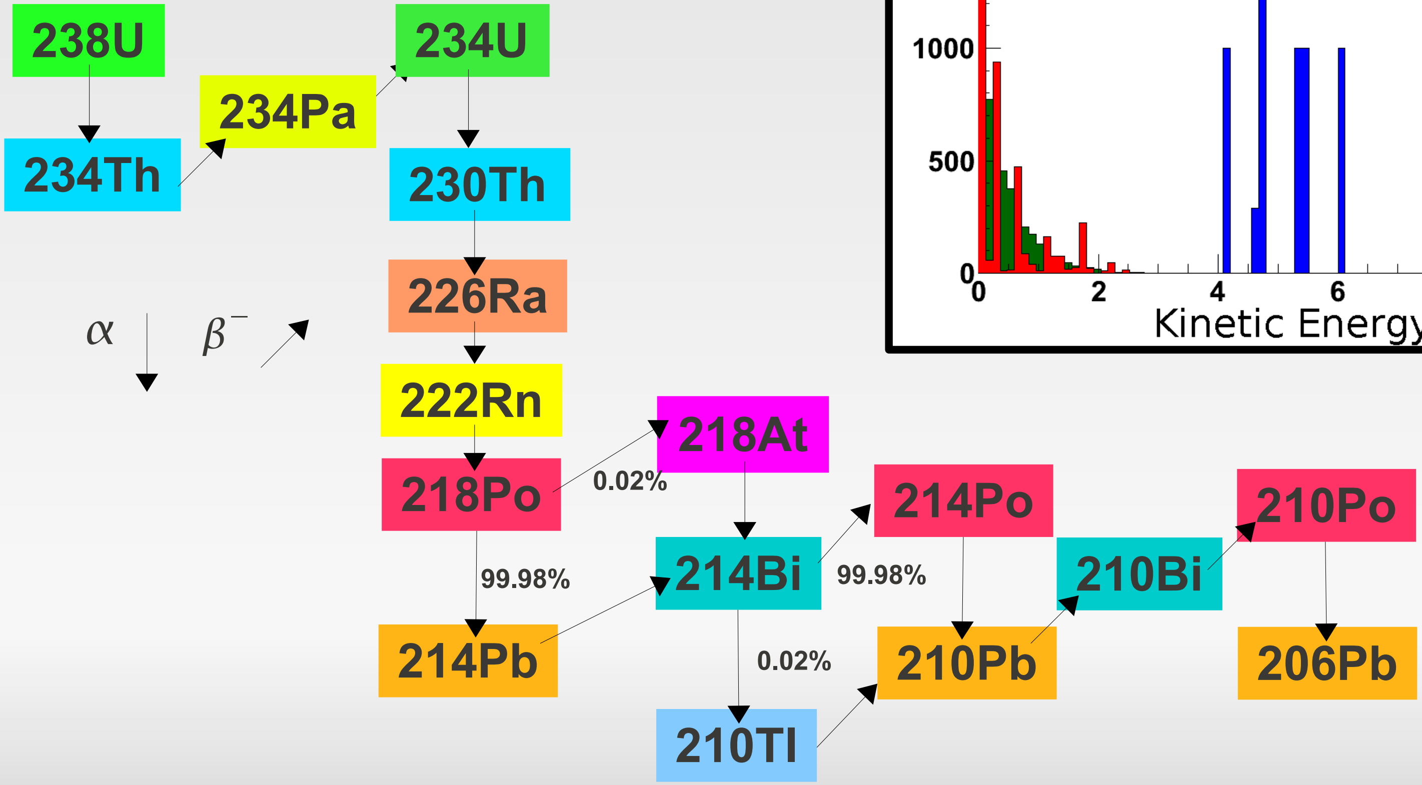


*Explained on slide 8

238U Decay Chain

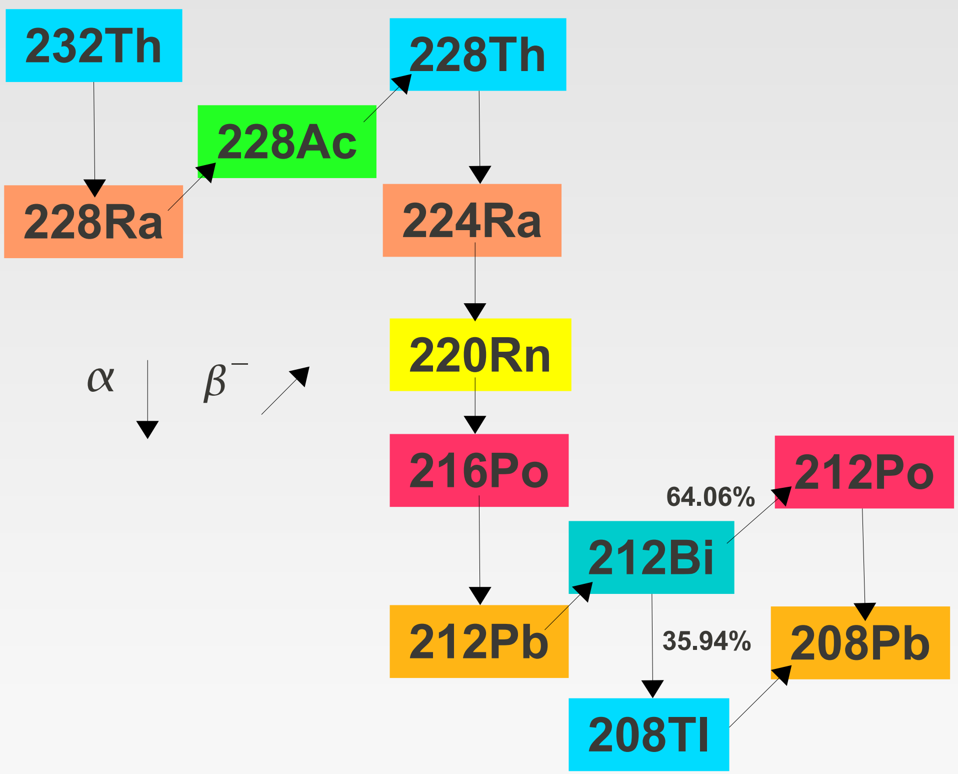
- 238U decay chain contains at least 9 β^- decays which emit $\bar{\nu}_e$

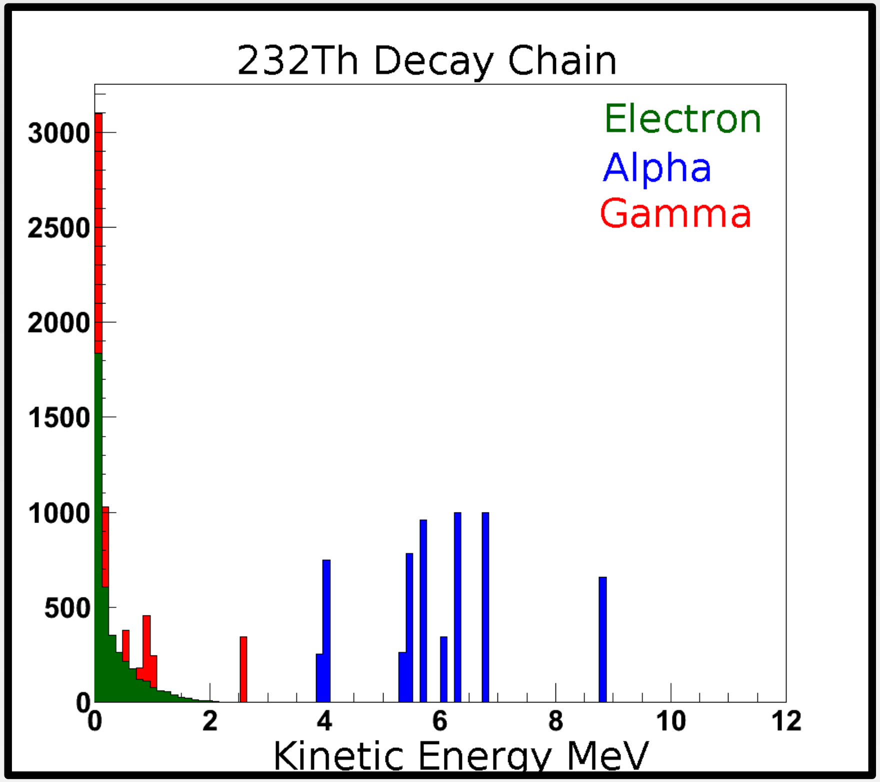




232Th Decay Chain

- 232Th has 4 β^- decays

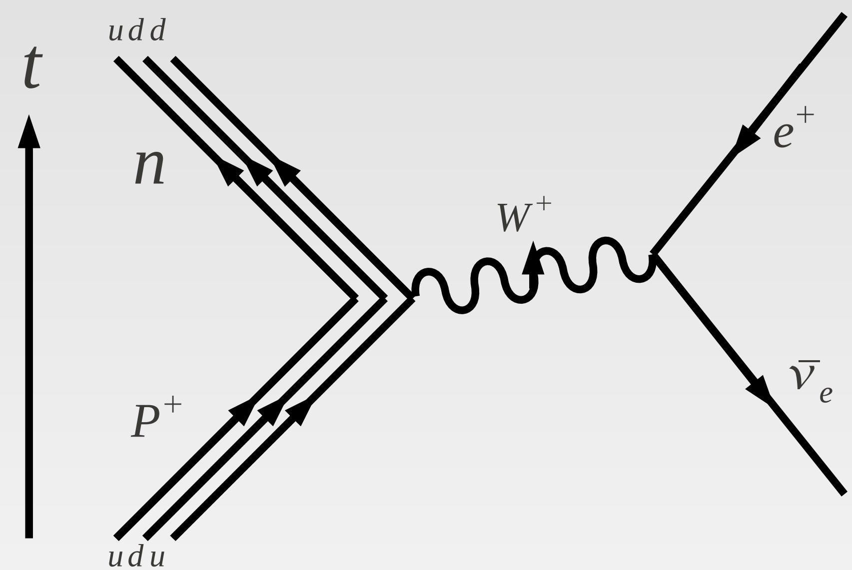




Neutrino Detection

- Liquid Scintillator produces optical photons when charged particles propogate through it
- Charged current interaction produces positron and neutron
- Positron produces scintillation light immediatly while the neutron is delayed creating a distinct signal

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



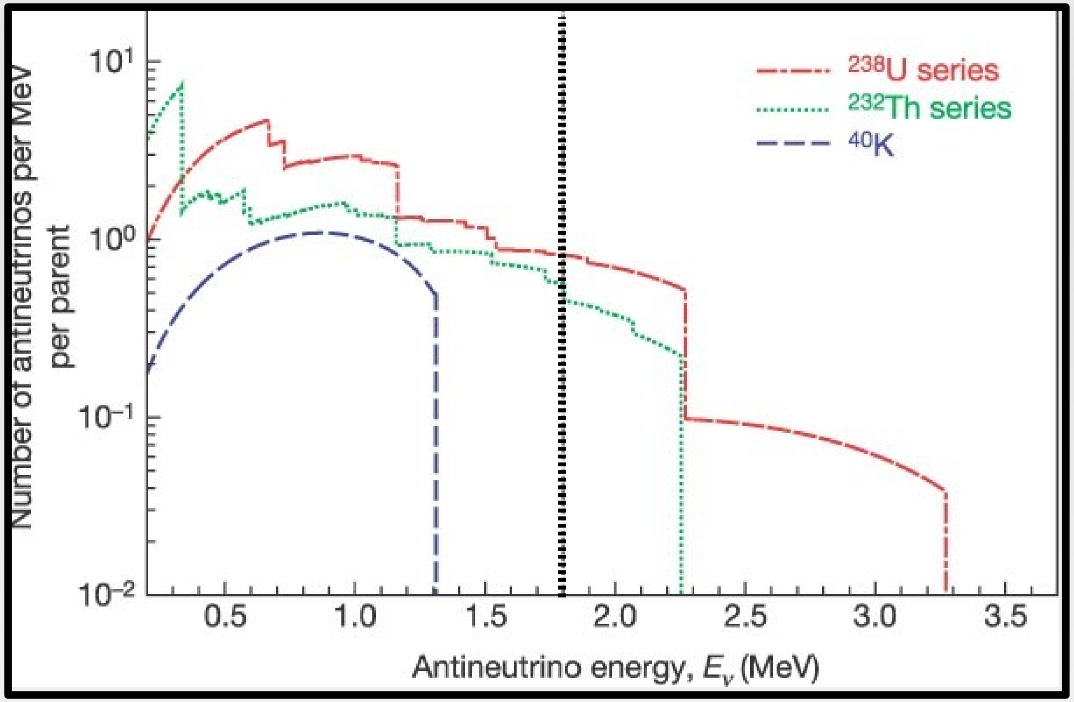
e^+ *produces scintillation light*

$e^+ + e^- \rightarrow 2\,x\,0.511\,MeV\,\gamma$

Neutron capture on Gd produces a coincidence event at ~200μs emitting two more γs

Charge current threshold

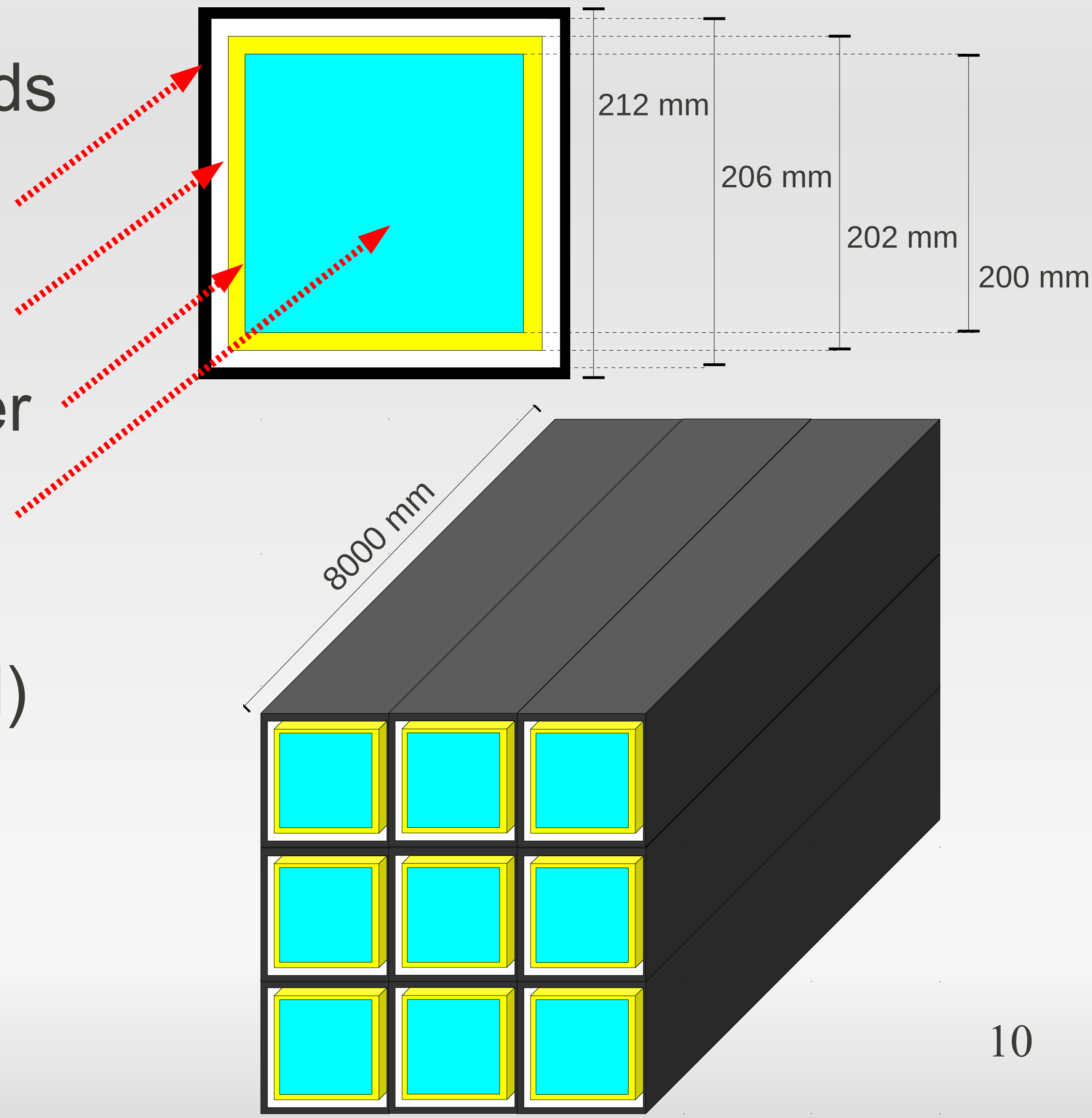
- Mass difference in $n + e^{+}$ and p^{+} results in a minimum energy for the $\bar{\nu}_e \approx 1.8\, MeV$
- This energy threshold is greater than the $\bar{\nu}_e$ energy from $K^{40} \rightarrow Ca^{40}$
- Some $\bar{\nu}_e$ from 238U and 232Th series are above this threshold



$$m_n + m_{e^+} - m_{p^+} \approx 1.8\, MeV / c^2$$

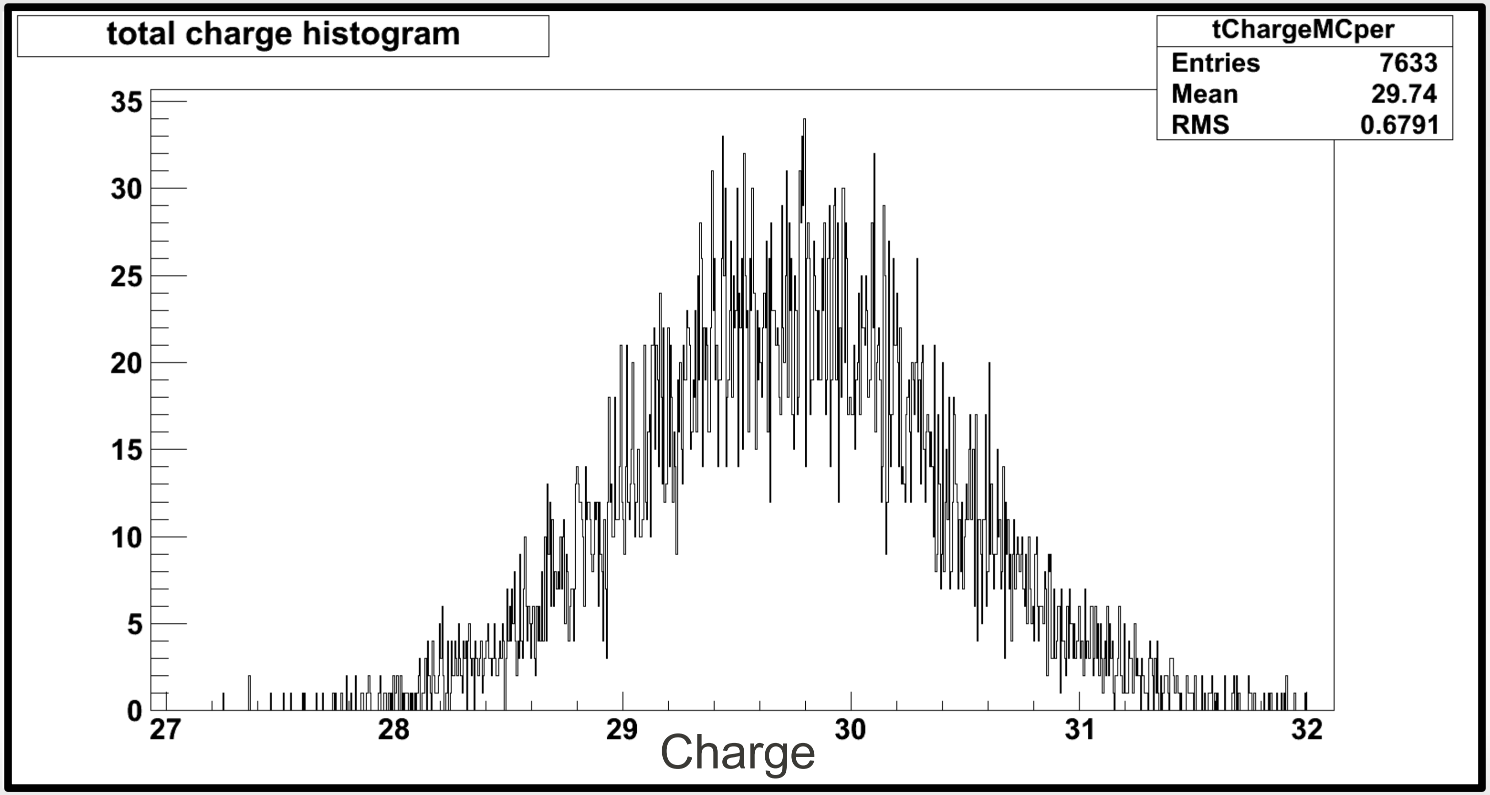
Detector Design

- nxn array of rectangular liquid scintillator filled rods
  - Optically thick acrylic
  - Air cavity
  - Clear acrylic container
  - Liquid Scintillator
  - Photomultiplier tube (one on each rod end)



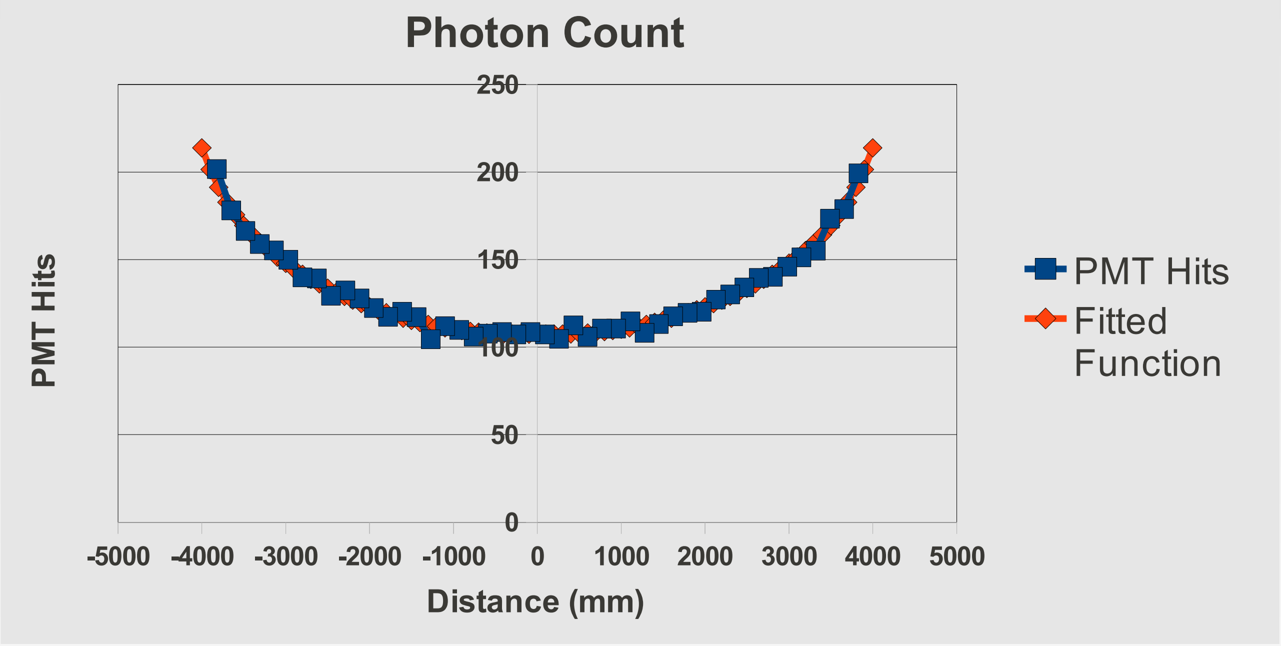
Calibration – PMT Charge

- Simulation of 1000 400nm optical photons fired at a single PMT. Total charge on the PMT is then normalized to a single photon.



Calibration – PMT Distance

- Simulation of 1000 1MeV electrons fired directly at the PMTs at various distances gives the position dependence on PMT measurements



$$y = (|(x/390)|)^2 - (|(x/410)|)^{1.5} + (|(x/3000)|)^{12} + 107.5$$

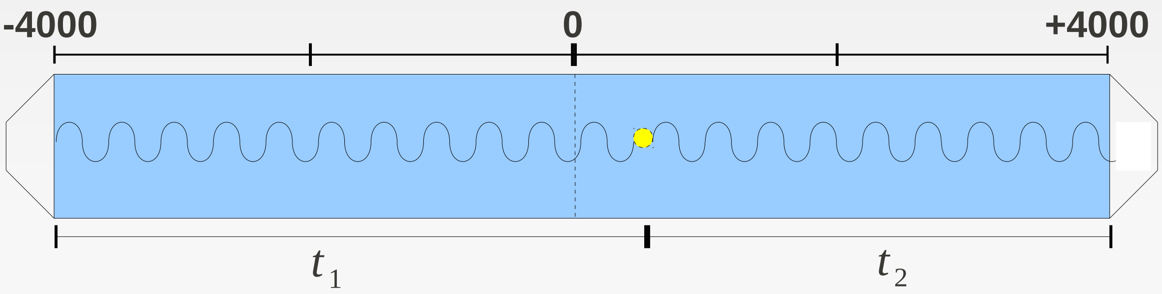
Reconstructed Position

- Position is determined based upon arrival times of the first two PMTs

  Assumes:

  - Spherically distributed photons
  - First photons don't scatter

$$Position = \frac{\Delta t c}{2n}$$

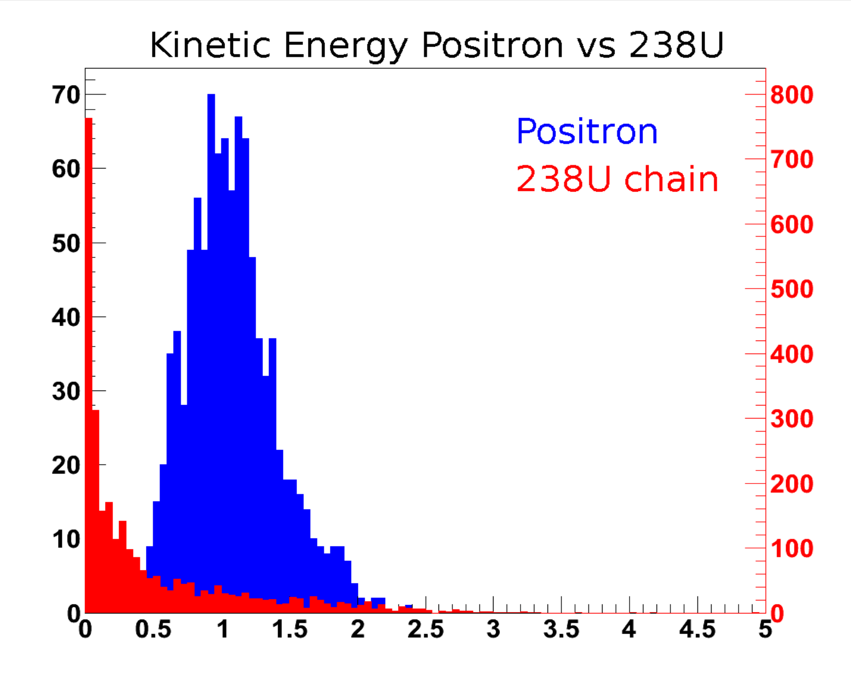


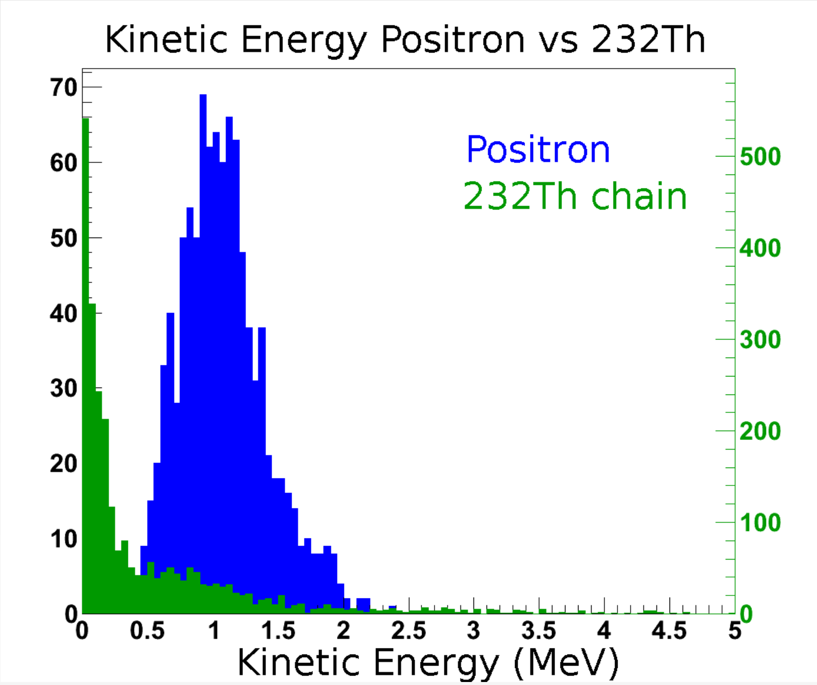
Scintillator Refractive Index

$$n = 1.505$$

Reconstructed Energy

- Kinetic energy determined using PMT charge and distance calibrations in conjuct with the reconstructed position

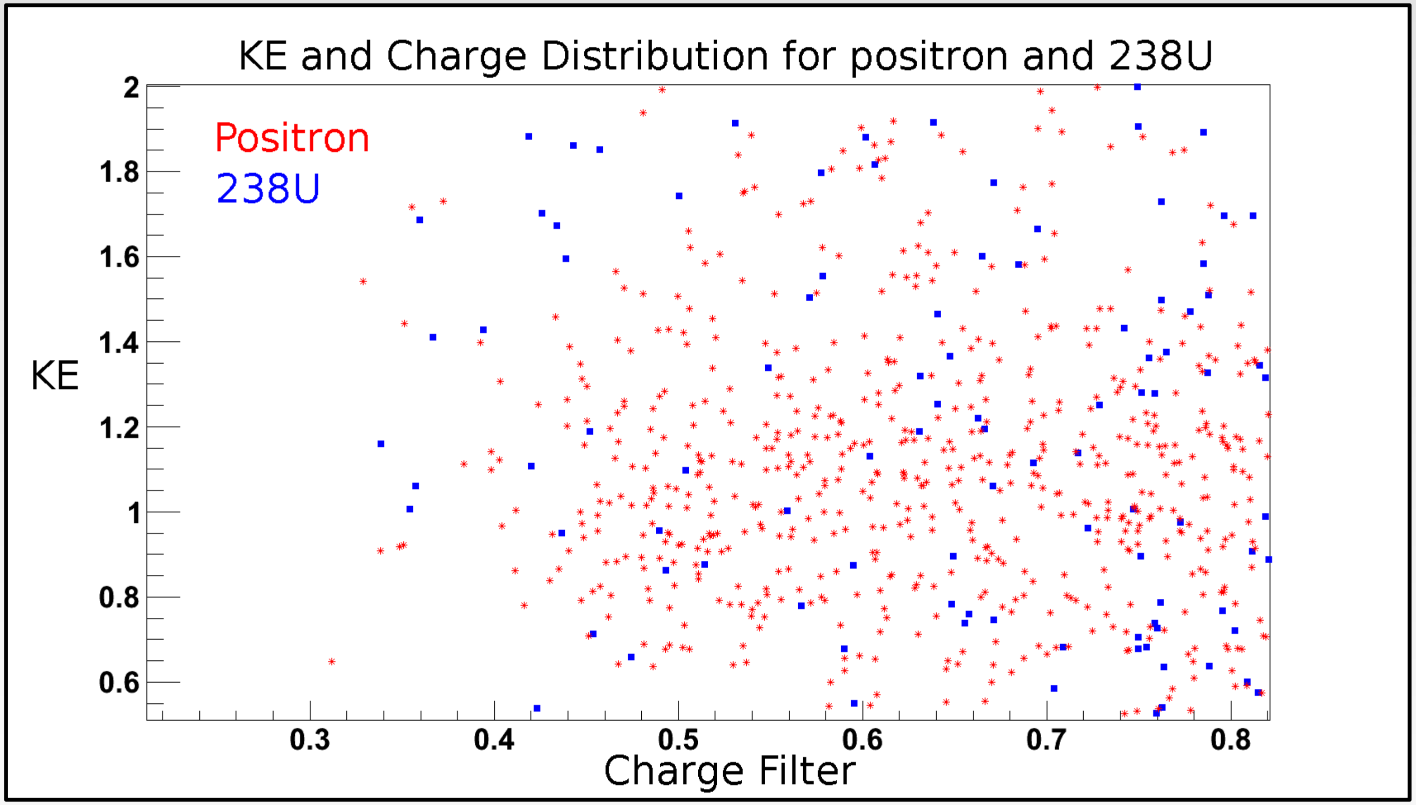




$$Energy = \frac{Total\ Charge}{(Fitted\ photons/MeV)*(Charge/photon)}$$

Energy and Charge Filter

- Cuts based upon energy and charge values are used to reduce the background levels



$$Charge\ Filter = \frac{Highest\ Total\ Charge\ \text{in}\ one\ tube}{Total\ Charge\ \text{over}\ all\ tubes}$$

Results

- By applying the filter
  - 238U background is reduced by ~93%
  - 232Th background is reduced by ~86%
  - Positron signal is reduced by ~36%

Acknowledgements

- Nikolai Tolich and the entire EWI group
- Alejandro Garcia, Subhadeep Gupta and the INT REU program