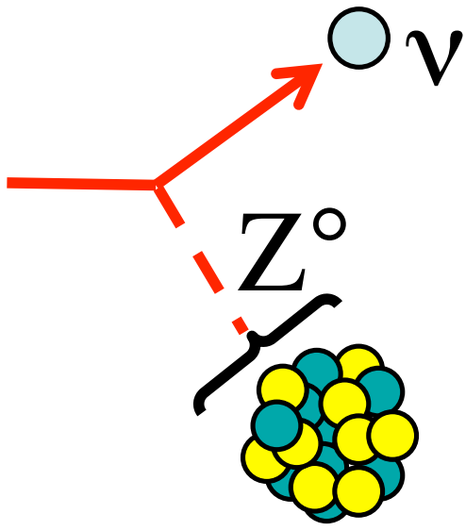
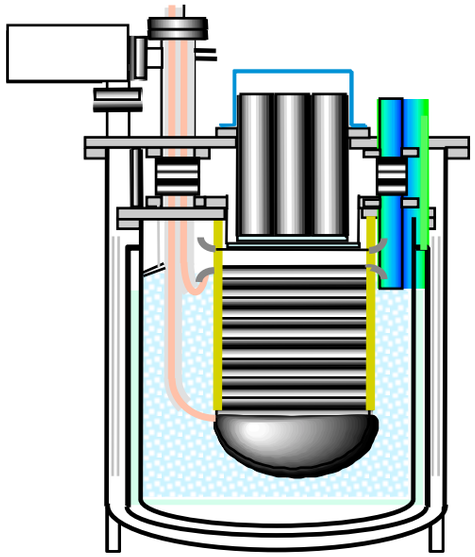


Nuclear Ionization Quenching Measurement in a Dual-Phase Argon Detector



Michael Foxe, The Pennsylvania State University

on behalf of

A. Bernstein, C. Hagmann, K. Kazkaz, S. Pereverzev, S. Sangiorgio - LLNL
T. Joshi - University of California Berkeley
I. Jovanovic - The Pennsylvania State University
J. Coleman, K. Mavrokoridis - University of Liverpool, UK

July 8, 2011 - Project on Nuclear Issues Summer Conference

PENNSTATE 1855

Project on Nuclear Issues
2012 SUMMER CONFERENCE

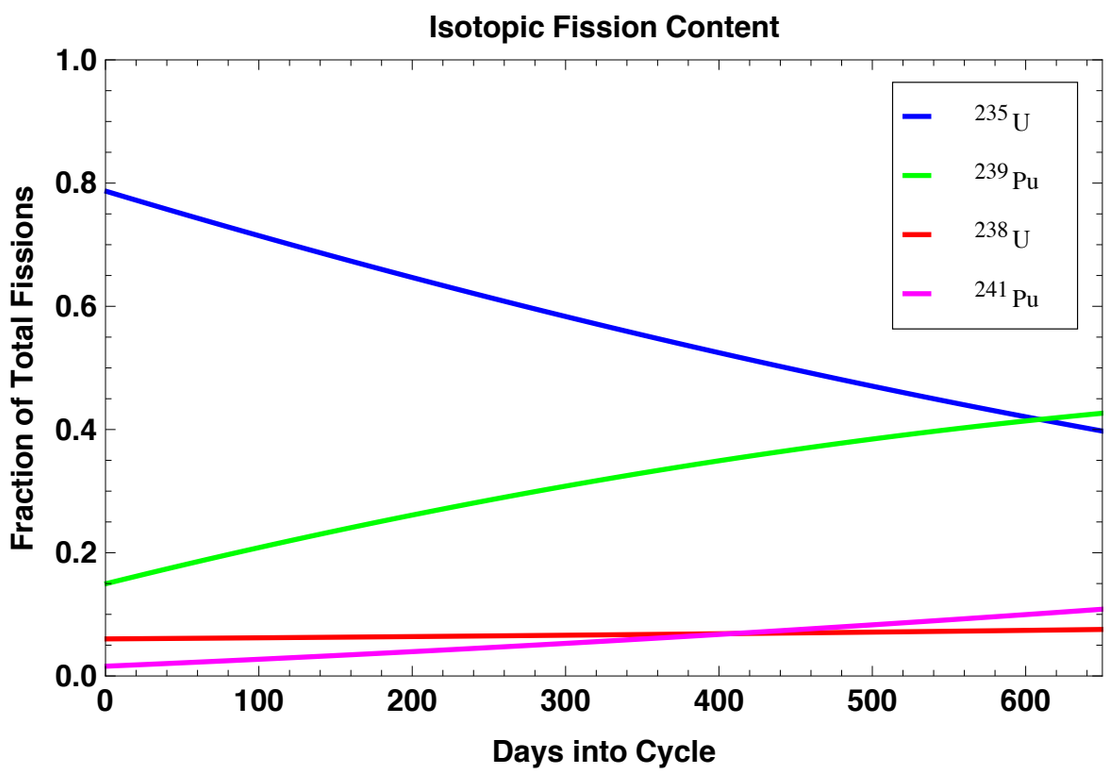
THE UNIVERSITY of LIVERPOOL

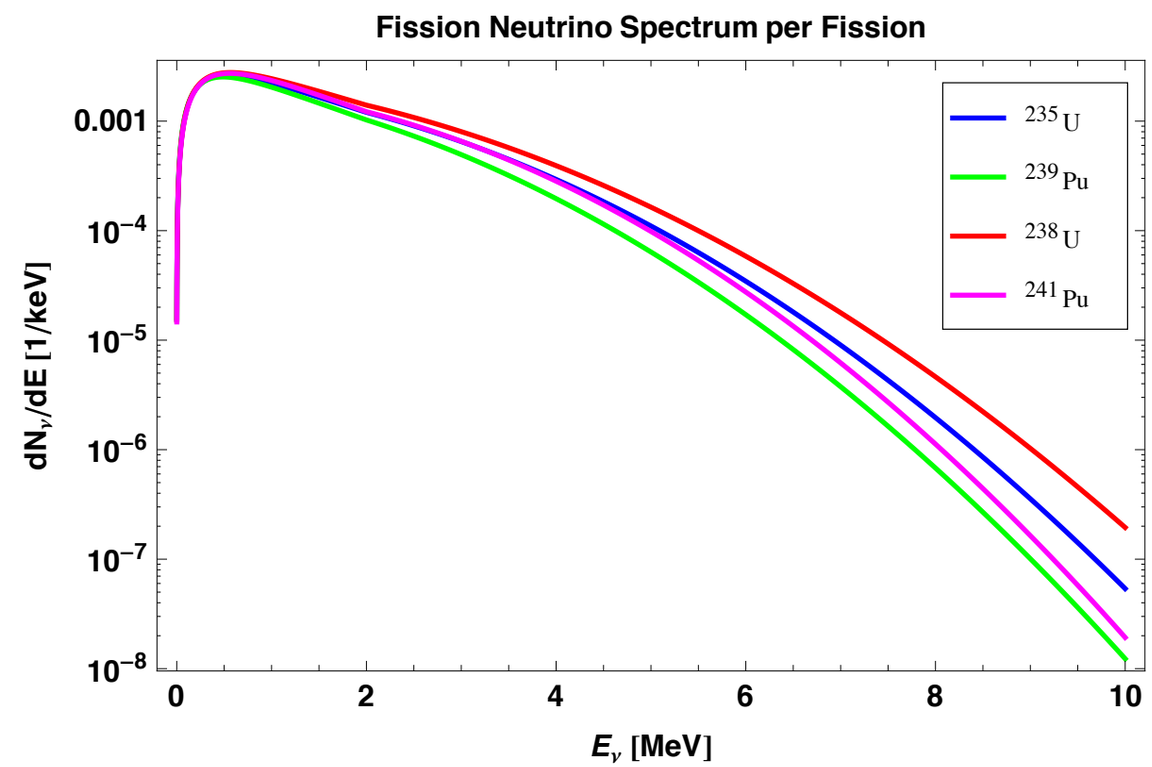
Outline

- Nuclear Reactor Monitoring via Antineutrinos
- Coherent Neutrino Scatter (CNS) and Nuclear Ionization Quench Factor
- Gamma or Neutron Argon Recoils Resulting in Liquid Ionization (G/NARRLI) Detector
- G/NARRLI Detector Operation
- Conclusions and Future Work

Reactor Antineutrino Spectra

- **The average number of antineutrinos varies between ^{235}U (5.51), ^{239}Pu (4.83), ^{238}U (6.28), and ^{241}Pu (5.63).**



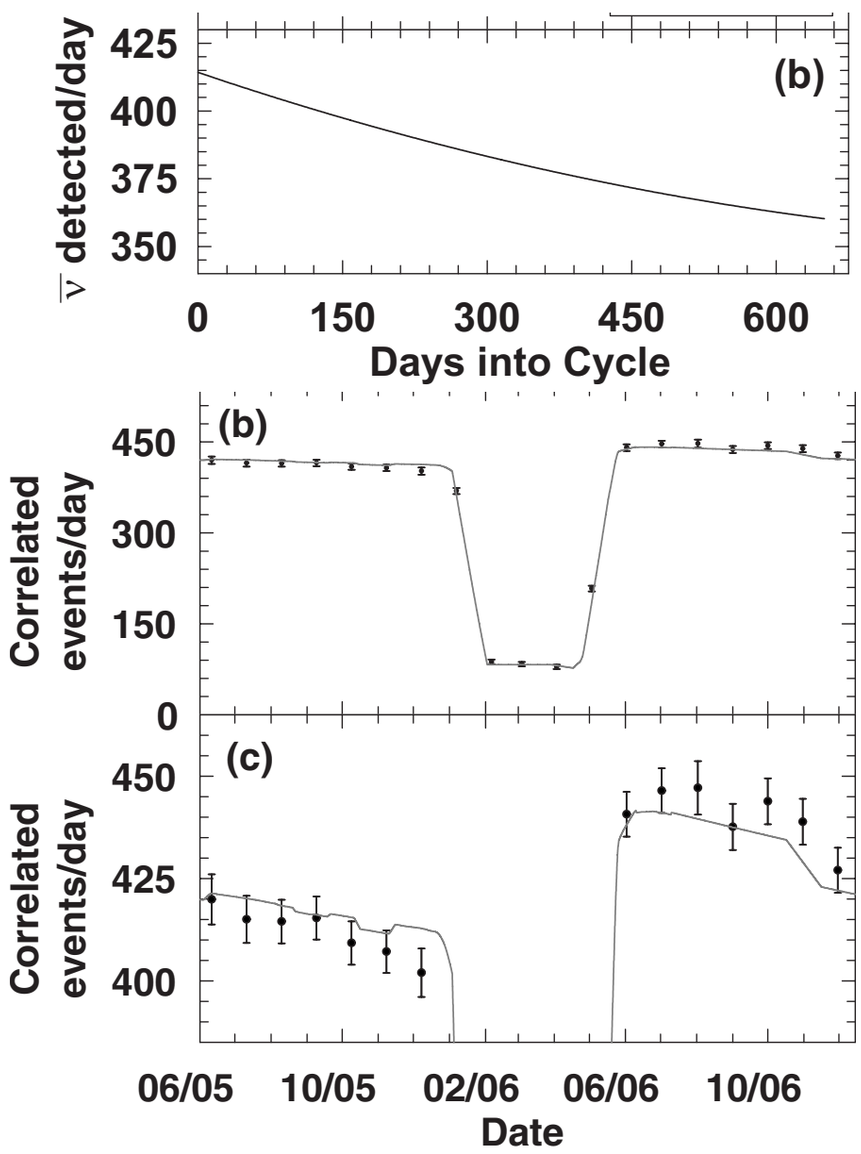


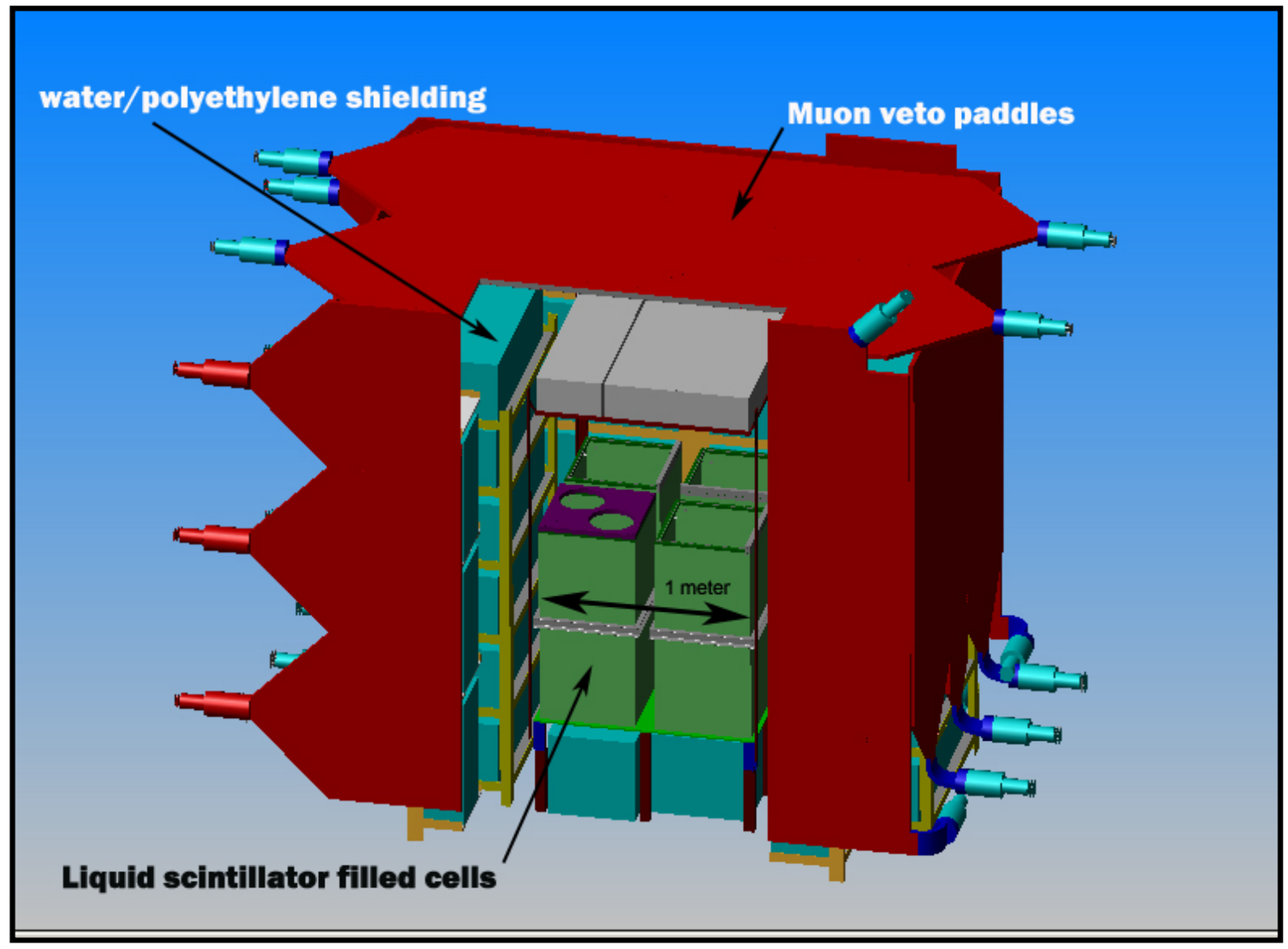
A. Bernstein et al., Journal of Applied Physics, 91, (2002).

P. Vogel and J. Engel, Phys. Rev. D, D39, (1989).

Current Antineutrino Reactor Monitoring

- **The difference in number of antineutrinos emitted allows for the power and isotopic content to be tracked**



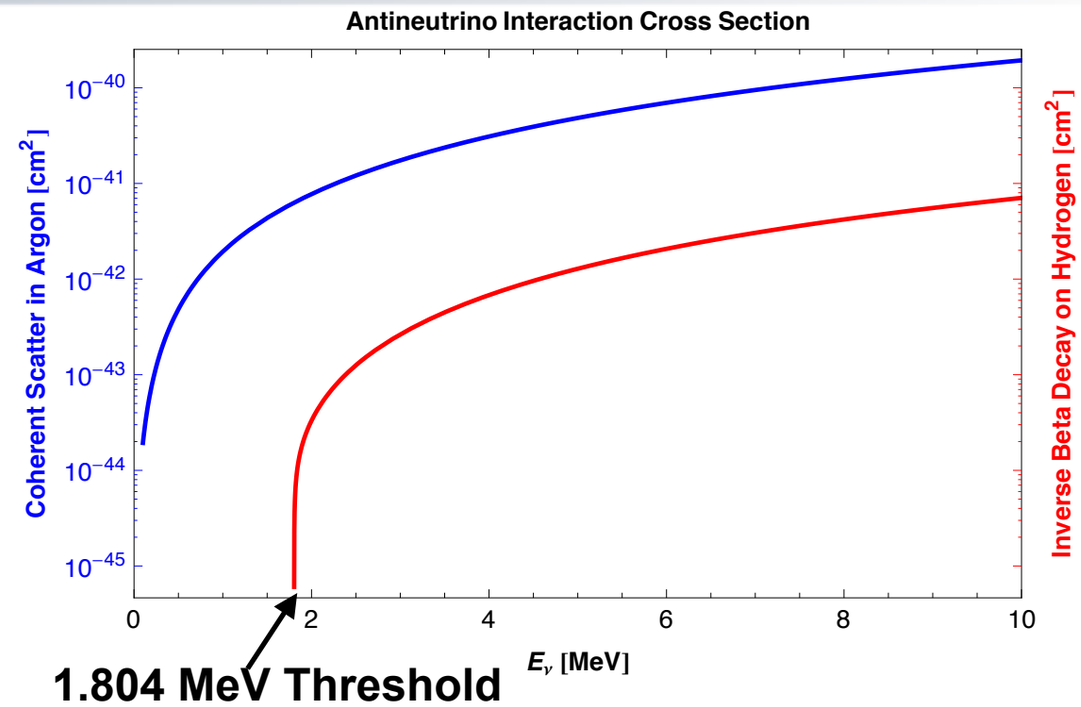


N. S. Bowden et al., J. Appl. Phys., 105 (2009).

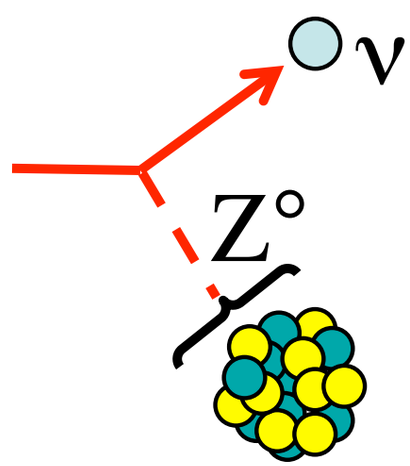
N. S. Bowden, Journal of Physics: Conference Series, 136 (2008).

Coherent Neutrino Scatter and Reactor ν's

- Predicted by the standard model
- Flavor blind interaction
- Cross section enhanced by the number of neutrons squared
- Recoil energy inversely proportional to atomic mass number
- Sub 6 keV argon recoils

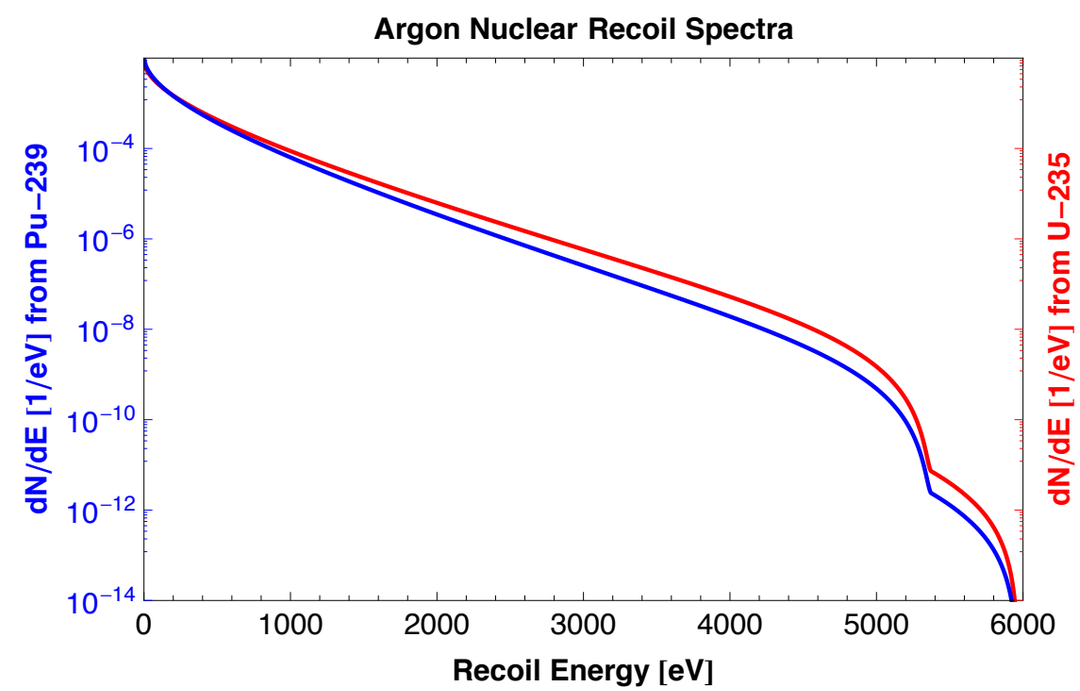


$$\sigma_{\mathrm{CS}} = \frac{G^2 N^2}{4\pi} E_\nu^2$$



$$E_{\mathrm{r}} = \frac{E_\nu^2 (1 - \cos\theta)}{\mathrm{M}\,\mathrm{A}}$$

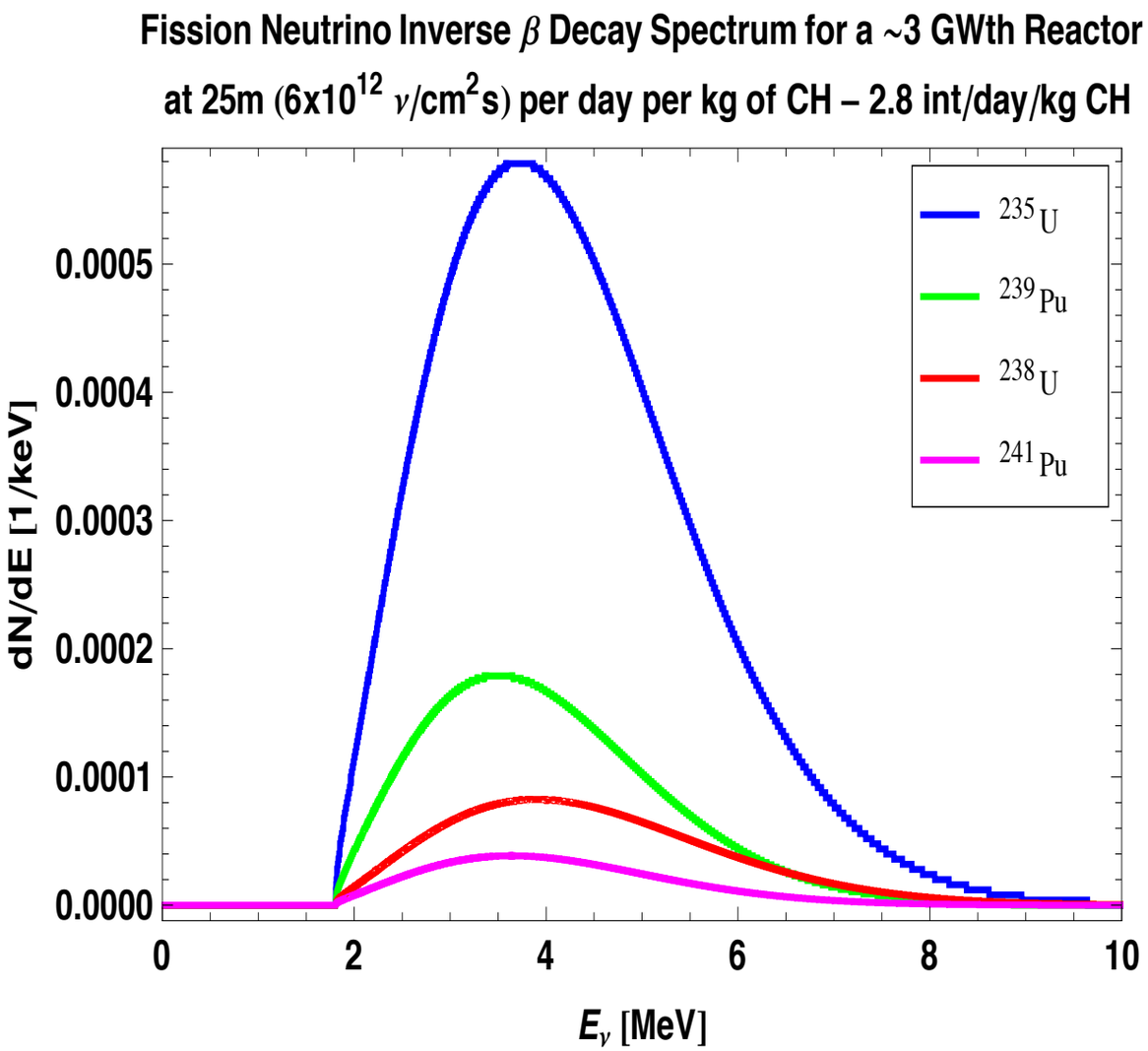
Drukier & Stodolsky, Phys. Rev. D 30(11), (1984)

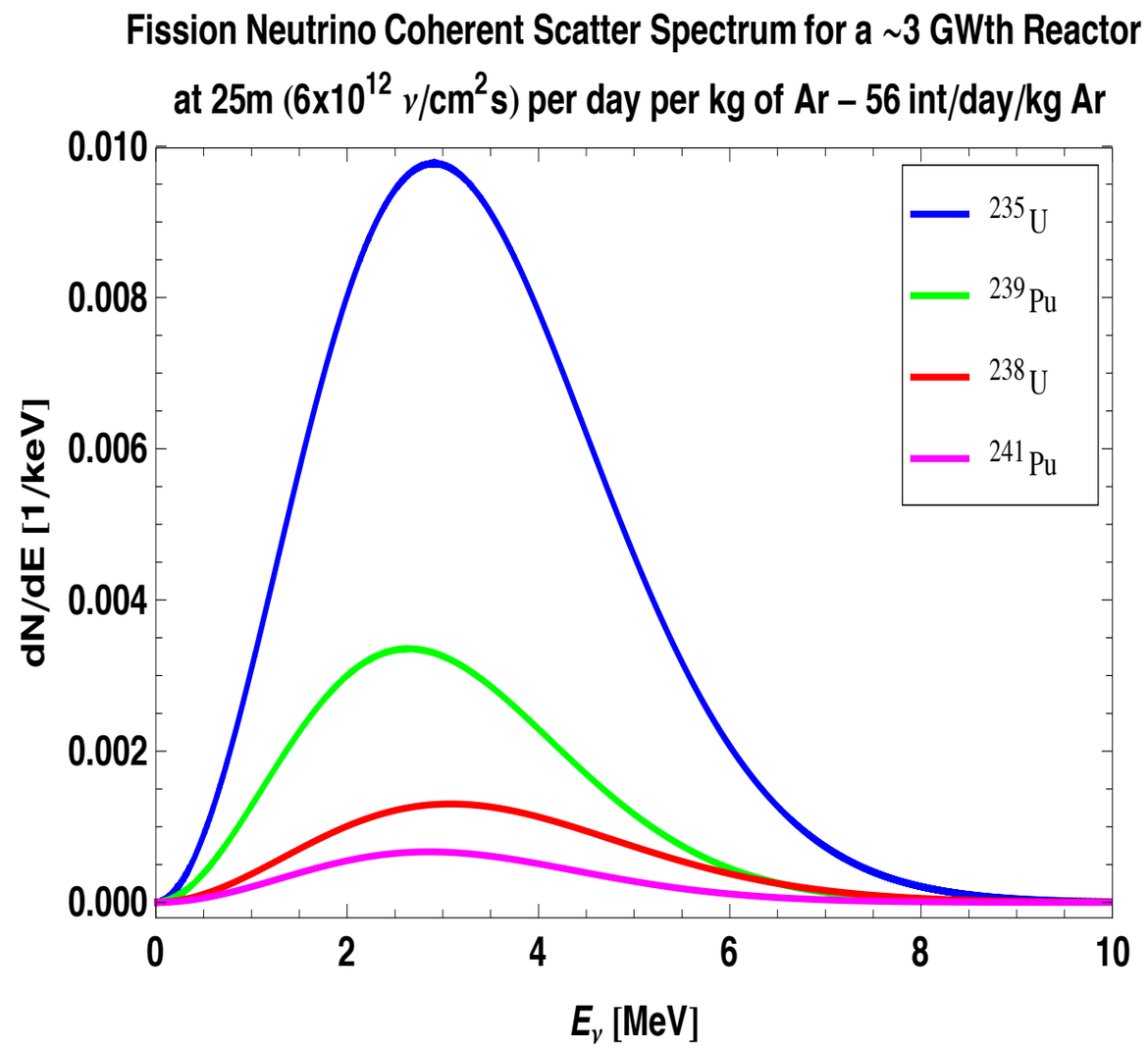


Hagmann & Bernstein, IEEE TNS 51(5), (2004)

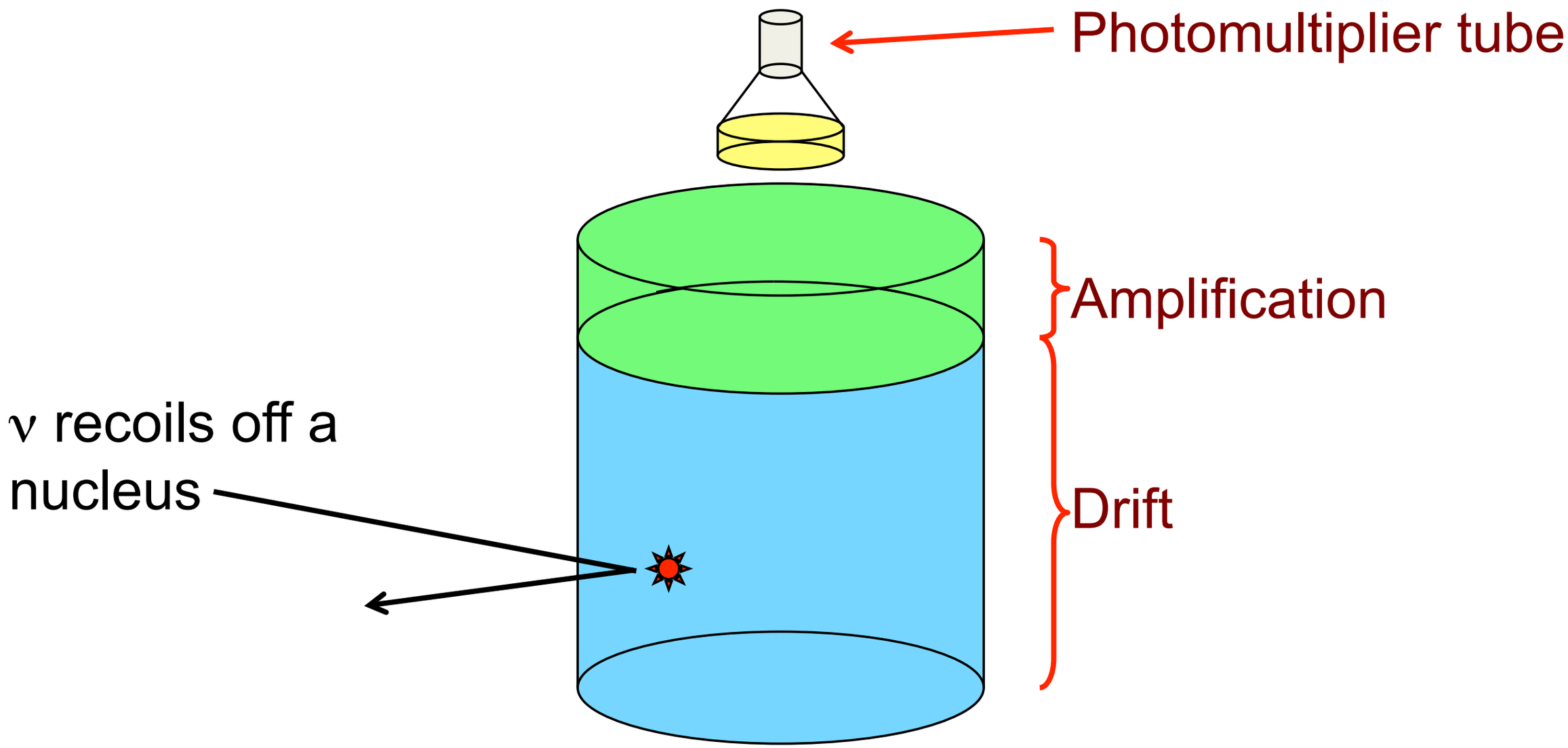
Reactor Neutrino Interaction Rates

- **Coherent Scatter Results in a LARGE increase in reaction rate**
- **Increase of ~20x events per kg between LAr (56 int/day/kg Ar) and CH (2.8 int/day/kg CH)**

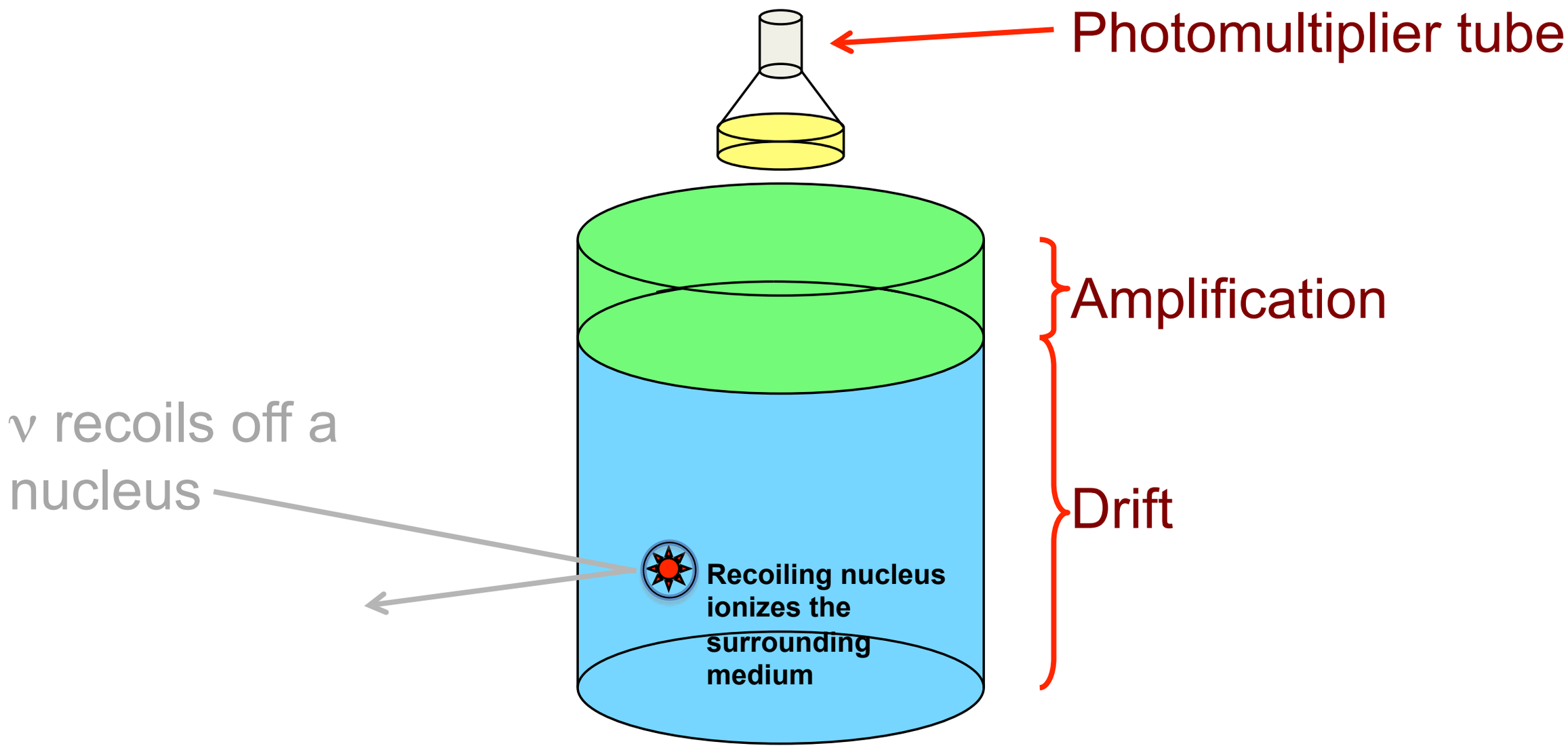




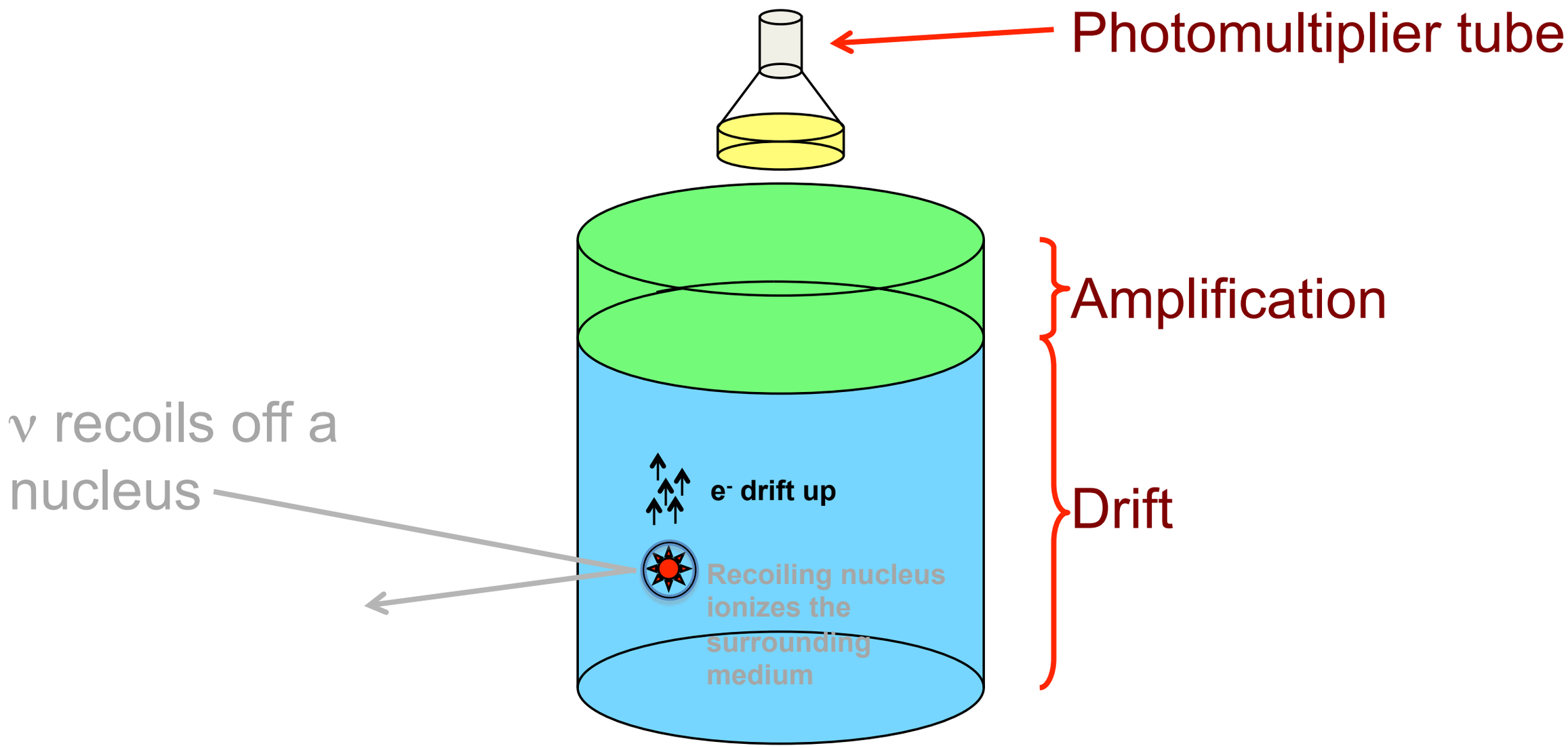
Mechanism of Detection



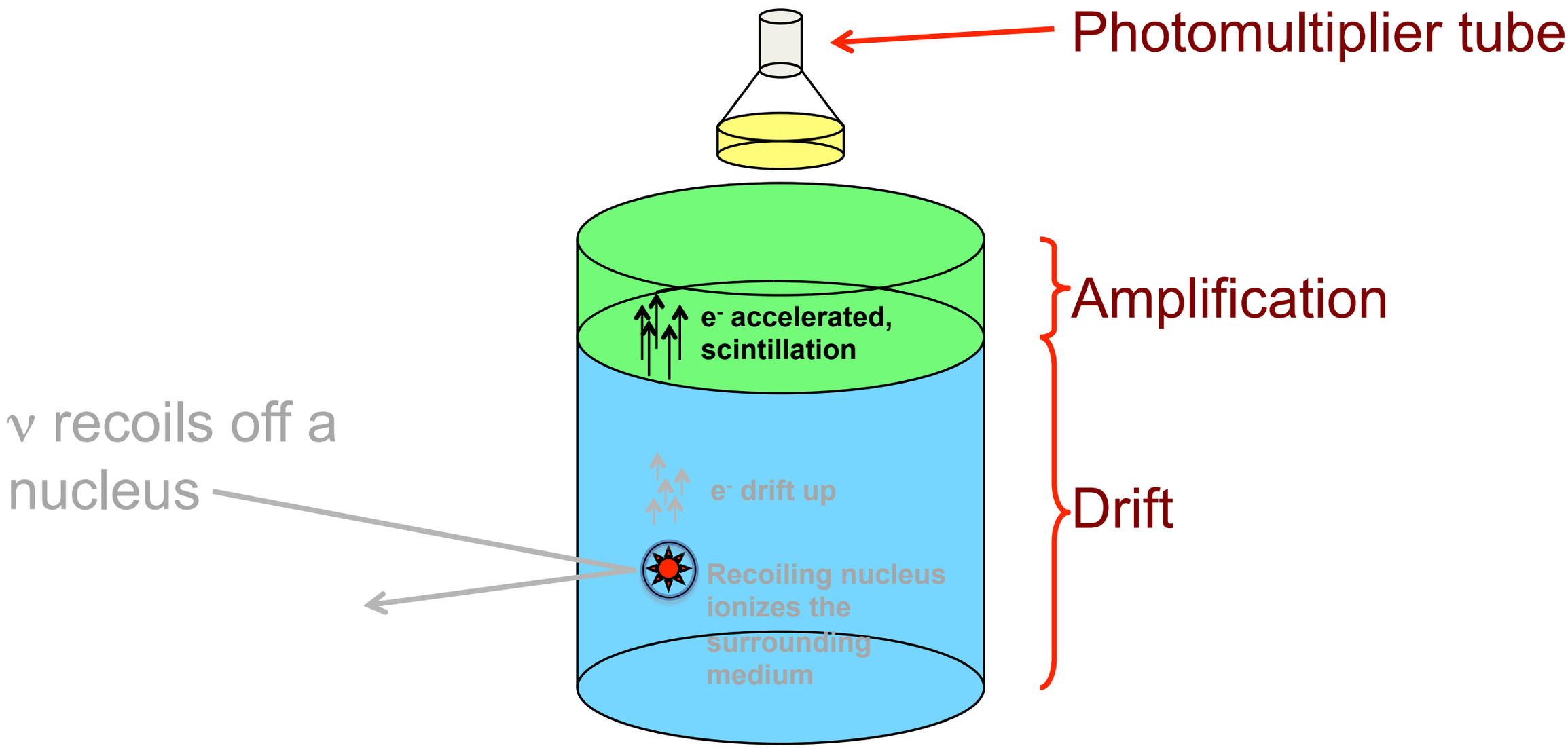
Mechanism of Detection



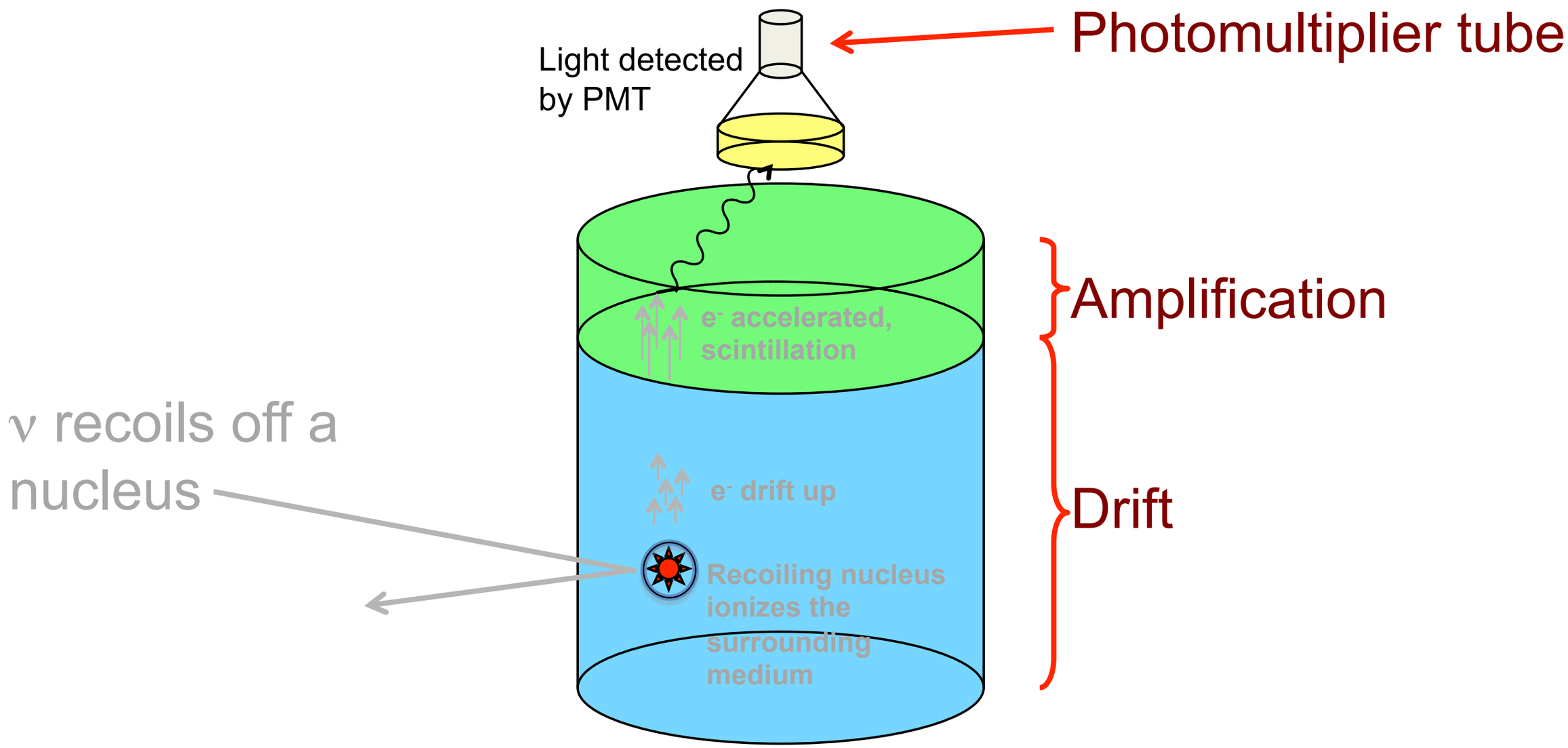
Mechanism of Detection



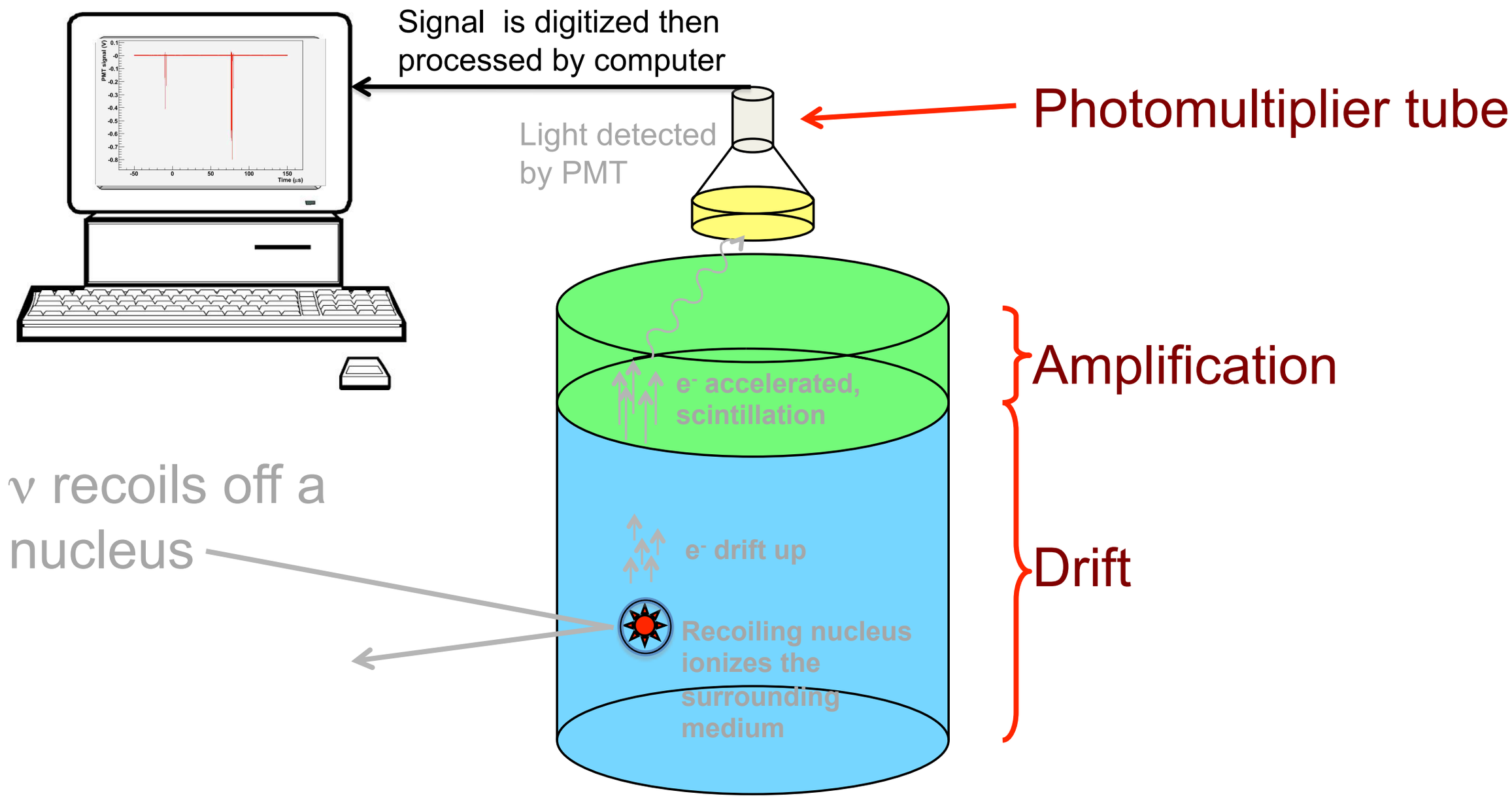
Mechanism of Detection



Mechanism of Detection



Mechanism of Detection

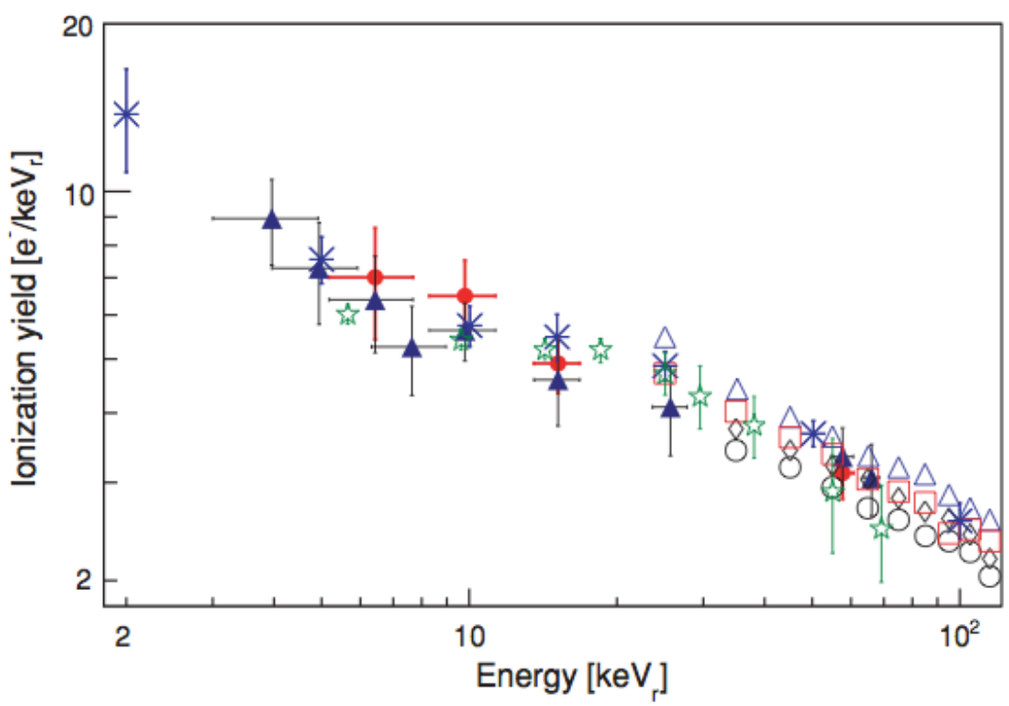


Nuclear Ionization Quench Factor

- **Nuclear recoils result in less ionization than electronic recoils - nuclear ionization quench factor**

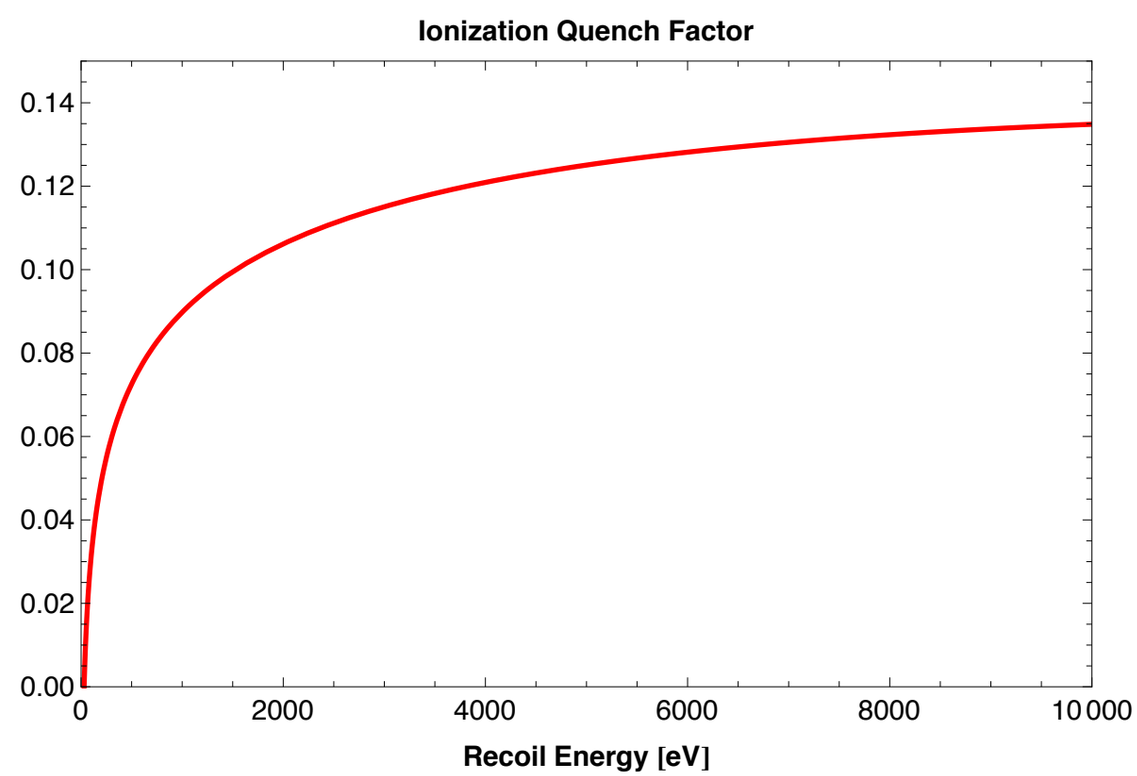
$$q_{\mathrm{ion}}(E) = \frac{N_{\mathrm{ion}}^{\mathrm{nucl}}(E)}{N_{\mathrm{ion}}^{\mathrm{elec}}(E)}$$

- **Only known down to 4 keV in LXe**



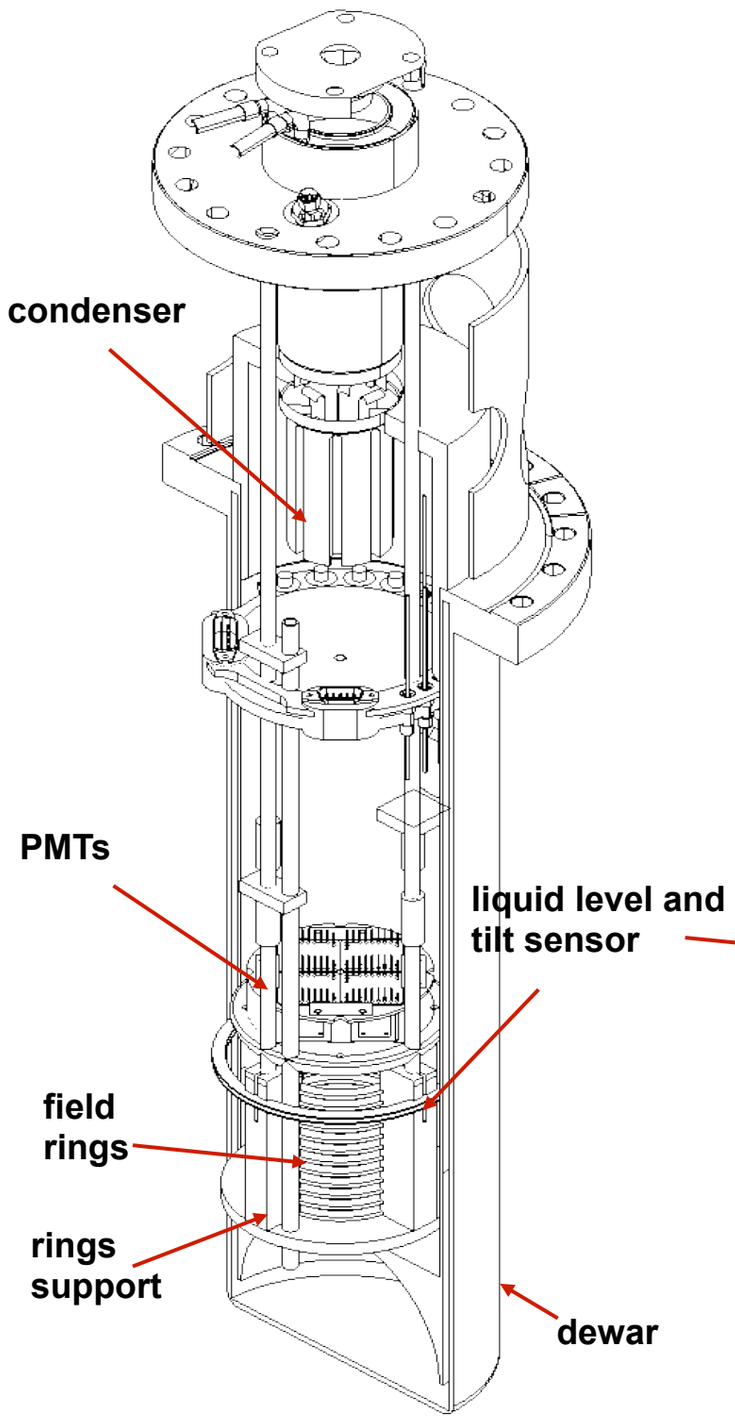
Manzur et al, Phys. Rev. C 81 (2010)

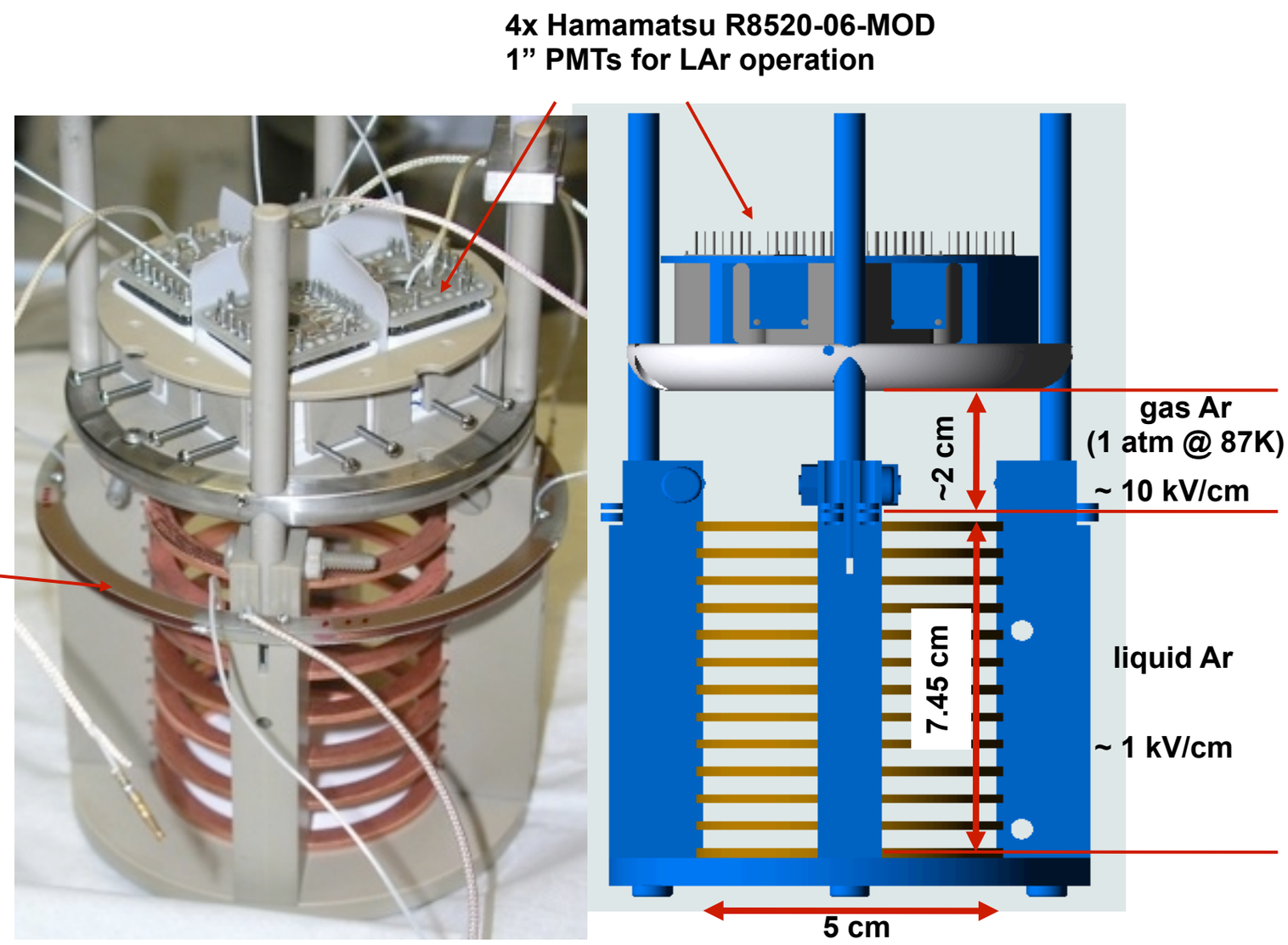
- **Unknown for Ar**
- **Only have a Monte Carlo model**



G/NARRLI Detector Internals

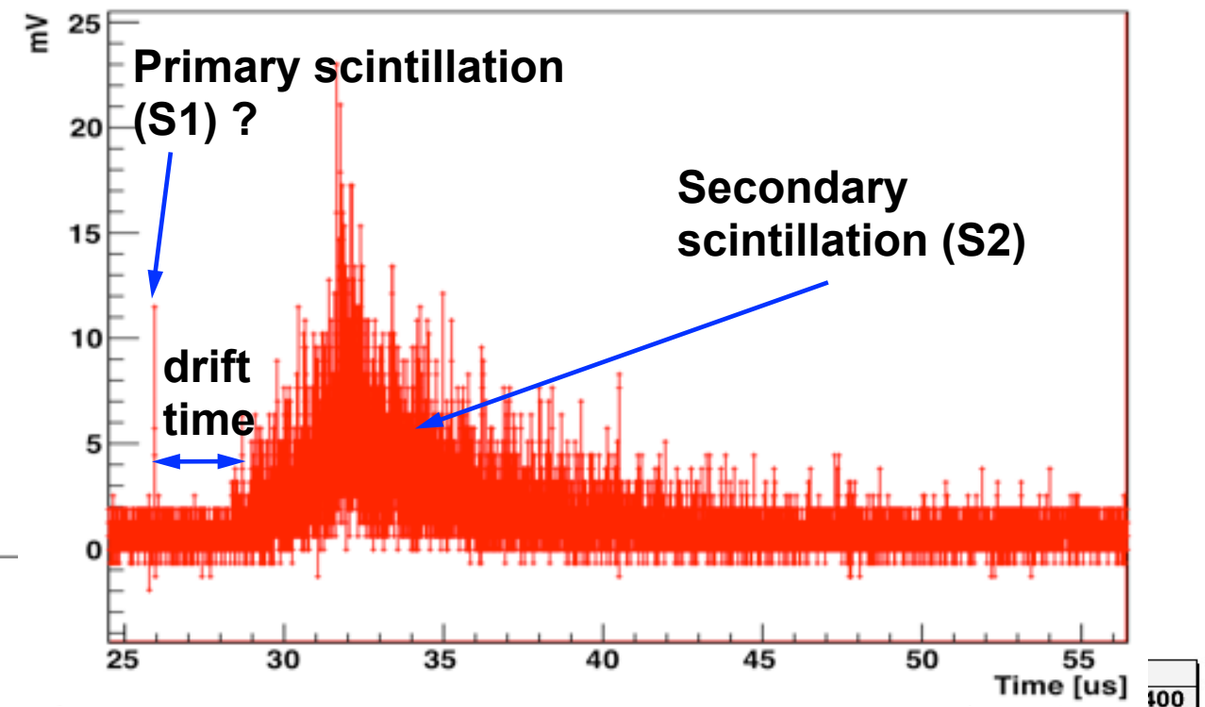
- In-situ Liquid Ar production w/ cryocooler
- Primary region volume: ~ 200 g LAr
- TPB as a wavelength shifter

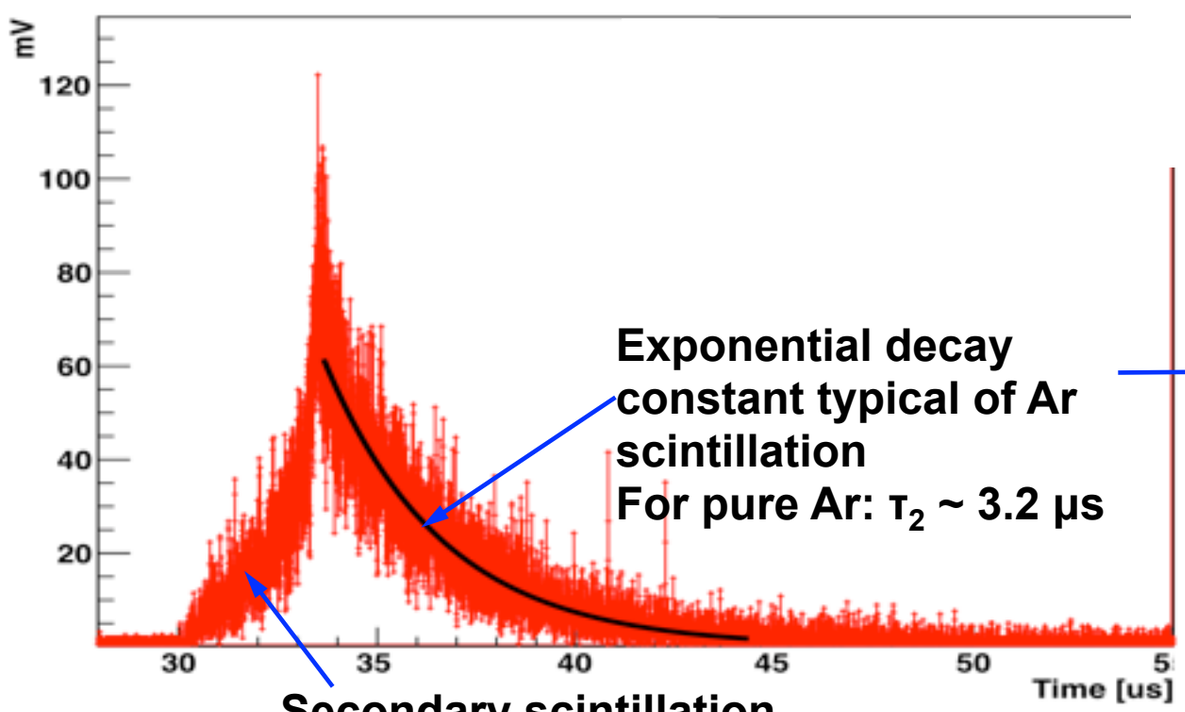


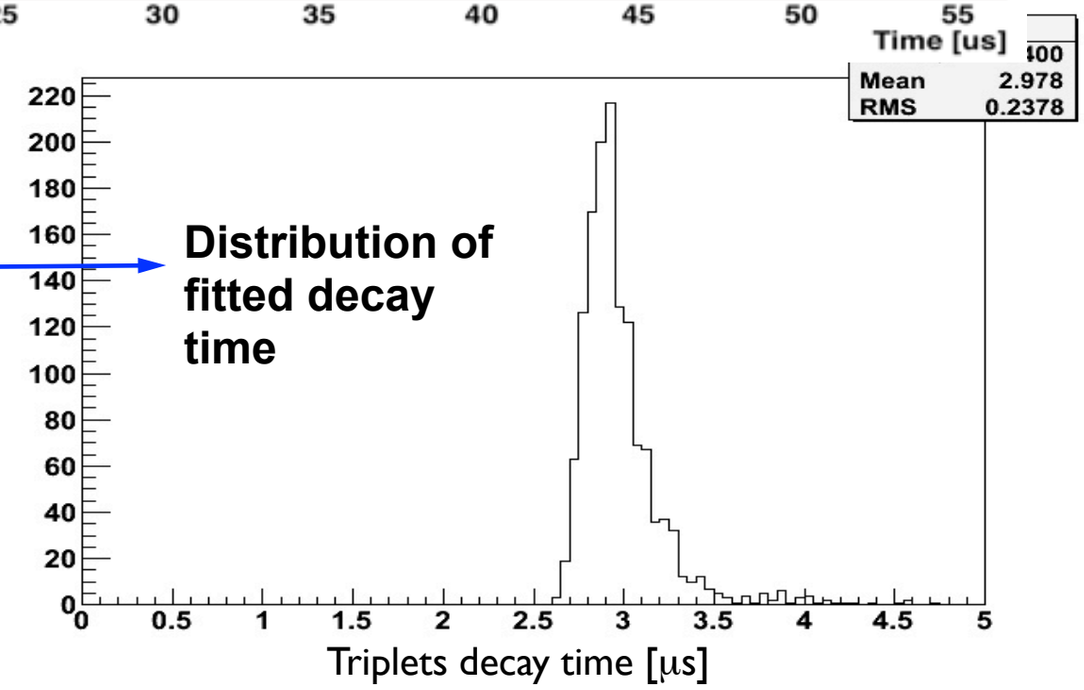


First light!

- Only a single 1” PMT
- Poor light collection efficiency
- No Ar recirculation
- Low E fields (~ 4 kV/cm in gas)
- External γ source







Conclusions and Future Work

- We are in the process of commissioning the G/NARRLI detector
- Calibrate the detector in the energy range of the nuclear ionization quench factor measurements
- Measure the nuclear ionization quench factor at ~8 keV using neutrons, lower than any previous measurements
- Measure the nuclear ionization quench factor between 90 eV and 4.7 keV using gamma rays, nuclear resonance fluorescence produces the lowest possible quench factor measurements, regardless of detector medium
- Use measured nuclear ionization quench factor measurements to compare with Monte Carlo models and determine the CNS signal
- Detection of the CNS interaction would be a significant validation of the standard model, and could allow for smaller antineutrino detectors for nuclear reactor monitoring

Acknowledgements

- **LLNL LDRD for project funding**

- **DHS Nuclear Forensics Graduate Fellowship for M. Foxe's funding**

Questions