Directional Detection of Antineutrino

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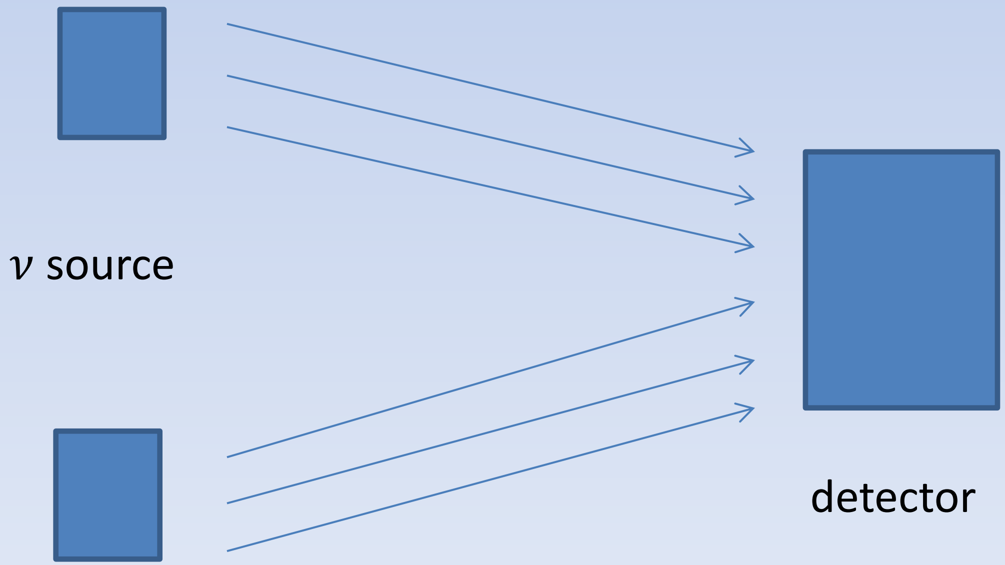
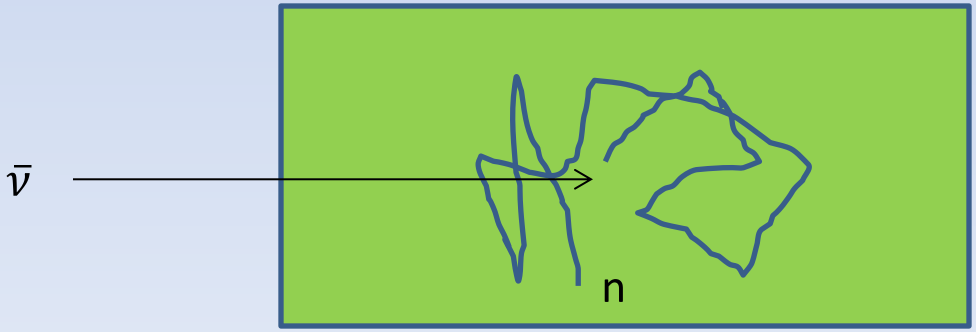
Why detecting $\bar{\nu}$ with direction?

- Mapping geo-neutrinos.
- Monitoring nuclear reactors.
- Nuclear non-proliferation.
- MSW effect for imaging earth?



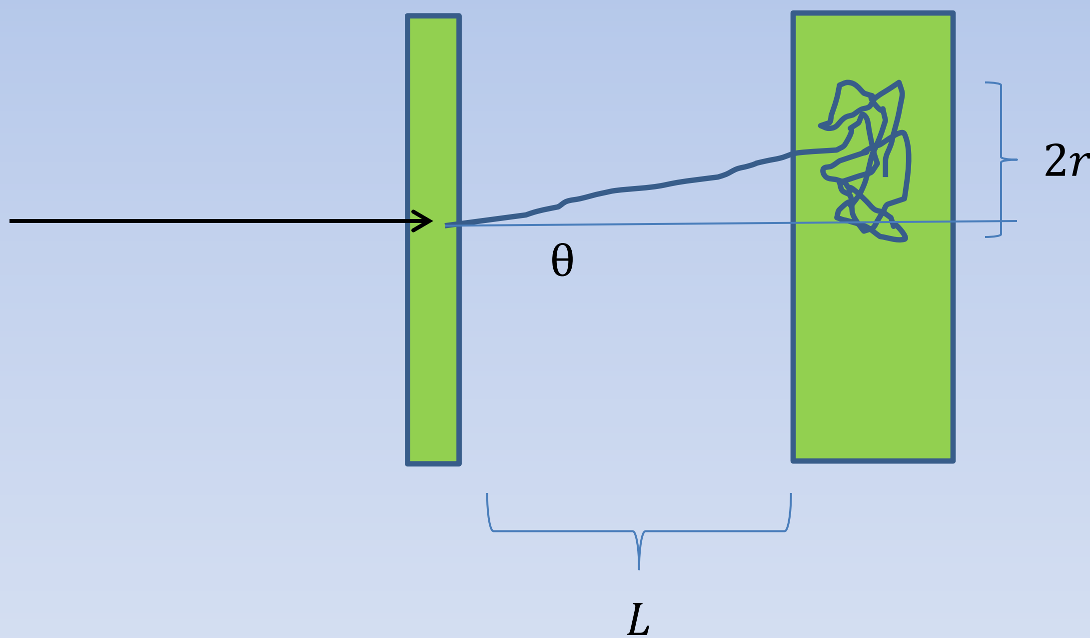
Why detecting $\bar{\nu}$ with direction is so hard?

- $\bar{\nu} + p \rightarrow n + e^{+}$
- Reaction has a threshold $\approx$ 1.8 MeV.
- Focus on reactor antineutrinos (2-7 MeV).
- Event is signaled by immediate e^{+} annihilation and a delayed neutron capture.
- The problem lies in neutron diffusion.



How do we solve the problem?

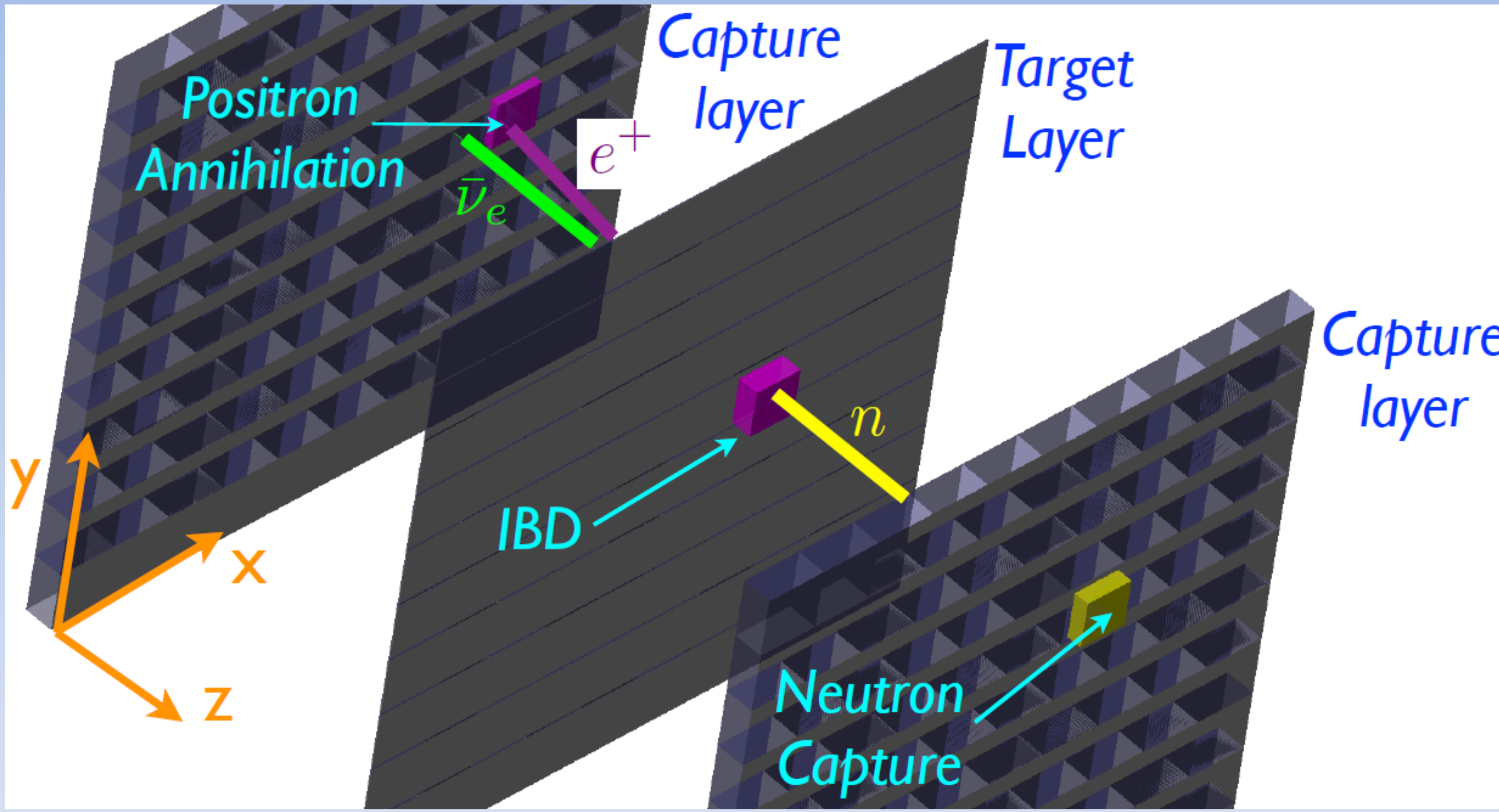
- Minimize the effect of neutron scattering!



$$\theta_{error} = \tan^{-1}\frac{r}{L}$$

For 10 keV neutron, 35 collisions before thermal.
Mean free path ≈ 1 cm, random walk ≈ $\sqrt{N}$, giving $\theta \approx 5°$.

How does the detector look like?



Why does the detector look so… simple ?

How does the detector look like?

- Segmented parallel plate detectors modeling plastic scintillators.

- Central: thin, target layer, plastic.
  Side: thick, neutron detection layer, boron-10 doped.

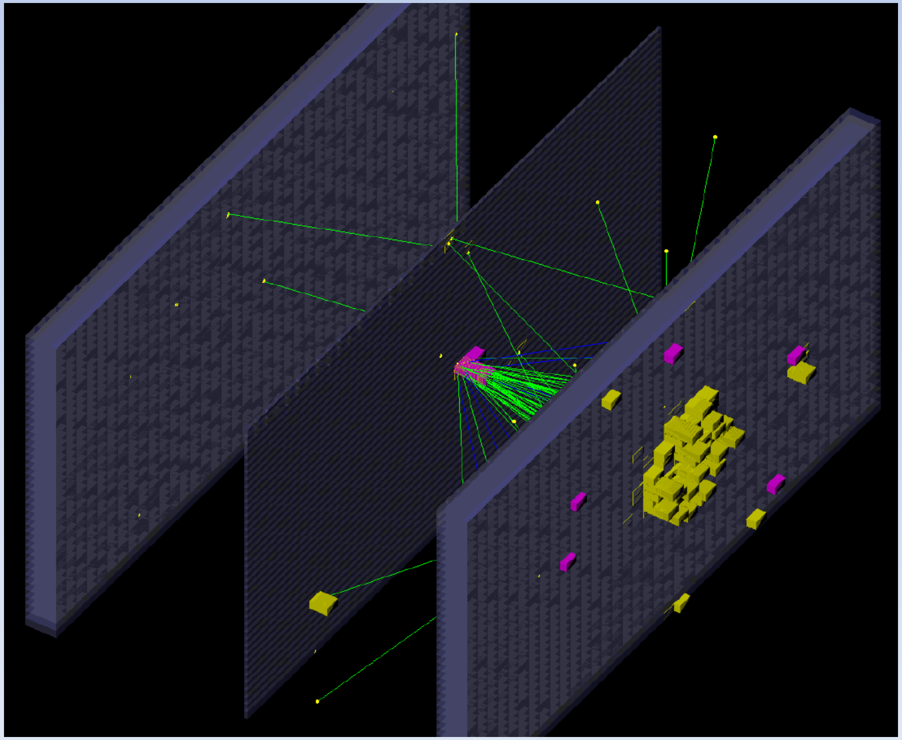
- $n_c = 4.44 \times 10^{22}, n_H = 5.18 \times 10^{22}, n_B = 5.68 \times 10^{20}\ cm^{-3}$

- Elastic cross section: $\sigma_H = 20\ b, \sigma_C = 5\ b$

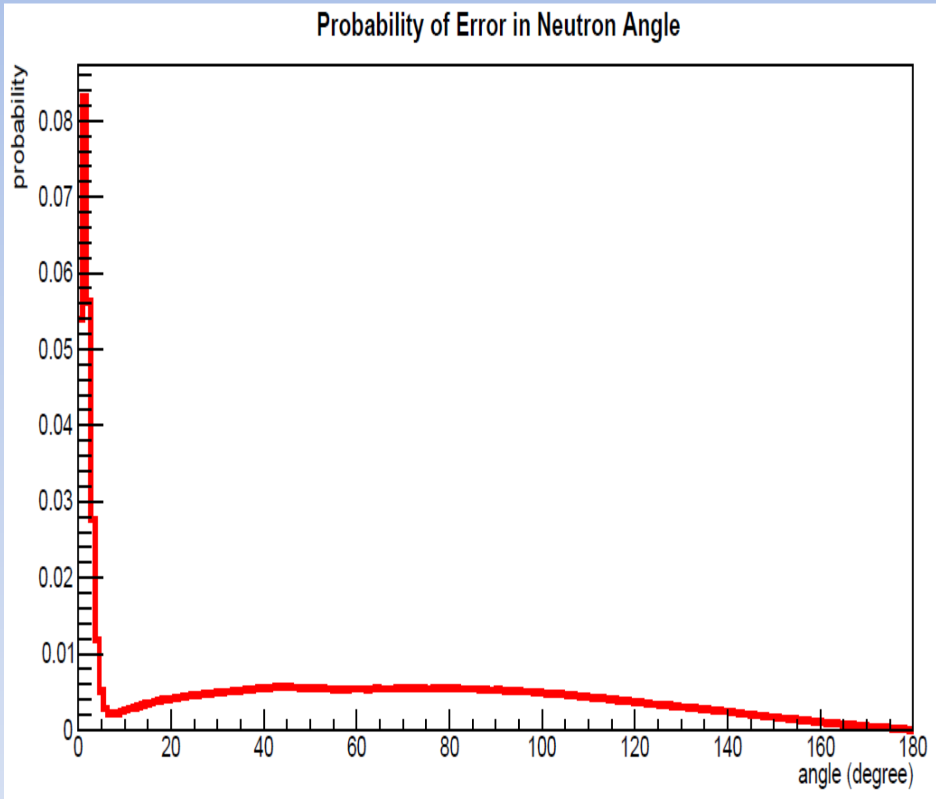
- $l = \frac{1}{n_H \sigma_H + n_C \sigma_C} = 0.8\ cm$

How do we find $\bar{\nu}$ direction?

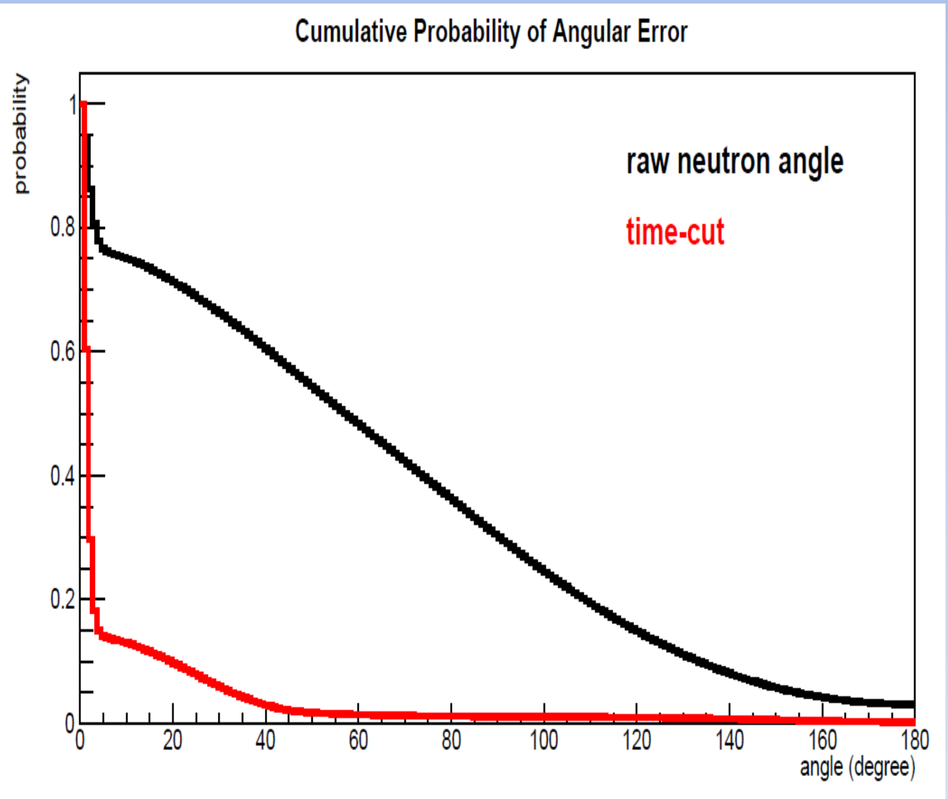
- When close to threshold, neutron direction is highly correlated with antineutrino direction.
- Missing neutron energy, need probabilistic treatment.
- Positron momentum?
- Signal:
  - e^+ ionization
  - e^+ annihilation
  - delayed neutron capture
  - Time-of-flight



C.D.F vs P.D.F

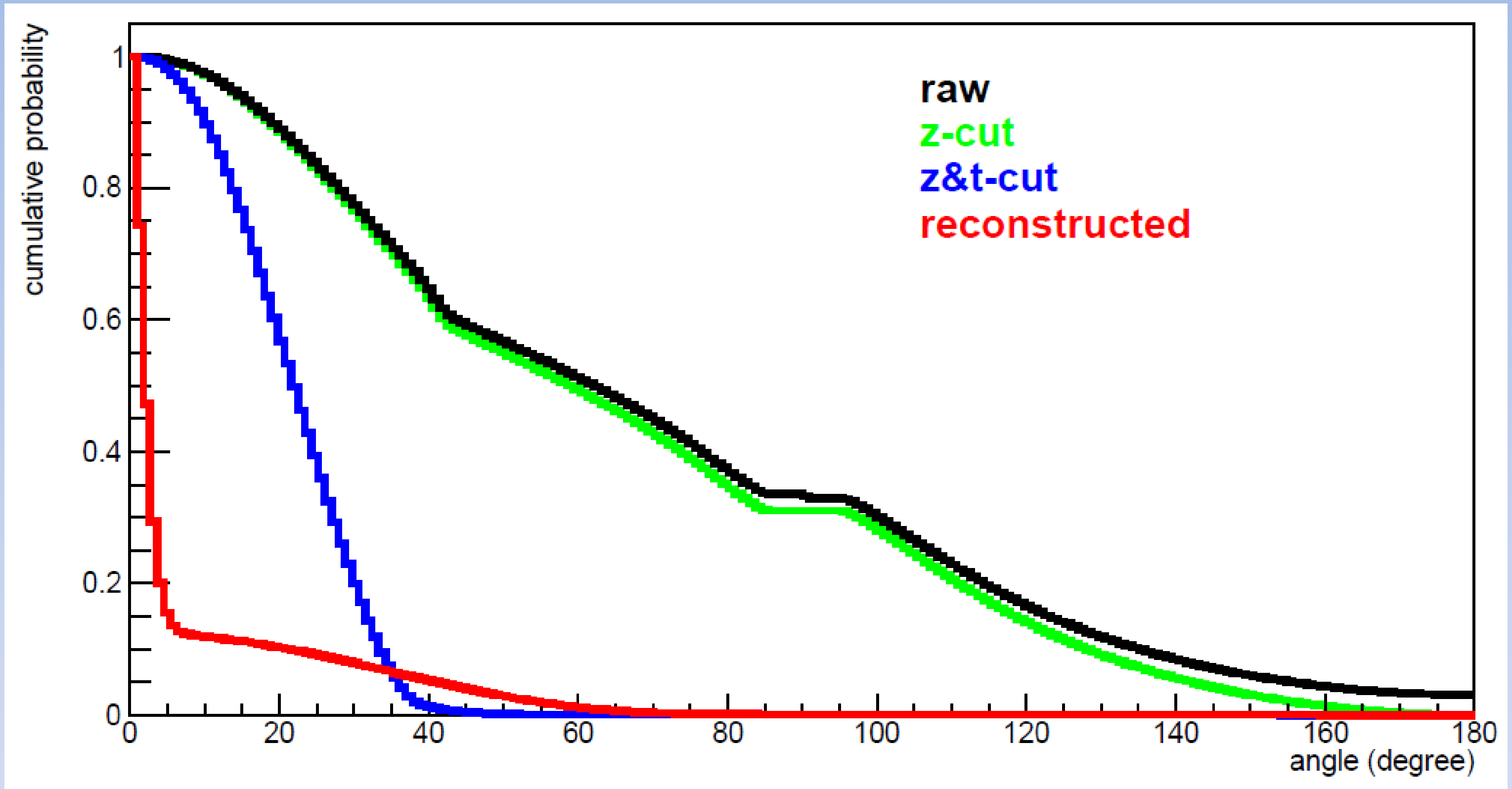


Probability of Error in Neutron Angle
probability
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
20
40
60
80
100
120
140
160
180
angle (degree)



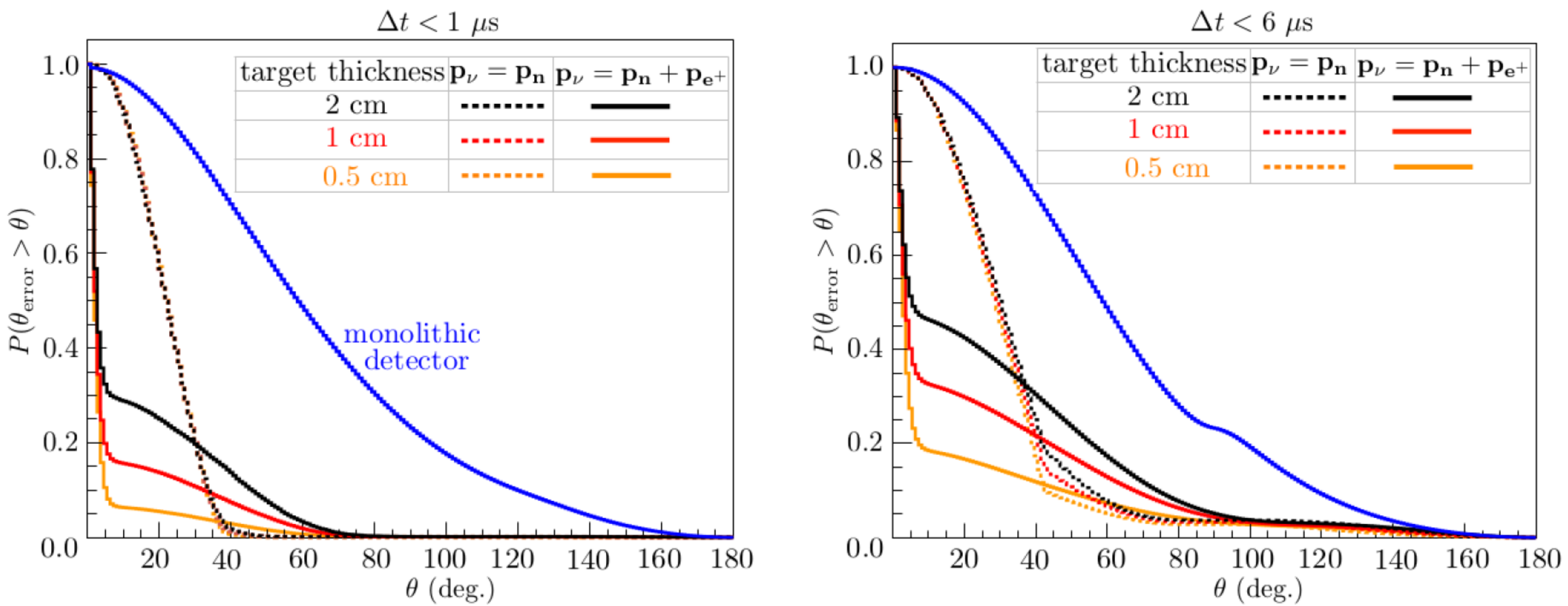
Cumulative Probability of Angular Error
probability
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
120
140
160
180
angle (degree)
raw neutron angle
time-cut

Is there directionality?



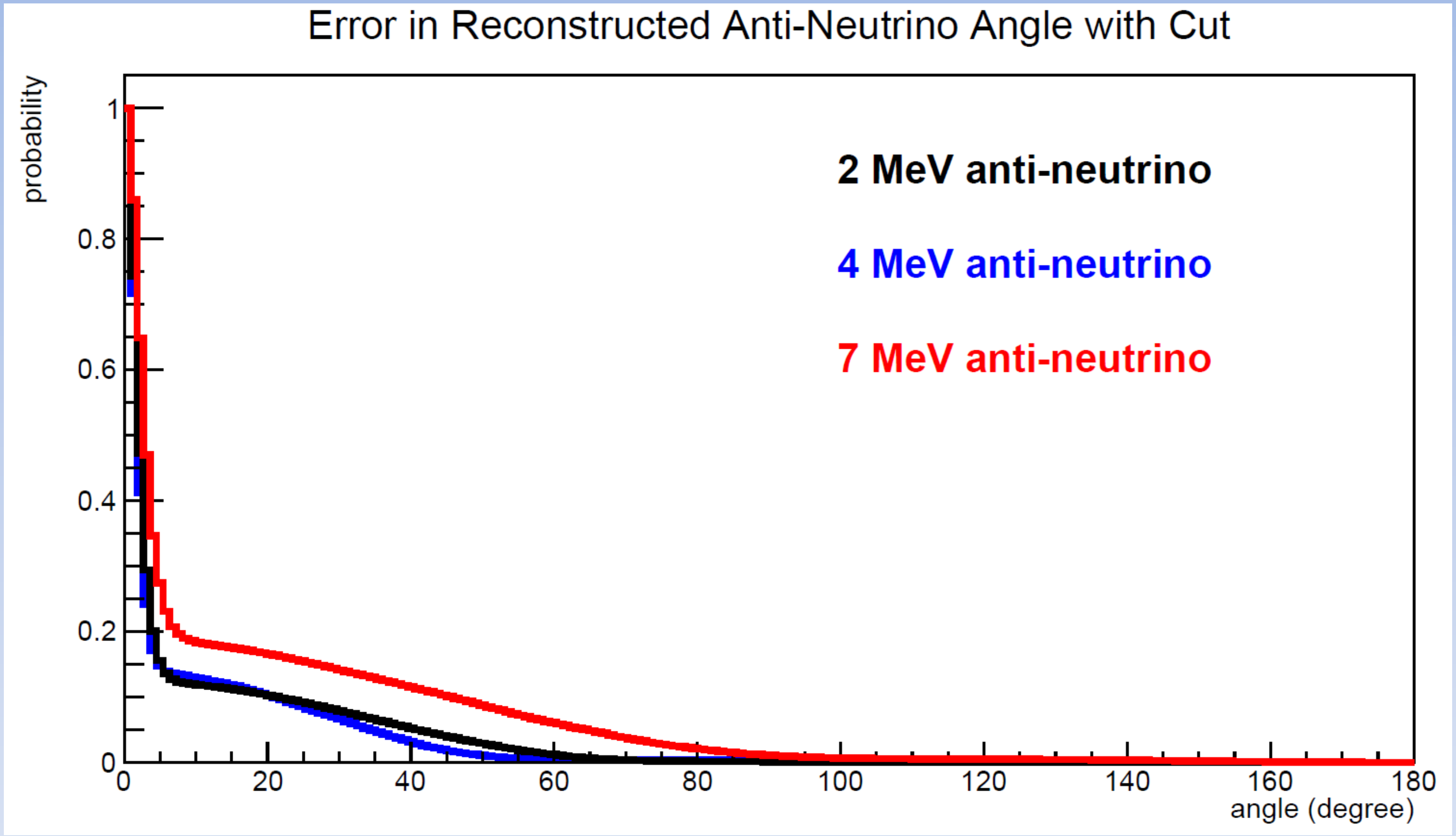
- 4 MeV antineutrino normal incident based on 10million events.
- Good! There is directionality!

Different Geometry



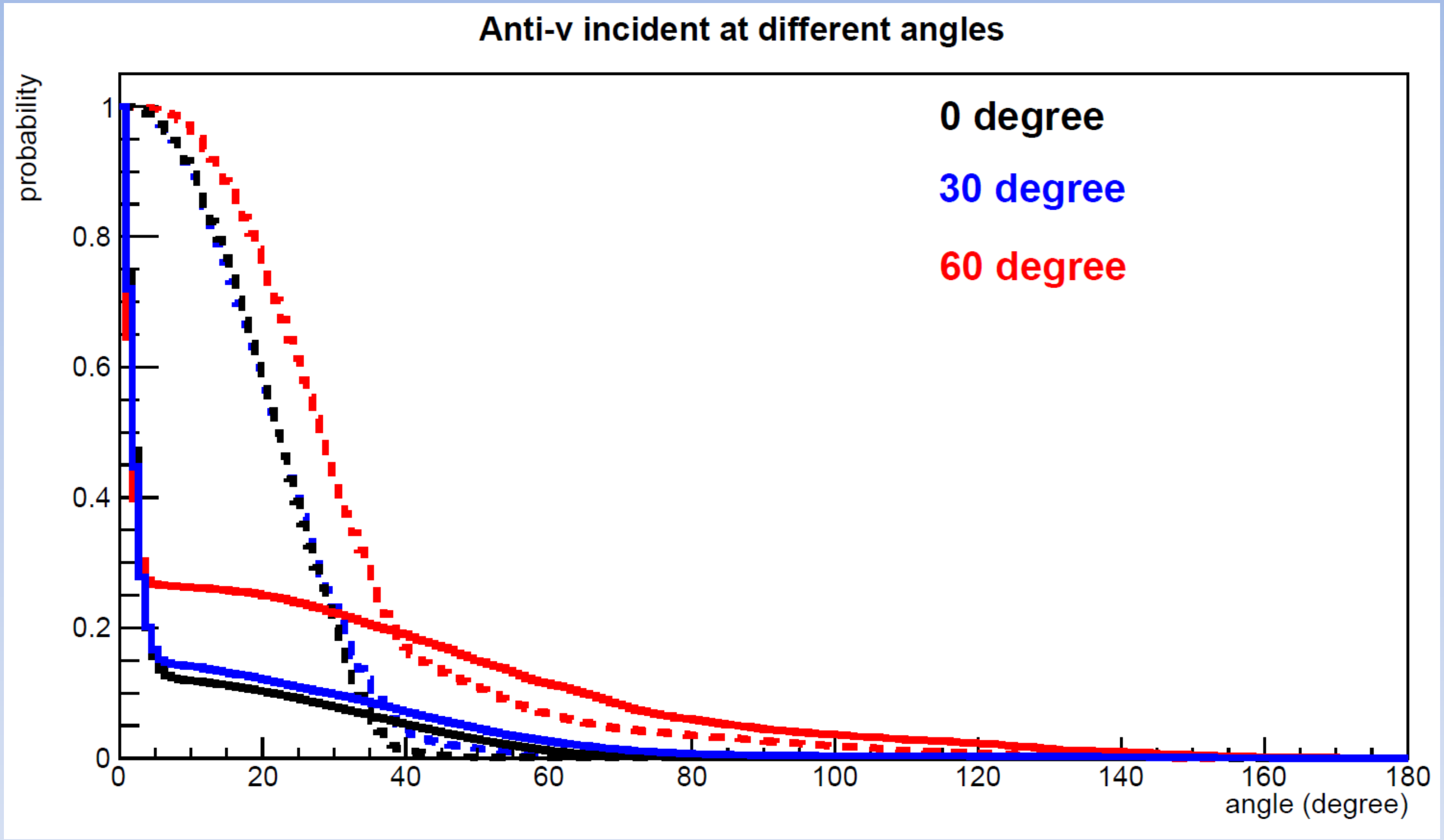
- 4 MeV antineutrino normal incident based on 10million events.

Different Incident Energy



- 2, 4, and 7 MeV antineutrino normal incident based on 10million events. 1 cm thick target.

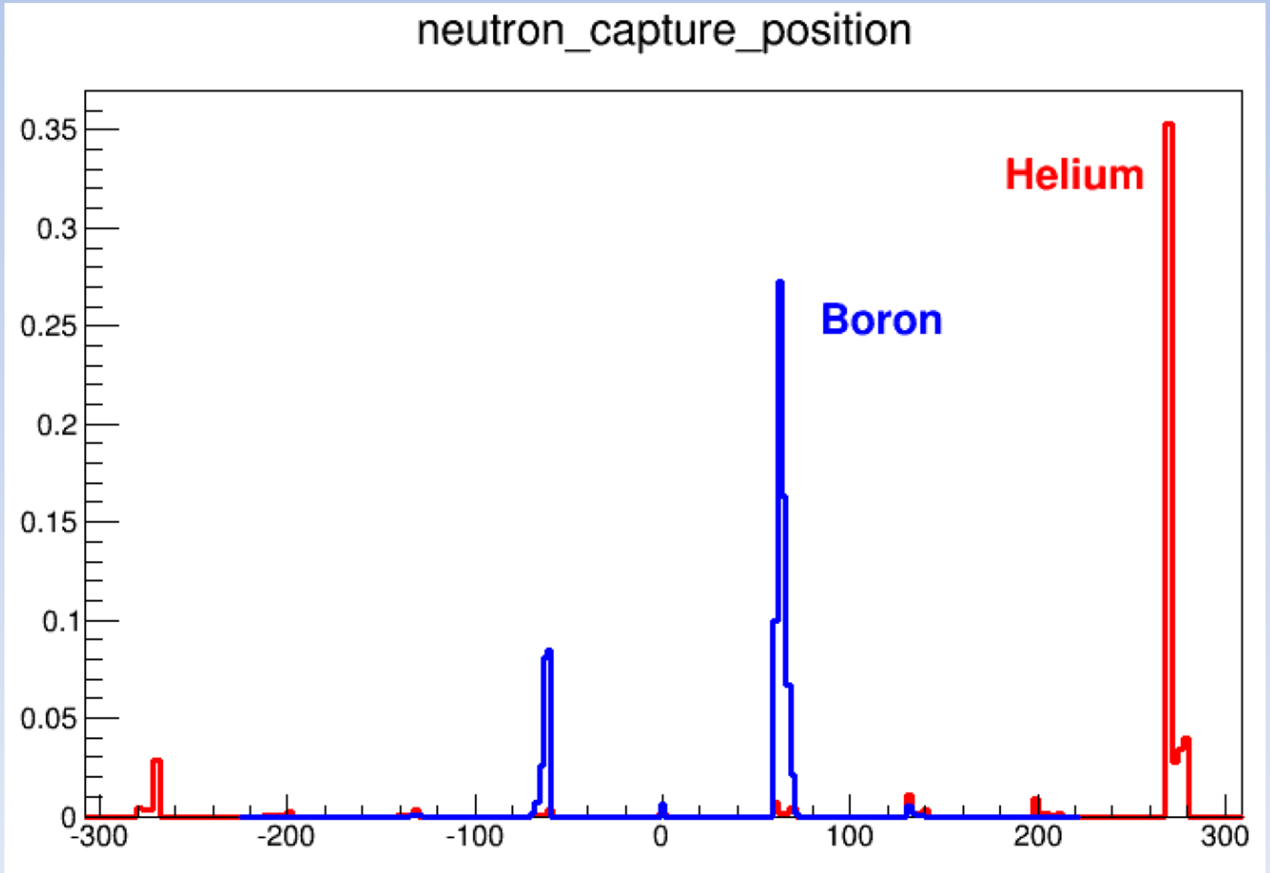
Different incident angle



- 4 MeV antineutrino, based on 10million events. 1 cm thick target.

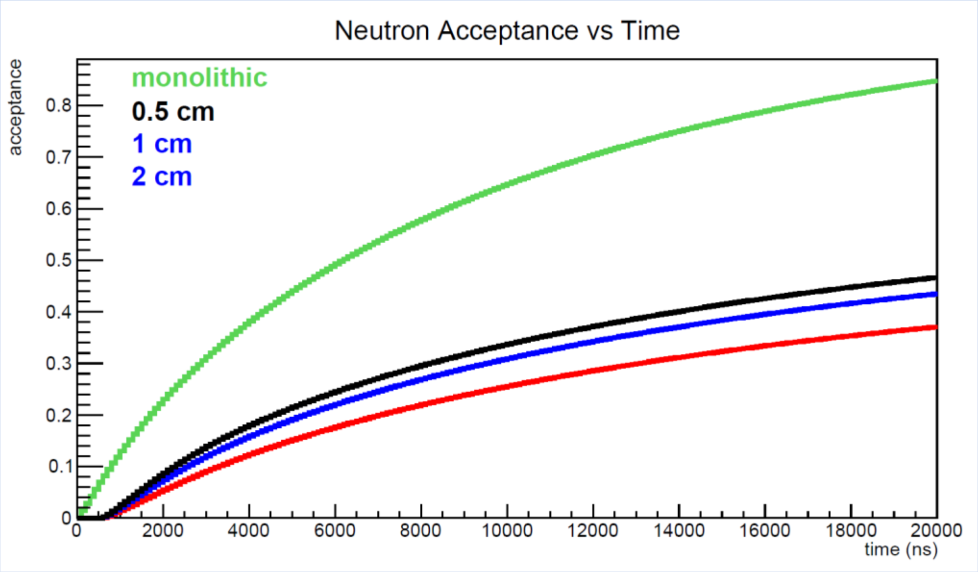
Different Material

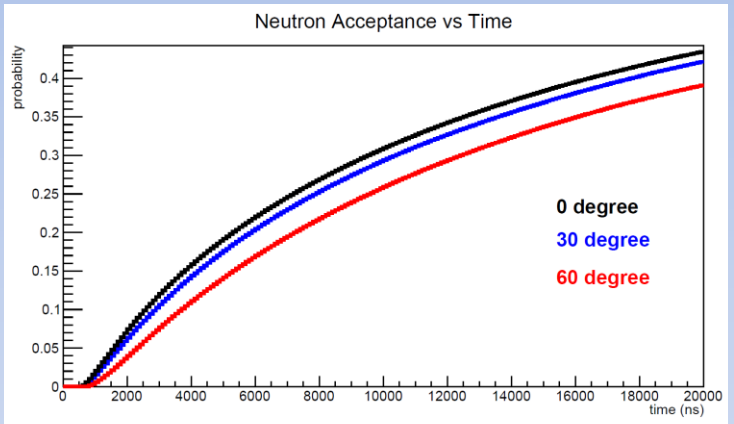
- 10B: 3835 b, (n, α)
- 157Gd: 259,000 b, (n, γ)
- 3He: 5333 b
- 6Li: 940 b, (n, α)

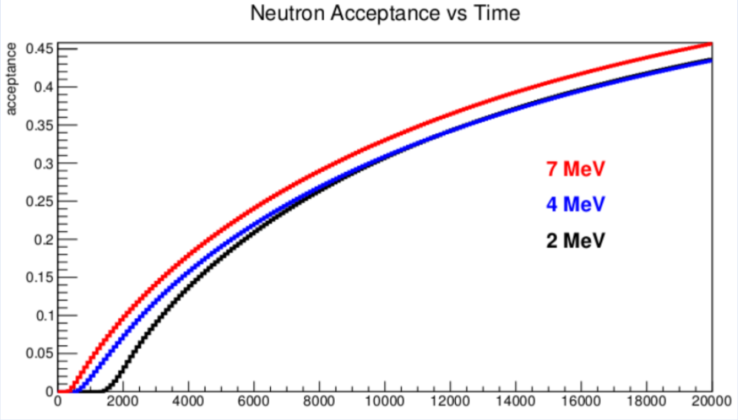


Acceptance is also important

- defined as fraction of neutrons passing through all cuts.
- time window changed to study change of acceptance.







Facing reality

- is the detector realistic?
- $\sigma = 10^{-42} cm^2, \rho = 10^{22} cm^{-3}$
- detector: $1m \times 1m \times 1cm$
- 4 GW reactor, $\Phi_{\text{tot}} = 10^{20} \sim 10^{22}\ s^{-1}$
- 20 m away: $\Phi = 10^{12} \sim 10^{14}\ cm^{-2} s^{-1}$
- Event rate: $R = 10^2 \sim 10^4 d^{-1}$
- $p_{accp} = 0.1$

What have we learned?

- $\theta_{error} = \tan^{-1}\frac{r}{L}$
- No free lunch

References

[1] L.M. Brown (1978). "The idea of the neutrino". Physics Today 31 (9): 23.

[2] C. L Cowan Jr., F. Reines, F. B. Harrison, H. W. Kruse, A. D McGuire (July 20, 1956). "Detection of the Free Neutrino: a Confirmation". Science 124 (3212): 1034.

[3] P. Vogel and J. F. Beacom, Phys. Rev. D 60, 053003

[4] M. Apollonio et al., Eur.Phys.J. C27, 331 (2003).

[5] Y. Kuroda et al., Nuclear Instruments and Methods in Physics Research A 690, 41 (2012).

[6] S. Agostinelli et al., Nuclear Instruments and Methods in Physics Research A 506, 250 (2003).

[7] http://www.eljentechnology.com/index.php/products/loadedscintillators/78-ej-254.

[8] NIST Center for Neutron Research. http://www.ncnr.nist.gov/resources/n-lengths/

[9] J. V. Dawson and D. Kryn, JINST 9, P07002 (2014).

[10] Z. Djurcic et al. (2013), 1309.7647.