Hunting the Potassium Geoneutrinos with Liquid-scintillator Cherenkov Detectors

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Geoneutrino: What powers the Earth?

Left from Accretion

Primordial

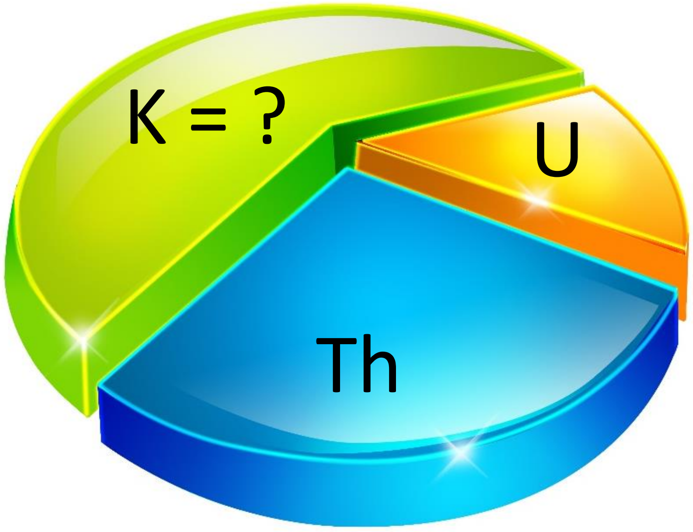
Radiogenic

U, Th, K Decay

- Total Heat Flow 47±3 TW
- Models for radiogenic heat 10-30 TW
- Experimental measurement with U, Th geoneutrinos 10-30 TW (KamLAND and Borexino)

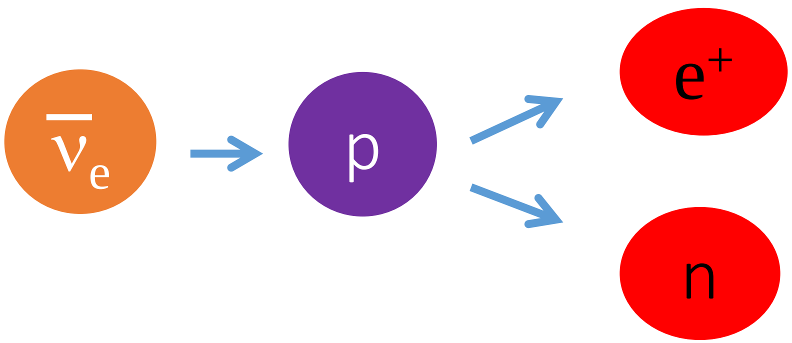
Important Questions

- Incomplete picture. K element has quite different chemical and physical properties than U or Th. It doesn't follow the path of U and Th in the Earth evolution.

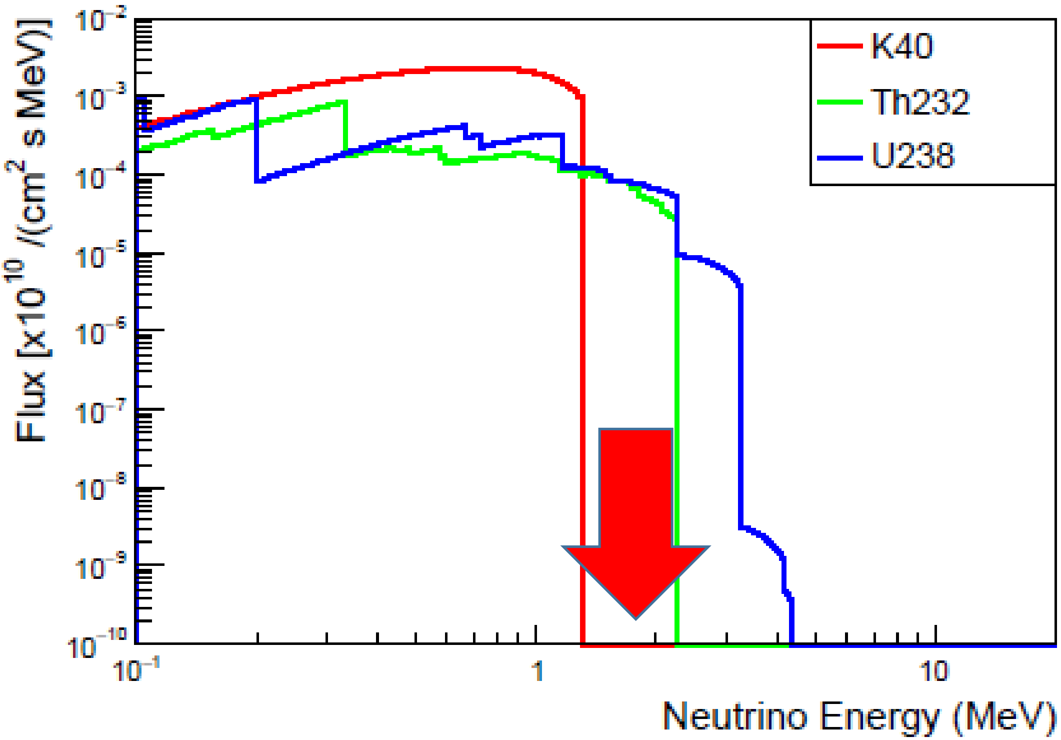


Measure it.
We can try.

IBD-based U, Th geoneutrino Detection

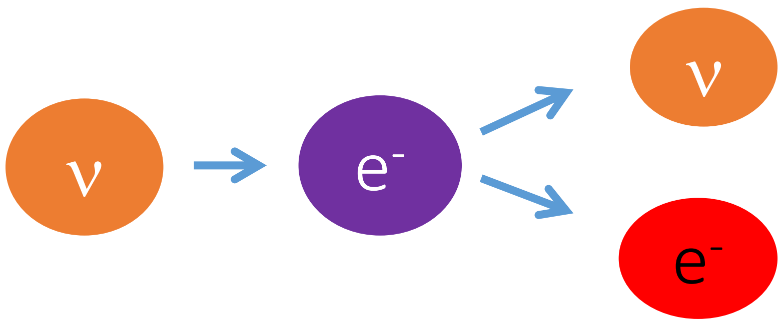


- IBD threshold = 1.8 MeV
- U, Th neutrinos only



- K-40 geoneutrino maximal energy 1.31 MeV
- K-40 not accessible

Neutrino-Electron Scattering



Pro:

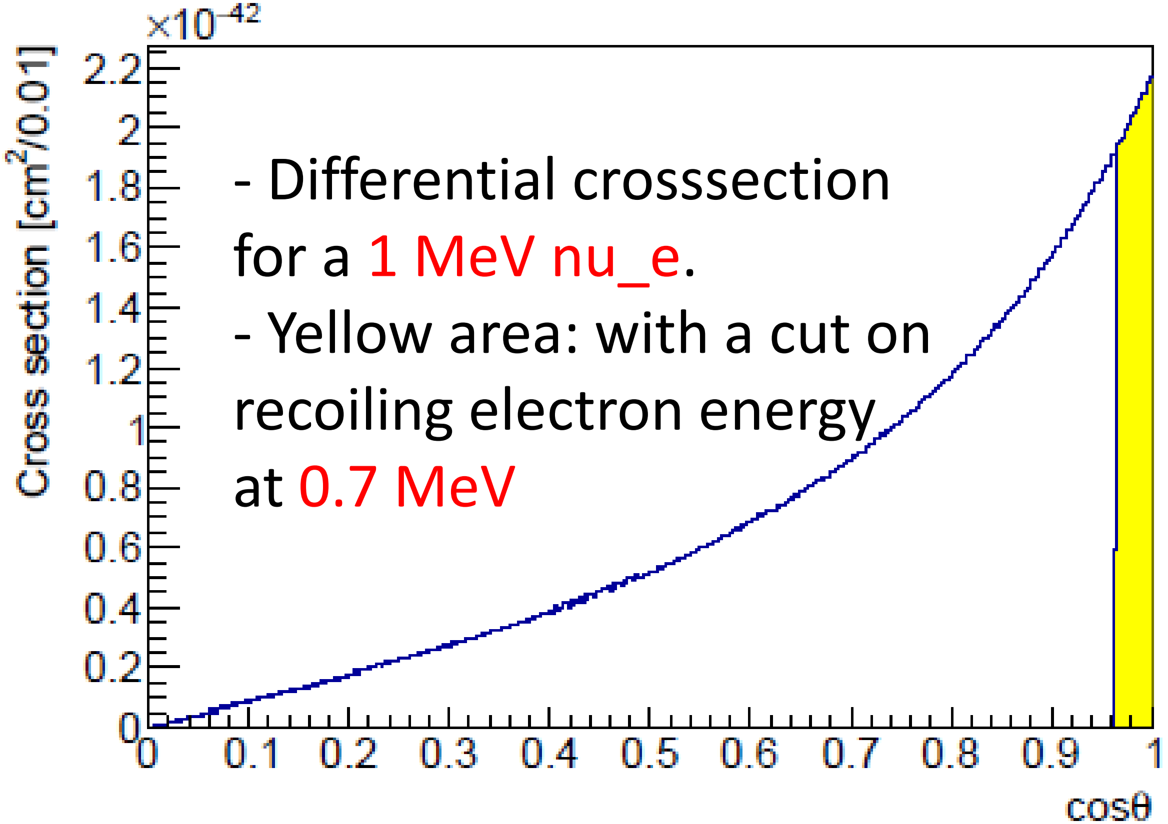
- No threshold

Con:

- Conventional liquid-scintillator detector: Geoneutrino signals overwhelmed by solar signals
- Water Cherenkov detector: Very few photons, poor energy resolution, not easy to trigger.

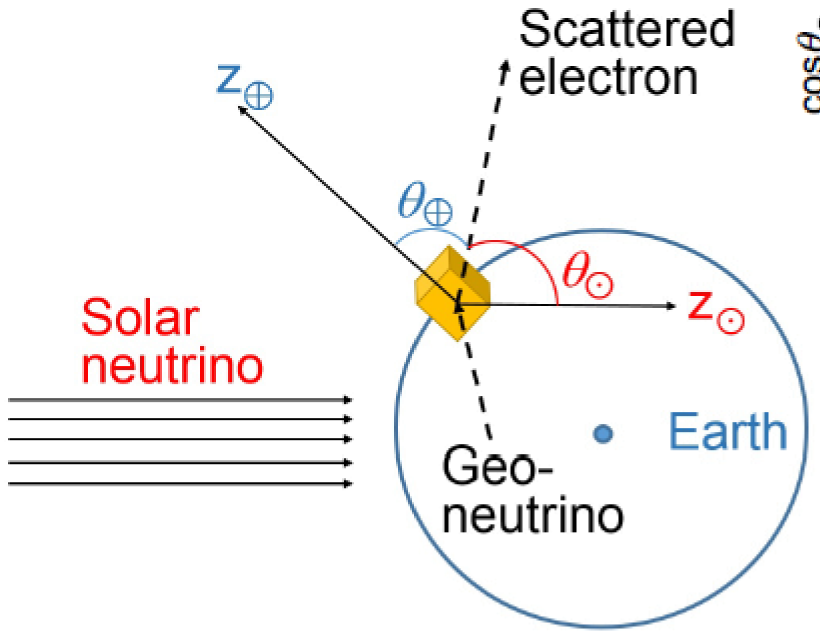
Strong Direction Correlation at Low E

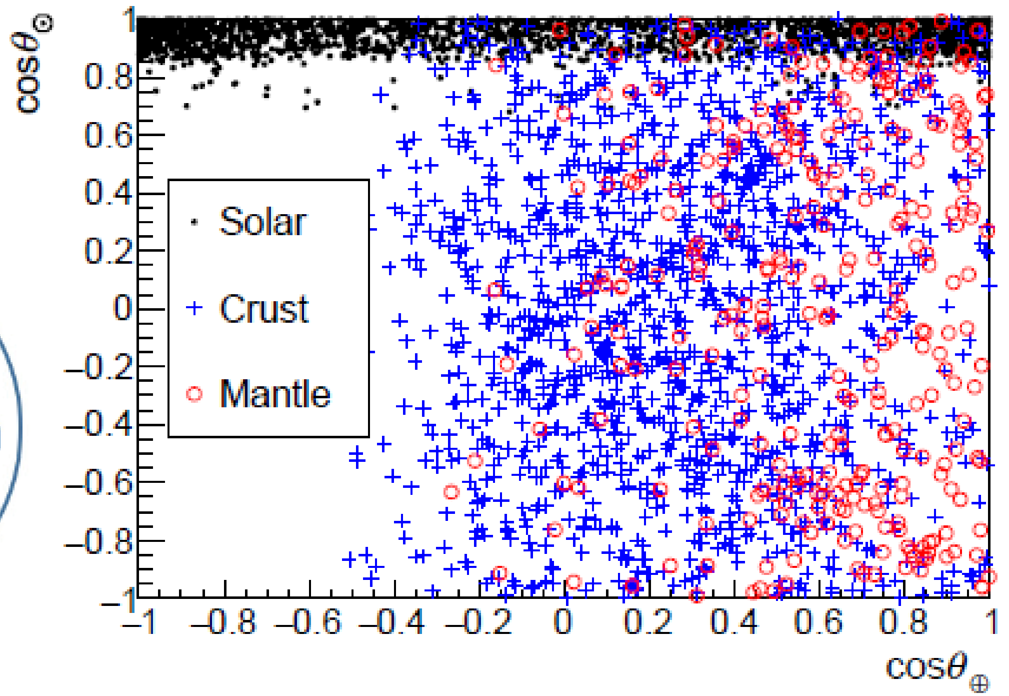
Even at low energy (E_ν<2 MeV) recoil electrons can still point back to the Sun after an energy cut



θ: the angle between neutrino and electron direction

Theoretical Distributions





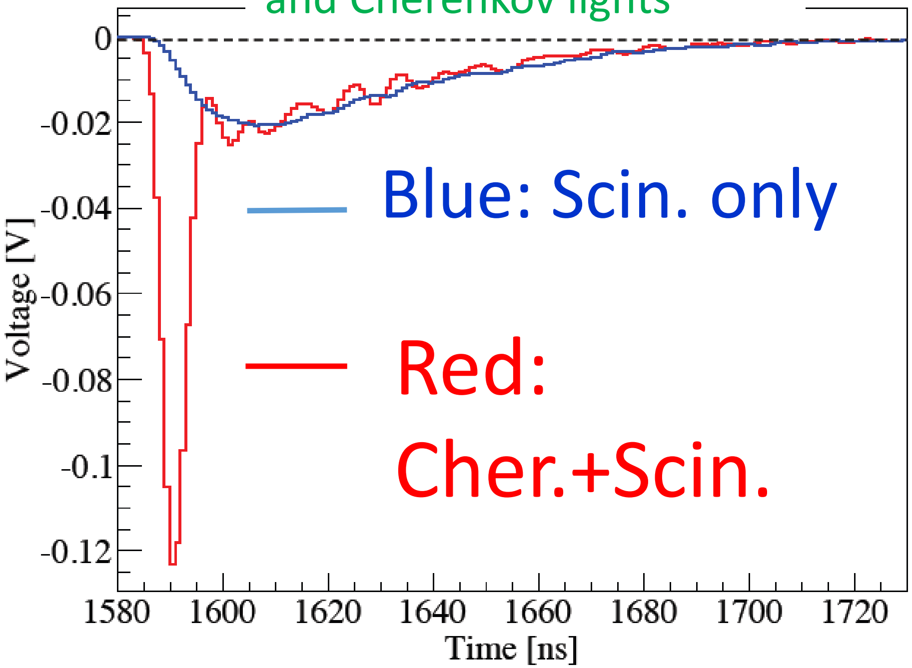
Solar and geo neutrinos can be well separated after requiring $K_e > 0.7$ MeV

Slow Liquid Scintillator, for example LAB

- Cherenkov emission: prompt
- Scintillation emission time constant: 10-20 ns (slow)
- PMT: TTS 1 ns

Other liquid-scintillator Cherenkov detector schemes also work.

Time profile of scintillation and Cherenkov lights

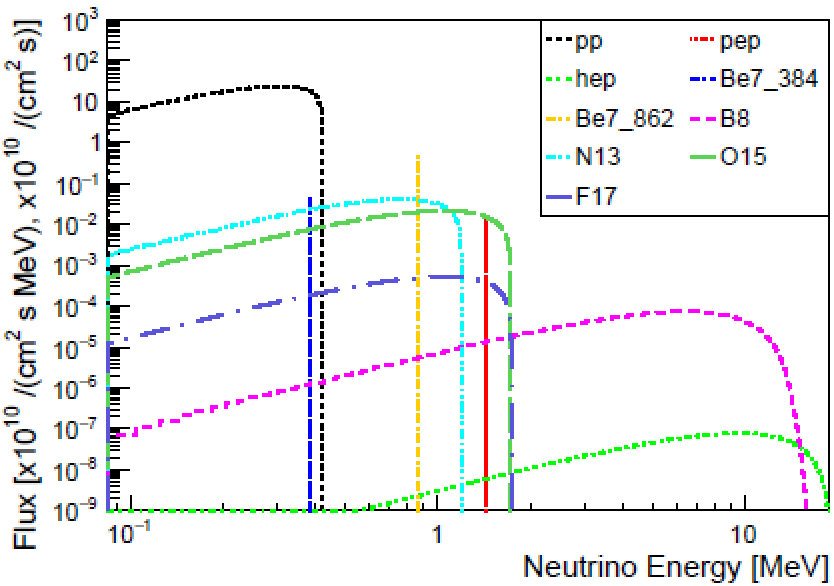


Feature: Both direction and energy measurements

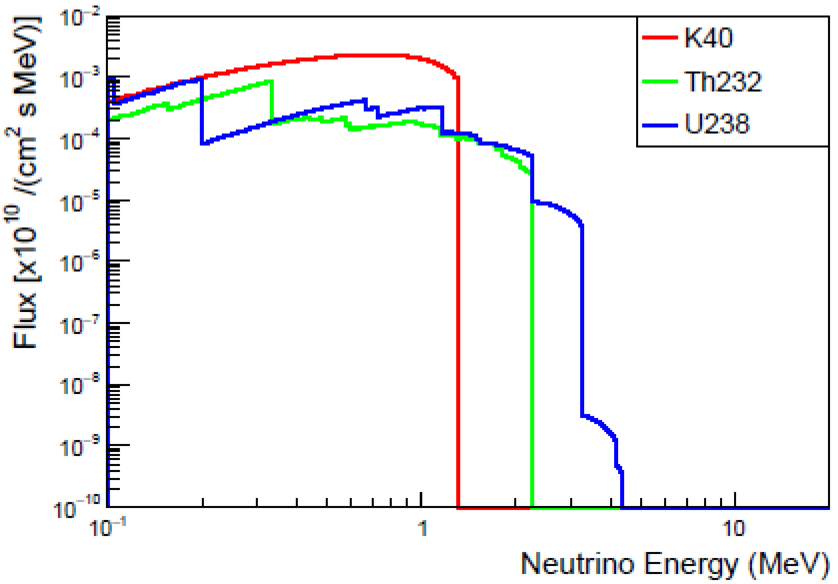
Question: With electron scattering, electronics, offline Cherenkov recognition, can Slow-LS work out at less than 2 MeV?

A simulation-based sensitivity study is carried out.

Solar and Geoneutrino Generation



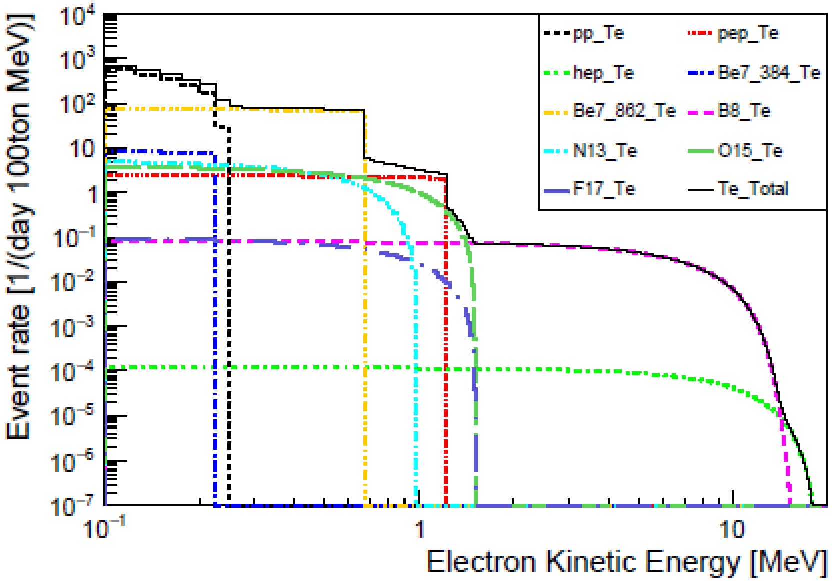
Standard solar neutrino spectra



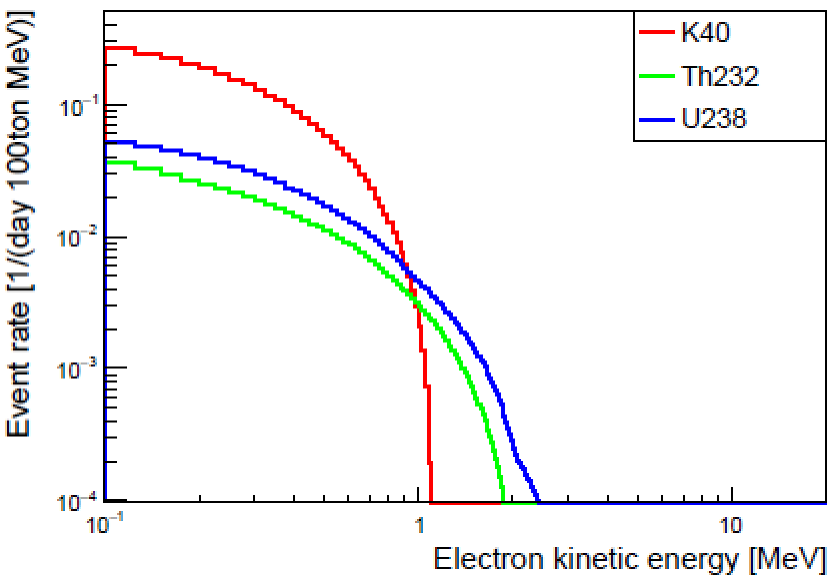
Geoneutrino spectra

A simplified Earth model to speed up my calculation. The integral flux is similar to 1) O. Sramek, et al.,Scientific Reports 6 (2016) 33034, and 2) L.Wan, et al., Phys. Rev. D 95 (2017) 053001.

Recoil electron spectra from the solar and geoneutrinos

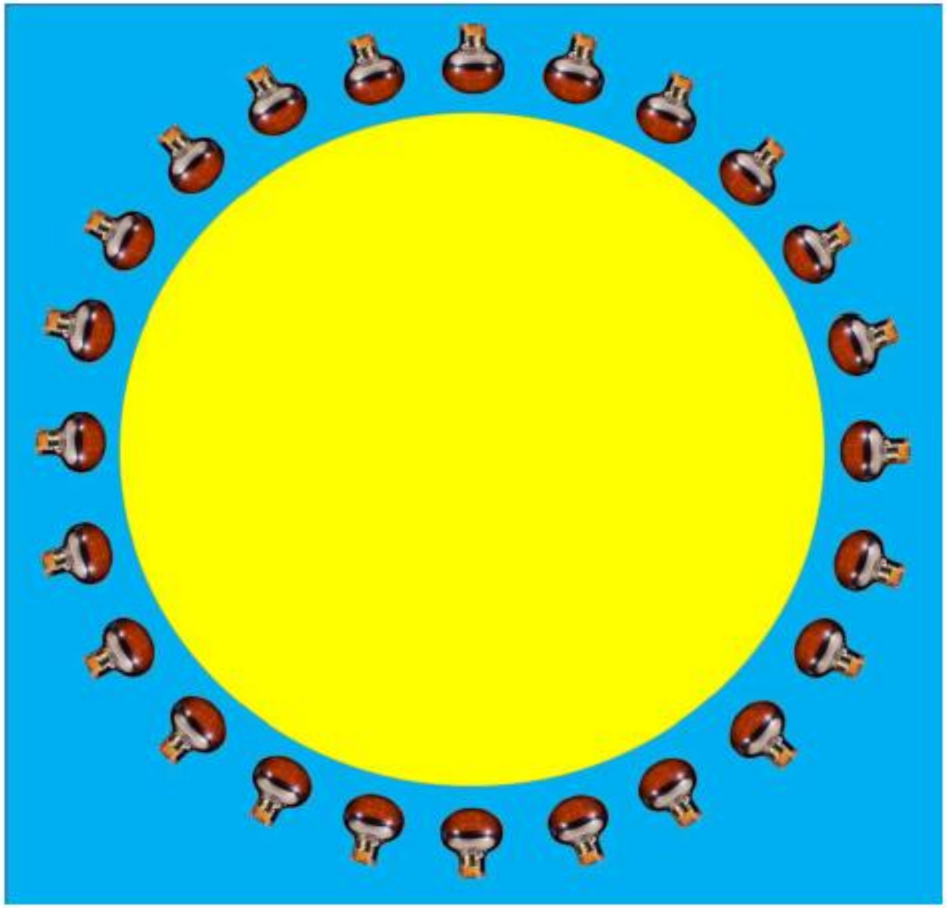


Electron spectra from solar neutrinos



Electron spectra from geo neutrinos

Slow Liquid-scintillator Detector Concept



PMT + liquid scintillator + buffer structure

Slow Liquid-scintillator Detector Simulation

1. Full Geant4 simulation of recoil elections
2. Full Geant4 simulation of Cherenkov production and scintillation production
3. Customized: Scintillation light yield, 2530 Photon/MeV; Rise time, 12.2 ns; Decay time: 35.4 ns. (Based on LAB)
4. Fast simulation for PE generation: efficiency ~20%
   ① Photon acceptance (attenuation and PMT coverage), only 2/3 of photons can reach PMT photocathode
   ② Quantum efficiency: 30% for [300, 550] nm, and 0 for the rest

Reconstruction

1. Reconstructed energy
   simple scaling based on the number of PE of each event
2. Direction reconstruction
   A weighted-center method using the accepted PEs' positions,

$$\vec{R} = \frac{1}{N_{\mathrm{PE}}} \sum_{i=1}^{N_{\mathrm{PE}}} \vec{r}_i$$

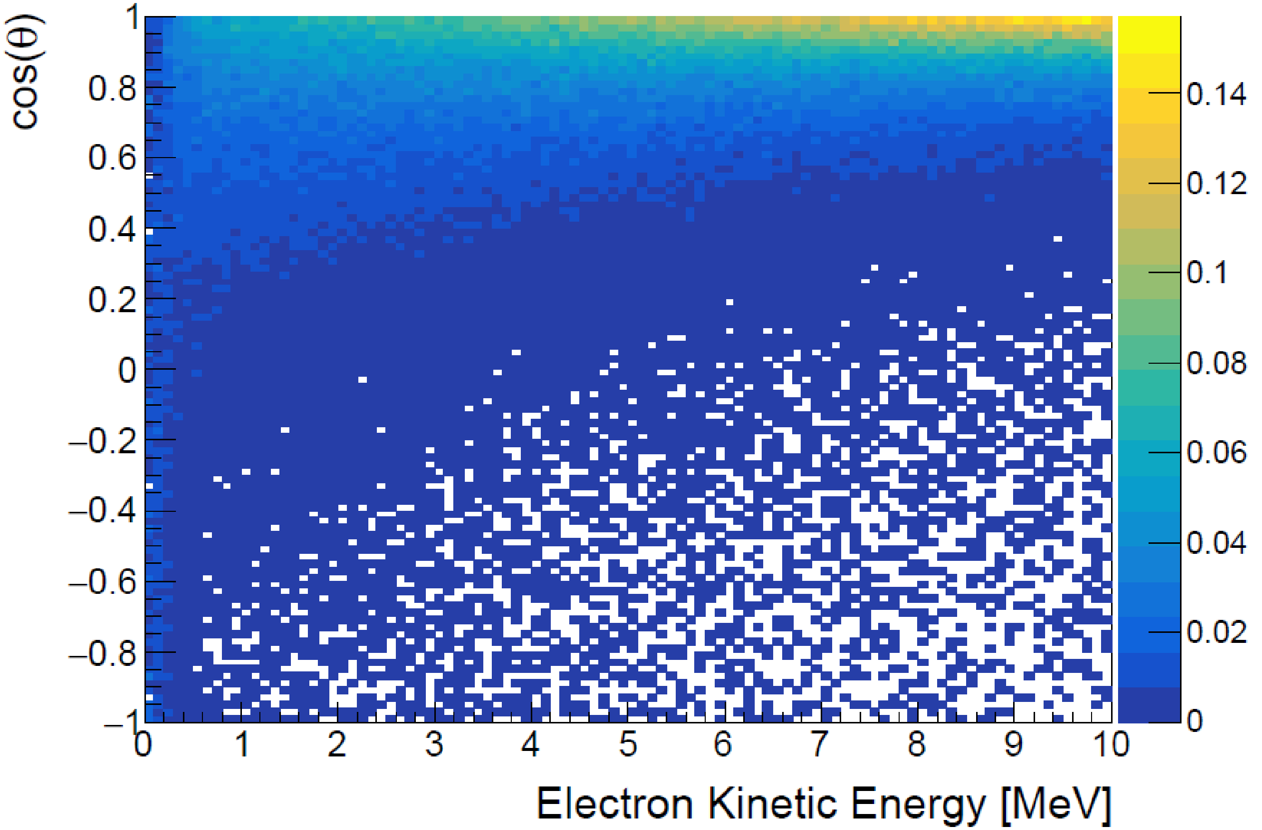
$\vec{r_i}$ is the PMT position of each PE

including

a) all Cherenkov PEs after the 20% eff cut, and

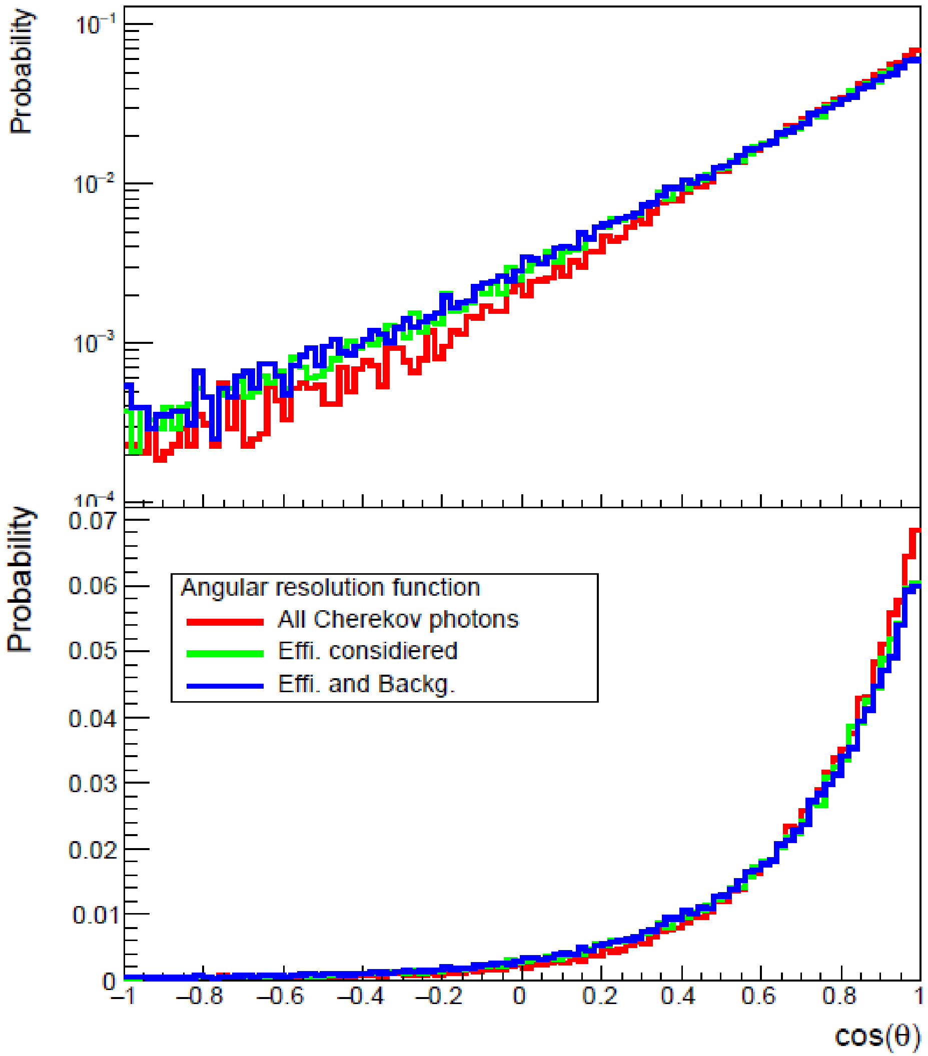
b) 2 ns of scintillation PEs

Angular Resolution Relative to Initial elec. Direction



Angular resolution turns better gradually with the increasing energy.

Angular Resolution relative to Initial e- Direction in K_e range [0.5, 2] MeV

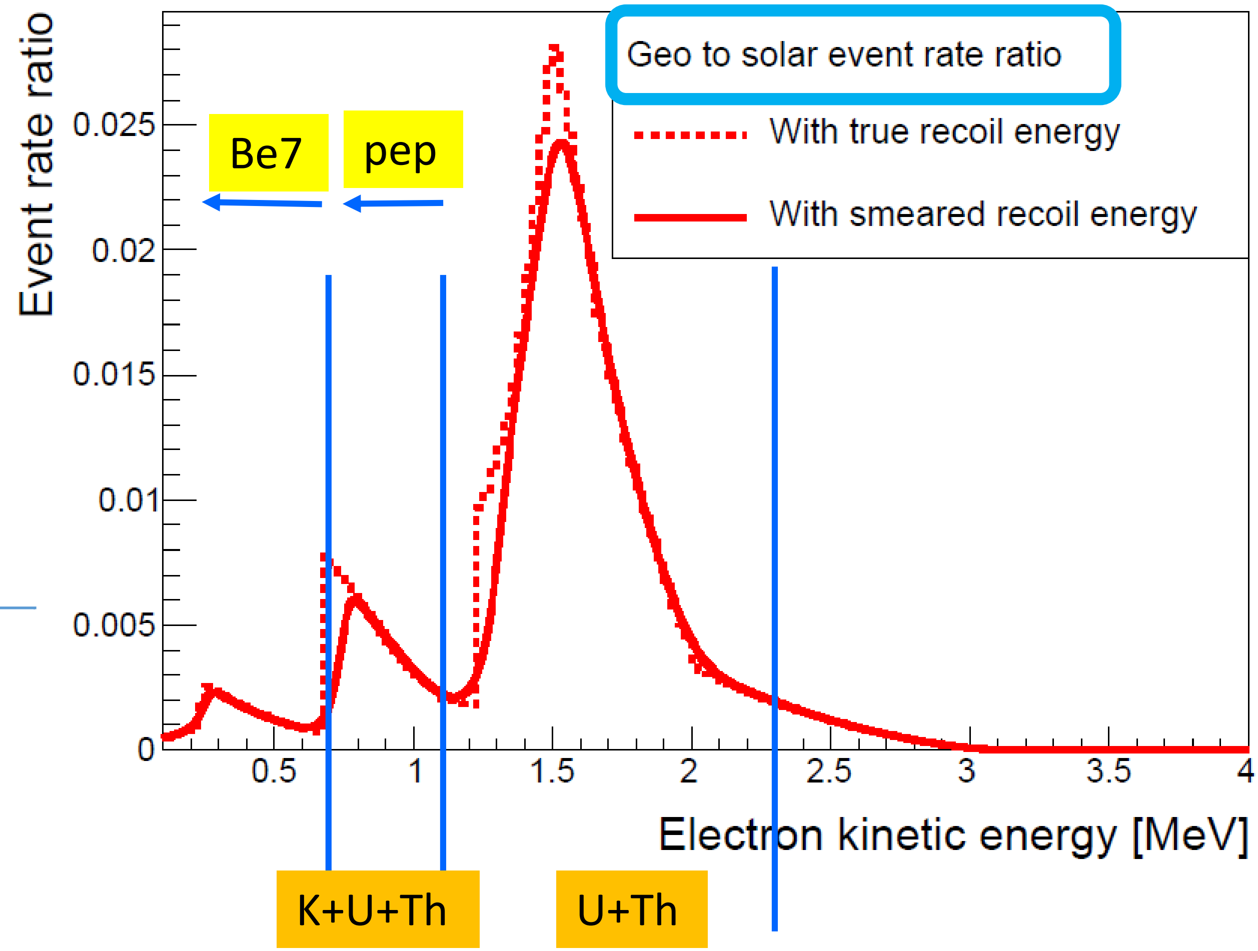


- 125 degrees for 99% coverage

- Remove scintillation Bkg PEs, 124 degrees for 99% coverage

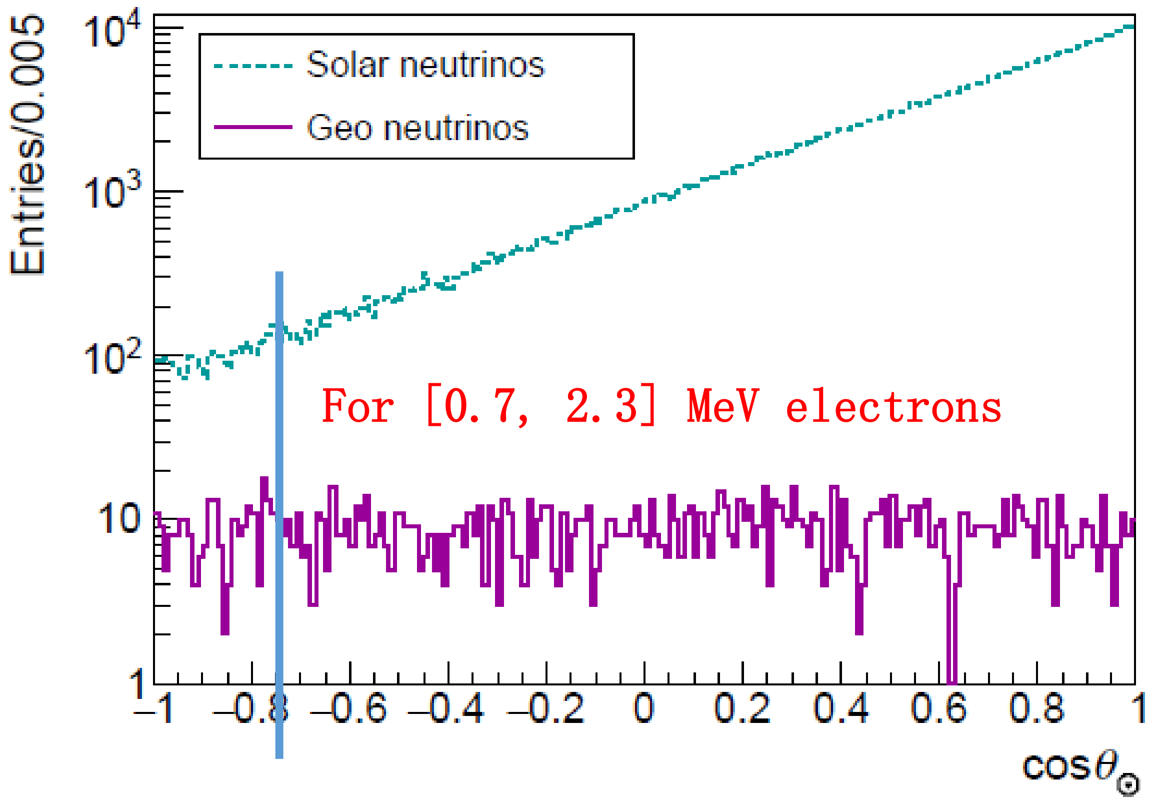
- No Scin. Bkg. and use all Cherenkov Photons: 116 degrees
(Scattering is the No. 1 reason to make it so bad)

Energy Signal Region Determination



We need a factor of 100-200 to suppress the solar background

Signal Region for Direction Criteria



A cut at −0.75 can suppress the solar background by a factor of 150. Signal-to-background ratio is close to 1 now.

Determine the Amount of Signals

We count the total number of candidates and subtract backgrounds

$$N_{geo} = N_{can} - N_{bkg} \times \epsilon,$$

$N_{bkg} \times \epsilon$ is the predicted number of background neutrino times detector efficiency

$$\sigma_{geo} = \sqrt{\sigma^2_{candidate} + N^2_{bkg}\sigma^2_{\epsilon} + \epsilon^2\sigma^2_{solar}}$$

$\sigma_{candidate}$: Statistical error of N_{can}

σ_{bkg}: flux uncertainty of background neutrinos

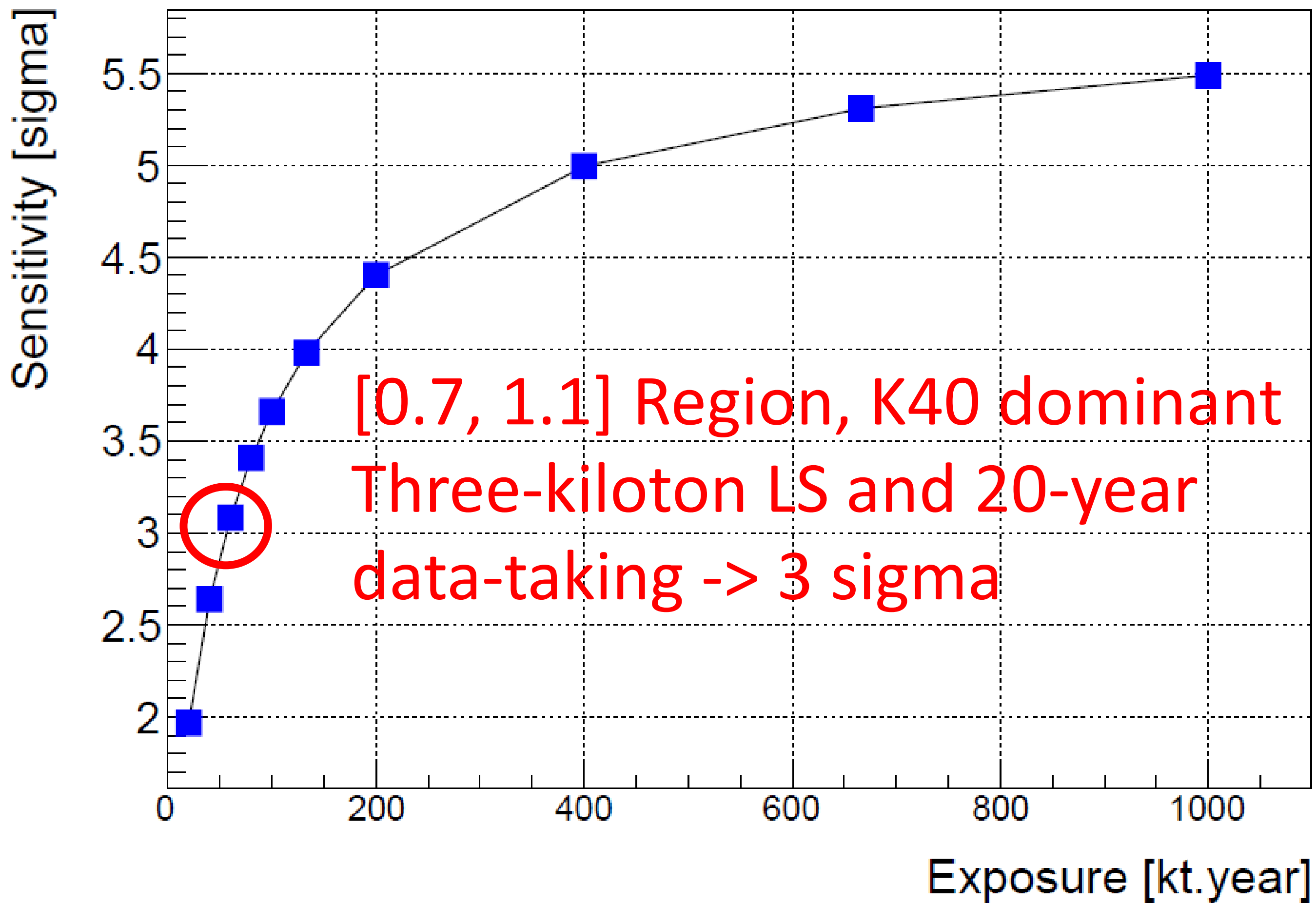
1% for solar at future Jinping Neutrino Exp.

5% for U+Th geoneutrinos at future Jinping too.

σ_{ϵ}: Detection efficiency error, 1% based on our experience (energy cut and $\cos\theta$ cut)

K-40 Geoneutrino Signal uncertainty

$$\text{sensitivity} = N_{geo}/\sigma_{geo}$$



The sensitivity U, Th window is poor.

Concerns and Thoughts

1. For LAB, the transmittance may not be satisfying, because its scintillation lights peaks at 340 nm and the 2/3 acceptance is difficult because of attenuation

2. Other backgrounds. Reactor background is not an issue at Jinping. Radioactive background is not intrinsic as solar neutrino background and hope purification can help.

3. The concept is using all the best expected detector performance, QE, PMT coverage, running time, and site.

4. The density cause the poor angular resolution, but, unless it's changed to gaseous state, it won't change much. Then we still need a fare amount of gas and fine readout system. Or other techniques.

Conclusion

1. Direction measurement helps, although still difficult.

2. K-40 geoneutrino detection is promising. 3 kton and 20 years for 3 sigma

Recently Steve Biller told me he may have a better slow LS.

Thank you.