PO-02:

Solar neutrino observation based on fluoride scintillation crystals

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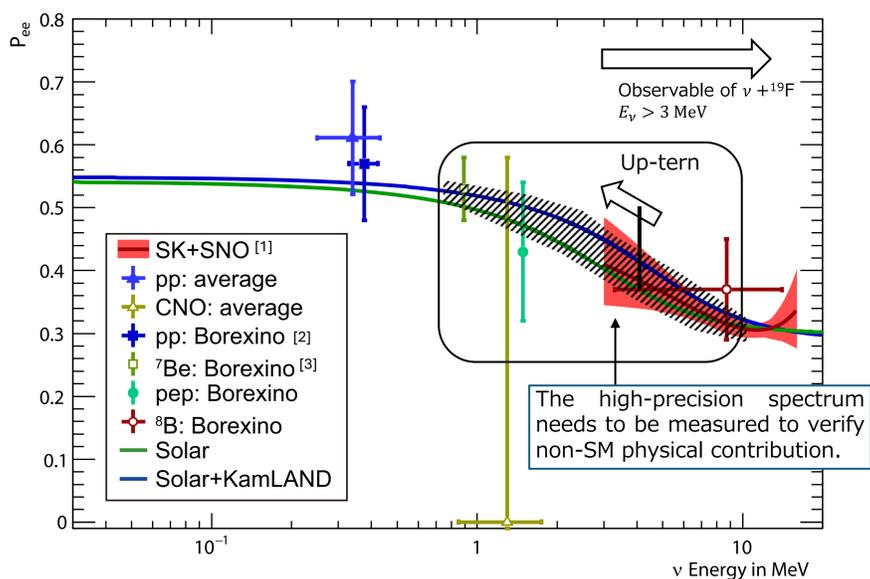ICRC 2025 - The Astroparticle Physics Conference

Abstract

We propose to develop future detectors to verify the MSW effect on the oscillation in **solar neutrinos based on the fluoride scintillation crystals**. Fluorine-19 captures electron neutrinos, then produces a ^{19}Ne and an electron. The Neon-19 decays with a half-life of 17 sec and emits a positron. The positron forms positronium and emits annihilated 2γ. In other words, using a pixelated detector design and the coincidence techniques for the four particles, the electron-neutrino events can be identified with strong evidence [...] the feasibility of solar neutrino observations with fluoride scintillation crystals. We will de[...]

1. Introduction (MSW effect)

The number of measured the os[...] survival probability [...] above a few MeV [...] effect), and the p[...] resolution measure[...]

図1. 太陽 ^{8}B および hep ニュートリノ

hep は ^{8}B の終端に埋もれてしまう

The high-precision spectrum needs to be measured to verify non-SM physical contribution.

Legend:
- SK+SNO [1]
- pp: average
- CNO: average
- pp: Borexino [2]
- ^{7}Be: Borexino [3]
- pep: Borexino
- ^{8}B: Borexino
- Solar
- Solar+KamLAND

2. New Sense to detect ν_e capture even[...]

The reaction of the electron neutrino captured in ^{19}[...] follows:

$$\nu_e + {}^{19}\mathrm{F} \to e^- + {}^{19}\mathrm{Ne};$$
$$^{19}\mathrm{Ne} \to {}^{19}\mathrm{F} + e^+ + \bar{\nu}_e;$$

which the ^{19}Ne has 17s half-life.

$^{19}\mathrm{F} \to {}^{19}\mathrm{Ne}$

$^{19}\mathrm{Ne} \to {}^{19}\mathrm{F}$

511 keV γ
511 keV γ

The ν ^{19}F **cross section is large** (1.7×10^{-42} cm^2 for $\mathrm{E}_{\nu_e} > 3$ MeV) and the inorganic crystals are expected to have high energy resolution due to their large emission[4–5].

However, solar ν observation with ^{19}F was difficult and unfeasible in the traditional design. A reason why not been achieved is accidental noise events caused by natural impurity radioisotopes.
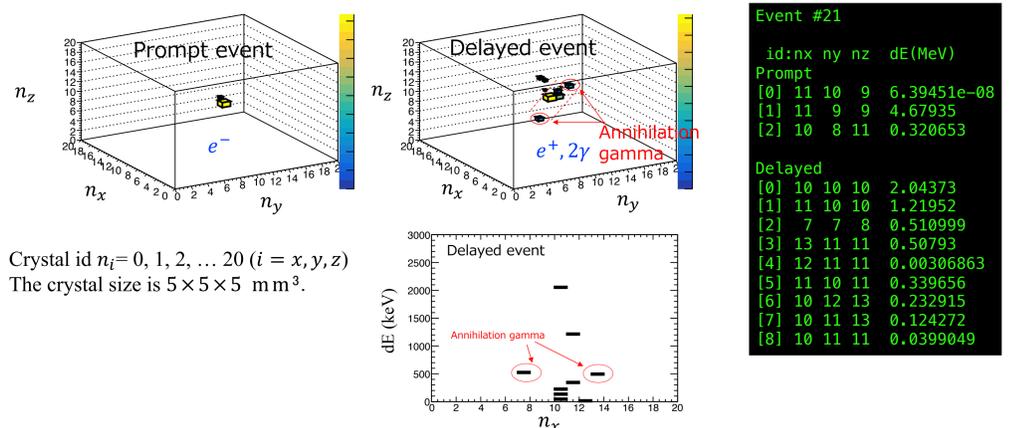
A new technique (the four-particle coincidence measurement) has the potential to strongly suppress background events, such as the radio-impurities in the crystals.

[Simula]tion

We have simulated the events of $\nu_e + F$ capture based on the GEANT4 toolkit. Typical event display of track is shown here, where the material is assumed to be a CeF$_3$ crystal ($\rho\sim6$ g/cm^3).

Case of Crystal: $\rho\sim6$ g/cm^3 CeF3
γ (511keV)
annihilation
γ (511keV)
e^+ (aft. T$_{1/2}$=17s)
e^- (prompt)
vertex
GEANT4.11.0

$T_{1/2}$ = 17.257 sec

The observable typical event display is shown here in the case of $5\times5\times5$ mm^3 crystal array. Note w.o. energy resolution.

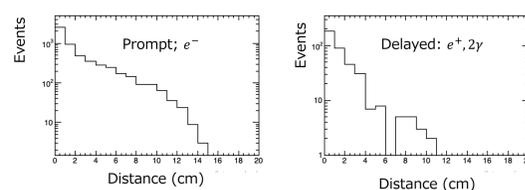Prompt event — e^-
Delayed event — $e^+, 2\gamma$ — Annihilation gamma

Event #21
id:nx ny nz dE(MeV)
Prompt
[0] 11 10 9 6.39451e-08
[1] 11 9 9 4.67935
[2] 10 8 11 0.320653

Delayed
[0] 10 10 10 2.04373
[1] 11 10 10 1.21952
[2] 7 7 8 0.510999
[3] 13 11 11 0.50793
[4] 12 11 11 0.00306863
[5] 11 10 10 0.339656
[6] 10 12 13 0.232915
[7] 11 11 13 0.124272
[8] 10 11 11 0.0399049

Crystal id n_i = 0, 1, 2, ..., 20 ($i = x,y,z$). The crystal size is $5\times5\times5$ mm^3.

17秒前

511 keV γ

Delayed event
Annihilation gamma

[Evalu]ation

Spread distance for e+, e−, and 2γ

Prompt; e^-
Delayed; $e^+, 2\gamma$

The particles can spread up to 15 cm in crystal ($\rho\sim6$ g/cm^3), so candidate events with four particle coincidences can be selected within that area.

Detection efficiency

100,000 events of e^- and e^+ (aft. 17s) are simulated w.o. energy resolution.
Two 511-gamma events detected
7336 / 100,000 ($\varepsilon\sim0.073$)

Two 511-gamma events detected and clusters are distant each other
3538 / 100,000 ($\varepsilon\sim0.035$)

Energy resolution

The resolution depends on the light yield of the crystals. The light yield and resolution for 511 keV and 1 MeV are calculated and summarized in the table for the candidate crystals. Note: assume PMT QE of 25%.

Crystal	Yield (ph./MeV)	σ(3MeV)
CeF$_3$ ($\rho\sim6.16$ g/cm^3)	~10,000	3~6%
CaF$_2$ ($\rho\sim3.2$ g/cm^3)	~16,000	~2%

Background

The expected main background is radiations emitted from the impurities in the crystal. The impurities concentration will be measured by HPGe detector, so on. Then, crystal purification should be done.

Results and Summary

This study introduces a new method to measure solar neutrinos based on fluoride crystals using the four-particle delayed coincidence technique. We estimated the performance based on simulations. Based on the results, we plan to develop a small detector and begin with performance tests on the ground level.

Reference

[1] Phys. Rev. D **109**, 092001 (2024).
[2] Nature **562**, 505 (2018).
[3] Phys. Rev. D **108**, 102005 (2023).
[4] Nucl. Phys. B **28A** (1992) 496.
[5] Nucl. Phys. B **35** (1994) 461.