Sensitivity of SciBar Cosmic Ray Telescope (SciCRT) to solar neutrons


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Particle acceleration by solar flares

- Particles are accelerated to
  - a few 10 MeV for electrons
  - a few GeV for ions

Energy release by solar flares (Magnetic reconnection)

Masuda flare observed by Yohkoh

Attenuation of neutrons in the atmosphere
S. Shibata, JGR 371 (1994) 495
Energy spectrum of solar neutrons

Stochastic acceleration

![Stochastic acceleration graph]

- $\alpha$: 3~4

Shock acceleration

![Shock acceleration graph]

- $\alpha$: 1~2

The production rate of solar neutrons at the solar surface
How to estimate the energy spectrum of solar neutrons?

The count rate of neutrons is registered with four different levels of thresholds (30, 60, 90, and 120 MeV).

The difference of arrival time: \(\Delta T\) -> Energy of neutrons

Rough estimate of the energy spectrum directly

But only two events have registered thus far (2005 Sep 7th, 2014 July 7th)

We need more events with large statistics without any assumption!
SciBar Cosmic Ray Telescope (SciCRT)

SciBar detector
- developed for neutrino oscillation experiments (K2K SciBar detector)
- fully active scintillator tracker
- fine segmentation (~15,000ch)

Purposes
- observations of solar neutrons*
- observations of muons for studying anisotropy of GCRs

Status-> M. Anzorena [683][SH113]
- deployed at Mt. Sierra Negra, Mexico
- 3/8 started operation from Sep, 2013
- 1/8 of Back-End Boards was newly upgraded in July, 2015
- Analyze the particle identification-> R. Garcia [1094][SH112]
- further upgrade of front-end electronics-> M. Anzorena [1083][SH111]
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Detector volume
: 15.3 m³

Detector diagram:
- Scintillator bar
- MAPMT
- WLS fiber
- neutron
- proton
- X side
- Y side

X side and Y side data plots:
- Color scale for data visualization

* denotes additional information or emphasis.
Development of new fast readout BEBs

- Many background neutrons induced by CRs at such a high mountain (4,600 m)
- The dead time of the DAQ system of the SciBar detector limits the efficiency of data acquisition.
- We produced new fast readout (10 times faster) Back-End Boards (BEBs) using SiTCP.


It enables us to discuss about the original capability of SciCRT. Hereafter, we assume that new BEBs are applied to 4/8 layers.
Solar neutrons

Atmospheric attenuation for solar neutrons: Shibata model

Background cosmic-ray estimation: PHITS (Particle and Heavy Ion Transport code System)

Force field potential: 750 MV

Vertical cutoff rigidity: 8 GV

Detector simulation: Geant4

SciCRT

Mt. Sierra Negra

Earth's atmosphere

Impulsive emission or Duration emission

Space

Sun

MC simulation

4/8 layers + New DAQ system

Mexico SNT
Energy spectrum reconstructed by energy deposit

Fixed power law index

It is possible to divide the impulsive emission and 8 min emission. How about the impulsive and 5 min?
It is possible to resolve the degeneracy problem between the energy and arrival time of neutrons.


**Conclusion**

- Solar neutrons have been observed for studying the acceleration mechanism of ions in association with solar flares.
- SciCRT is motivated to observe solar neutrons with high statistics and to determine the energy spectrum.
- New fast readout BEBs were deployed into 1/8 layer.
  - We will install new BEBs to the rest 3/8 layers in the near future.
  - Further improvement of the sensitivity could be made by deployment of new FEBs to other 4/8 layers. M. Anzorena [1083][SH111]
- SciCRT has a capability to resolve the degeneracy problem between energy and arrival time of neutrons.
Back up
Time profile and energy deposit

Counts/120 sec

Power law + duration
-3.4 + 0 min
-3.4 + 5 min
-3.4 + 8 min
-4.0 + 0 min
-4.0 + 5 min

200 MeV cut criteria

Time (sec)
Separation between neutrons and gamma rays

Total deposit energy vs maximum energy deposited in one segment (Y. Nagai, doctoral thesis)
The most significant Solar Neutron Event in 2005 September 7

The count rate of SNTs deployed in Mexico (Neutral 30, 90 MeV) and Bolivia (Neutral 40, 80 MeV)

- Detected by four detectors: Mexico SNT, Mexico NM, Bolivia SNT, and Bolivia NM.
- Ions are continuously accelerated or trapped in the flare loop.

This event puts constraints on the production time of solar neutrons. We need more events like this!
It is possible to discriminate the difference of the power-law index 0.1.

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$\chi^2$/n.d.f

Assuming impulsive emissions

Counts / 1060 sec

Energy (MeV)