Solar Neutron Decay Protons observed on November 7, 2004

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—Bolivia·Japan·Mexico (BJM) solar neutron collaboration--

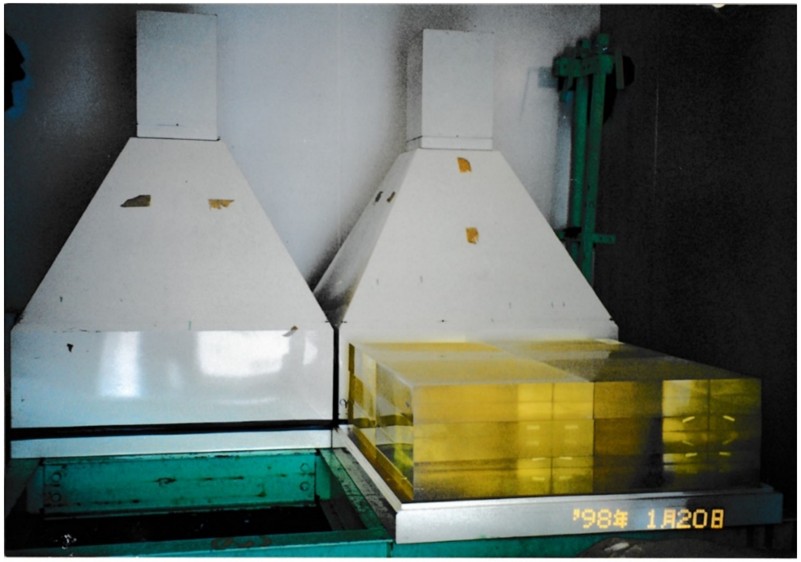
Abstract

In association with X2.0 solar flare on November 7, 2004, we have found an event of solar neutrons and a possible solar neutron decay proton event. Here we report the results of analysis.

Next slide shows our SNT; how to catch neutrons and gamma-rays.

2021.7.16 @ ICRC2021_1264.pdf

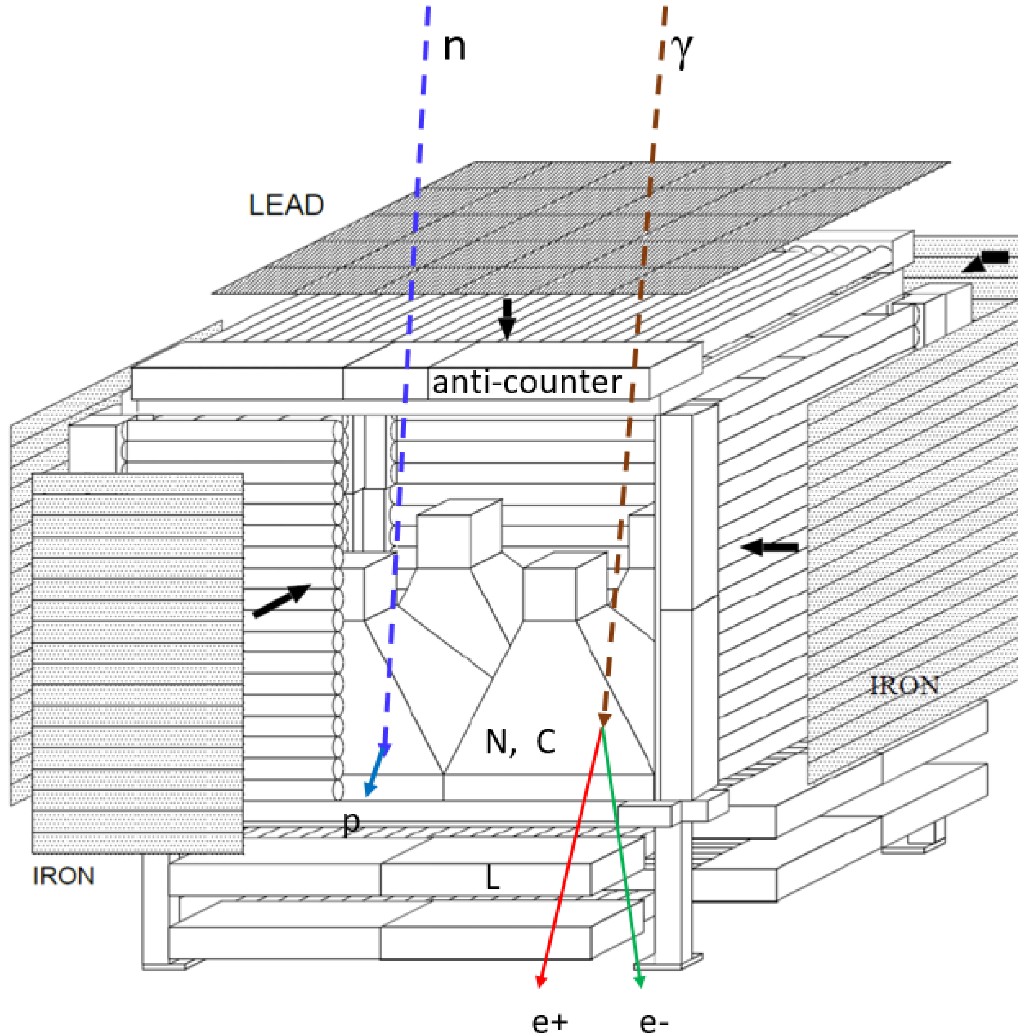
1. The Solar Neutron Telescope located at Mt. Sierra Negra



Incident neutrons and gamma-rays are converted into protons and e^+e^- in the thick plastic scintillator.

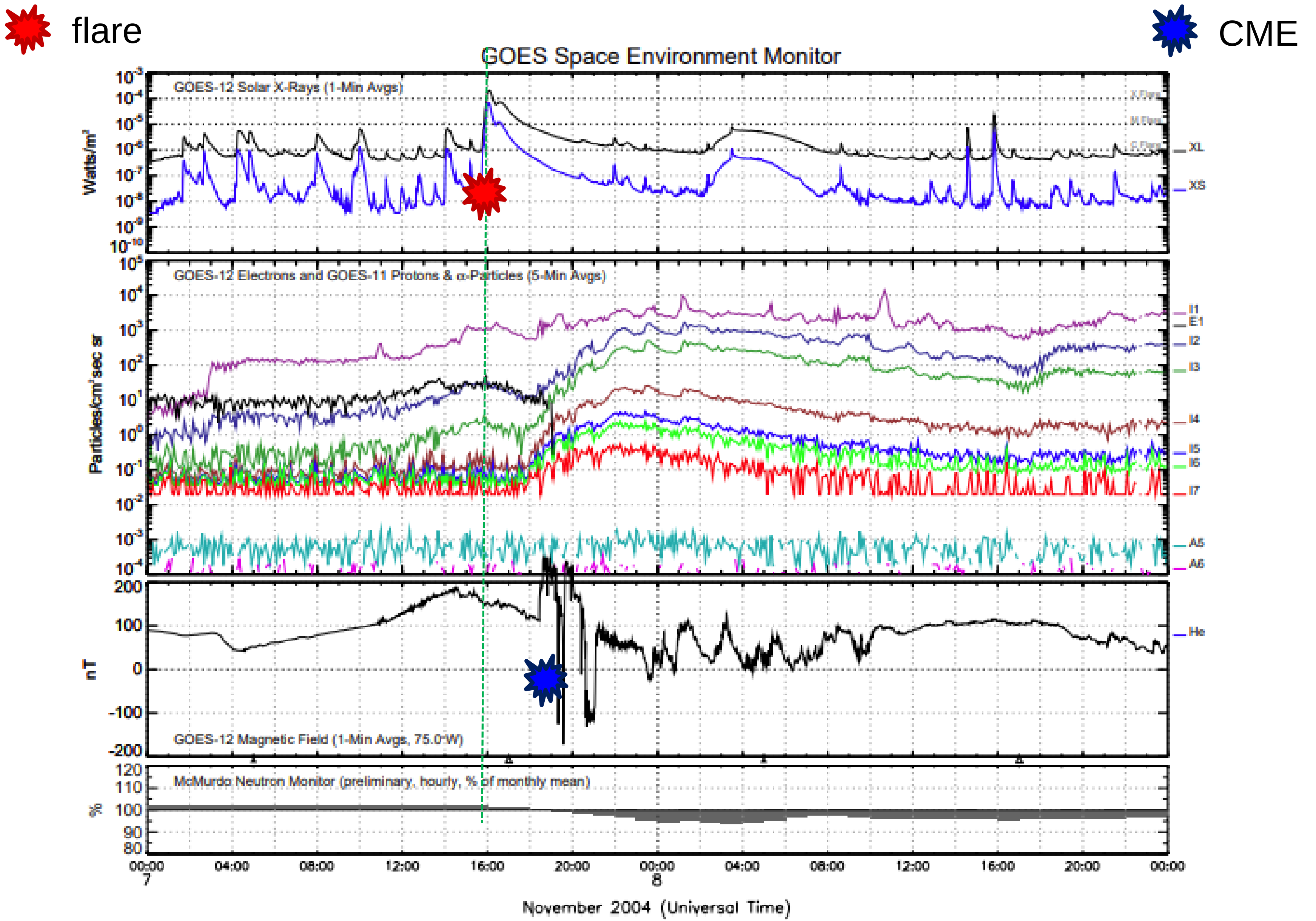
The energy calibration was made by muons.

Identification between charged particles and neutral particles can be made by the anti-counter. Above the anti-counter, 5mm thick lead plate was installed.

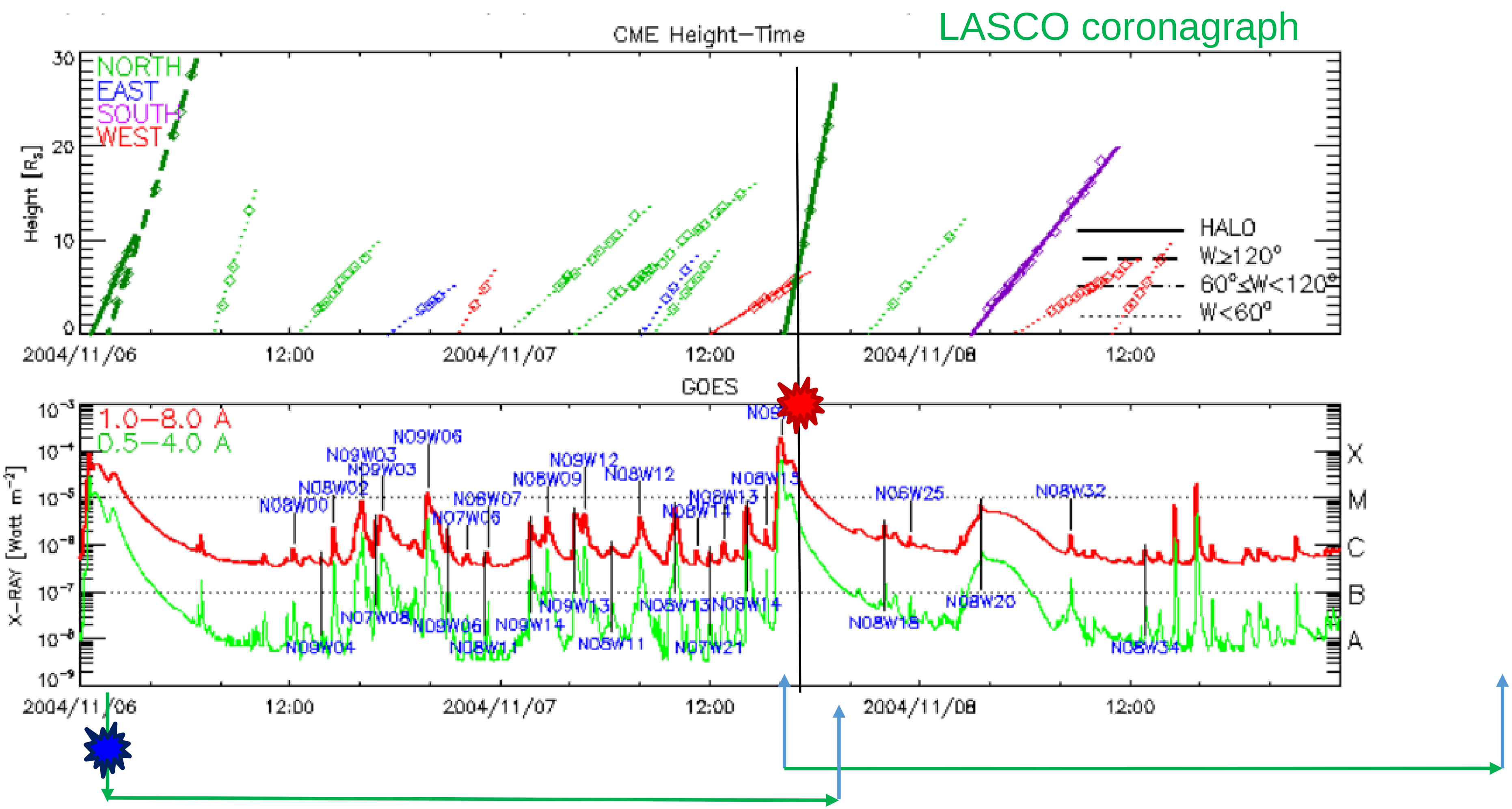


The next slide shows general feature of the solar-terrestrial environment around November 7-8th of 2004

Solar Terrestrial Environment around 2004.11.7-8 based on GOES data



SOHO CME data on STE space



FD start 18:27UT

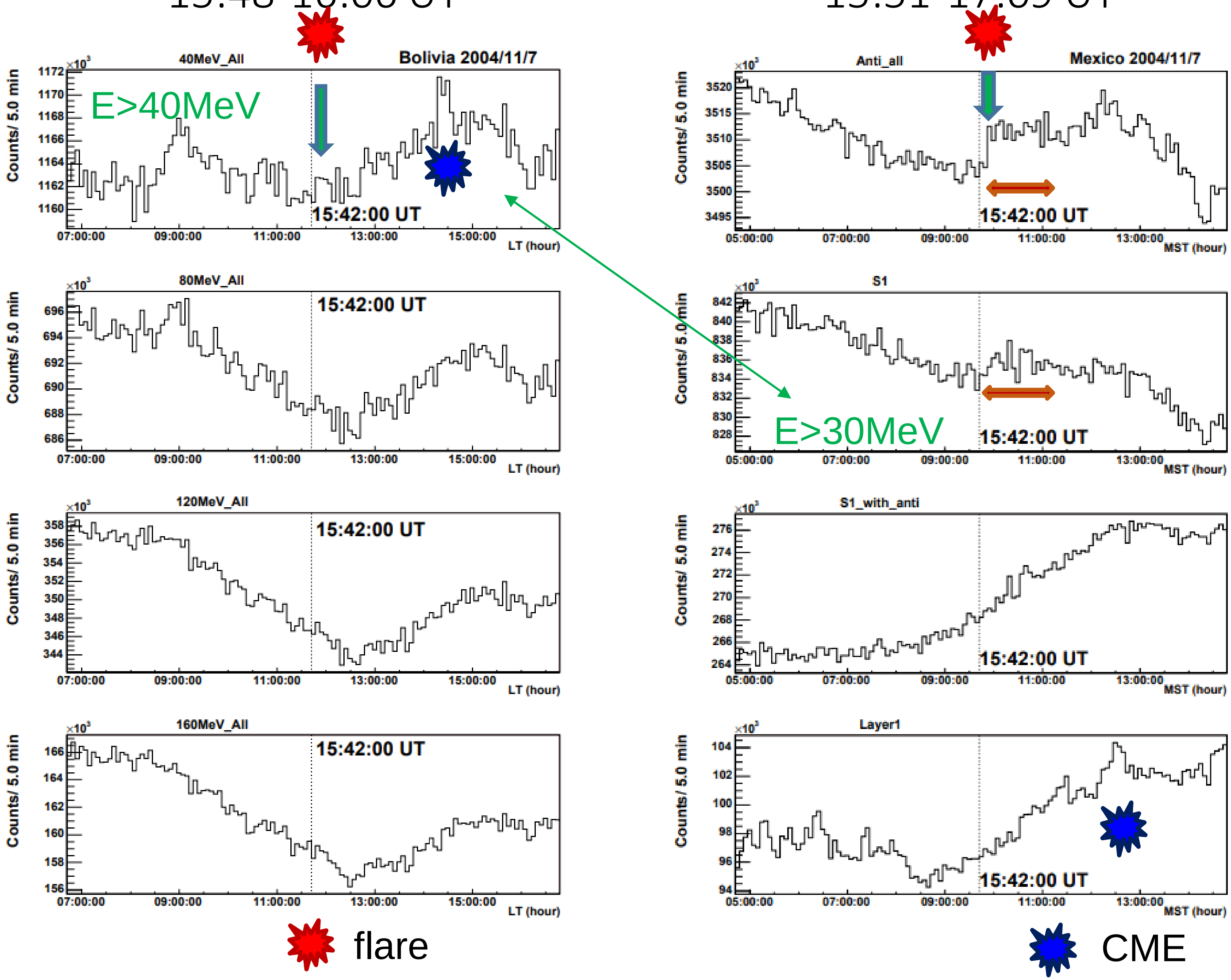
FD start

The origin of the CME1 was produced by the M9 flare one day before.

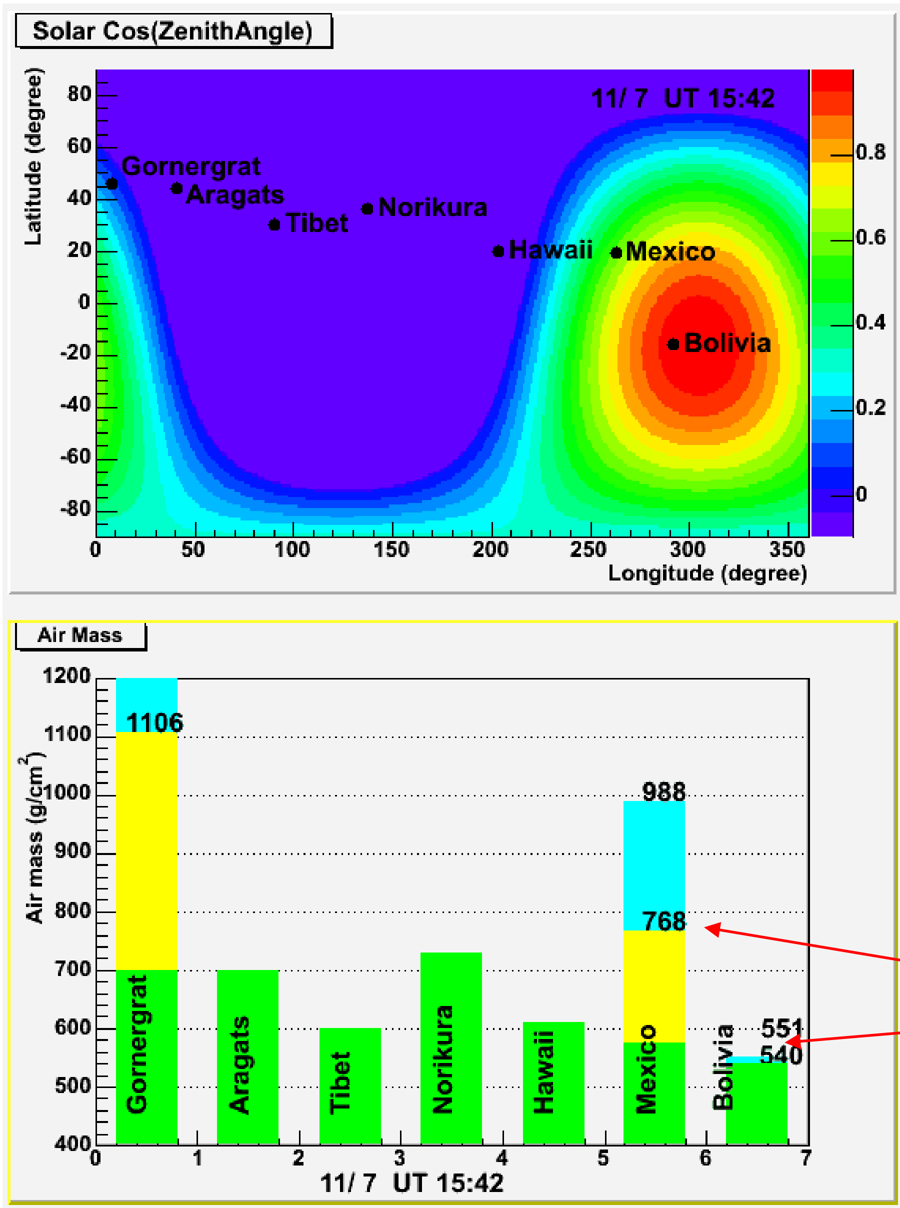
2. Data (5-minute-value)

Bolivia(~20 min.) 15:48-16:06 UT

Mexico (~78 minutes) 15:51-17:09 UT



The observation condition of neutrons around 15:48UT



The sun was just over Bolivia at the flare time. The pressure difference between Sierra Negra and Chacaltaya was ~200g/cm^2.

Therefore, the flux over Mexico should be less than <1/10. However the fluxes are observed with nearly equal intensity. So the event of Sierra Negra could not be explained by

→ Arrival of neutrons.

→ We need another explanation,

→ maybe, protons arrivals.

Bolivia E>40 MeV

Mexico E>30 MeV (S1-channel)

200g/cm^2

Let us at first to get neutron intensity observed at Chacaltaya.

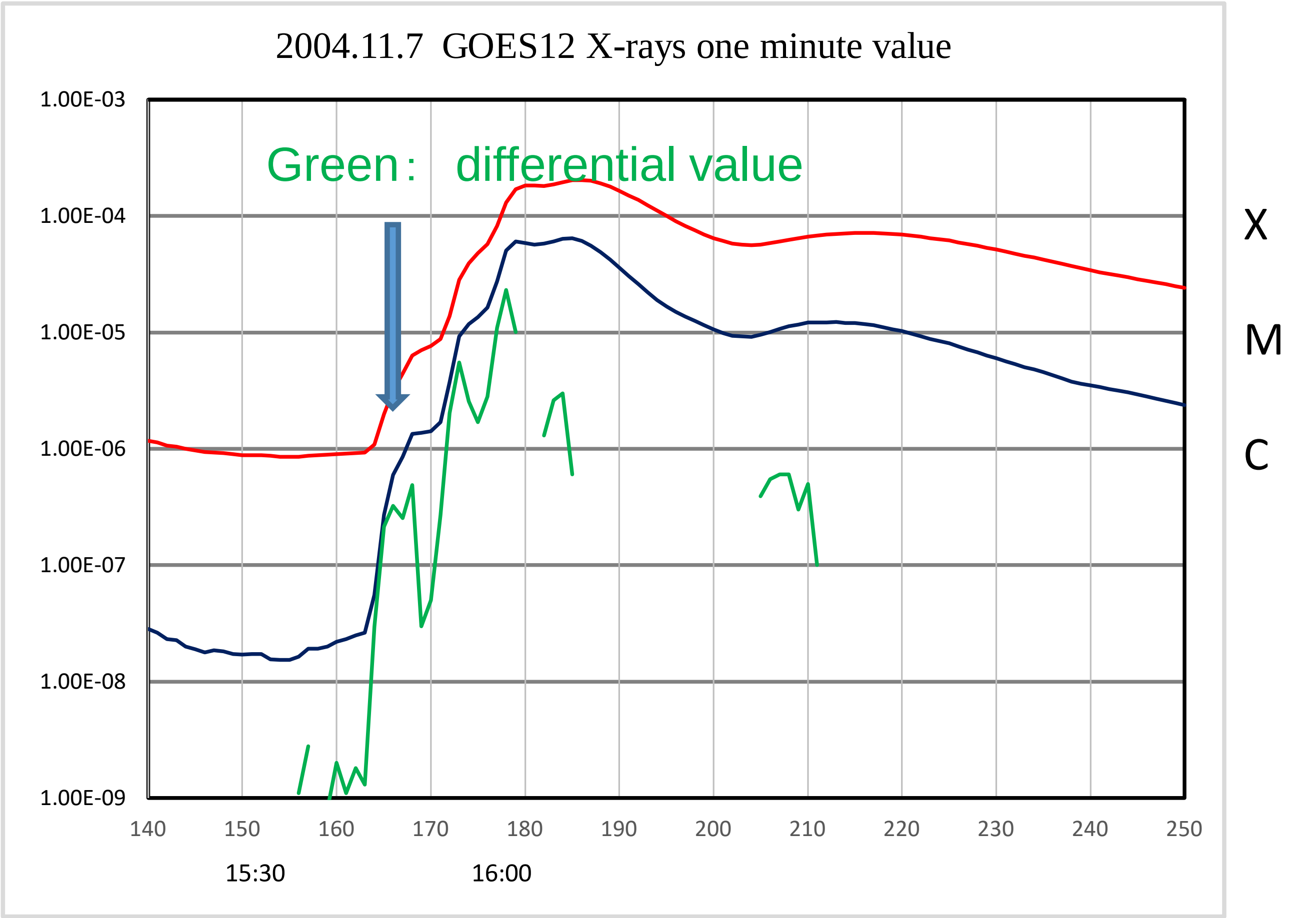
Obtaining the differential energy spectrum of solar neutrons

Since we will determine neutron energy spectrum by the time of flight method, we need an information of the production time of solar neutrons.

We assume that these neutrons were produced instantaneously.

The start time will be determined by the X-ray data.

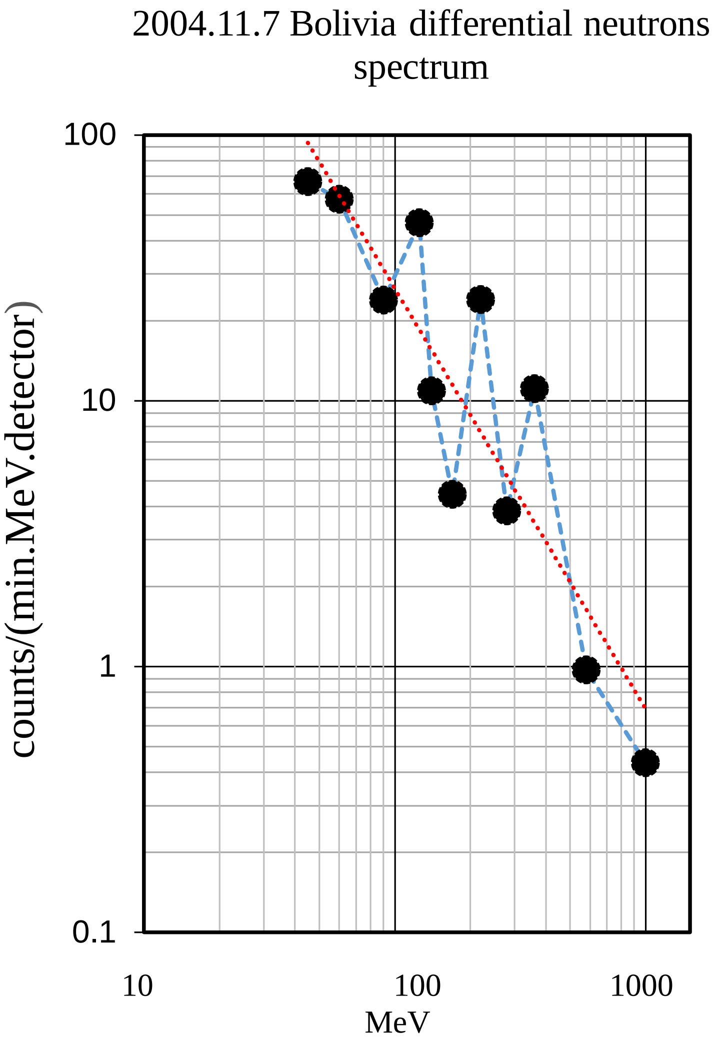
3. GOES X-rays: 1-8Å, 0.5-4Å, derivative one minute value



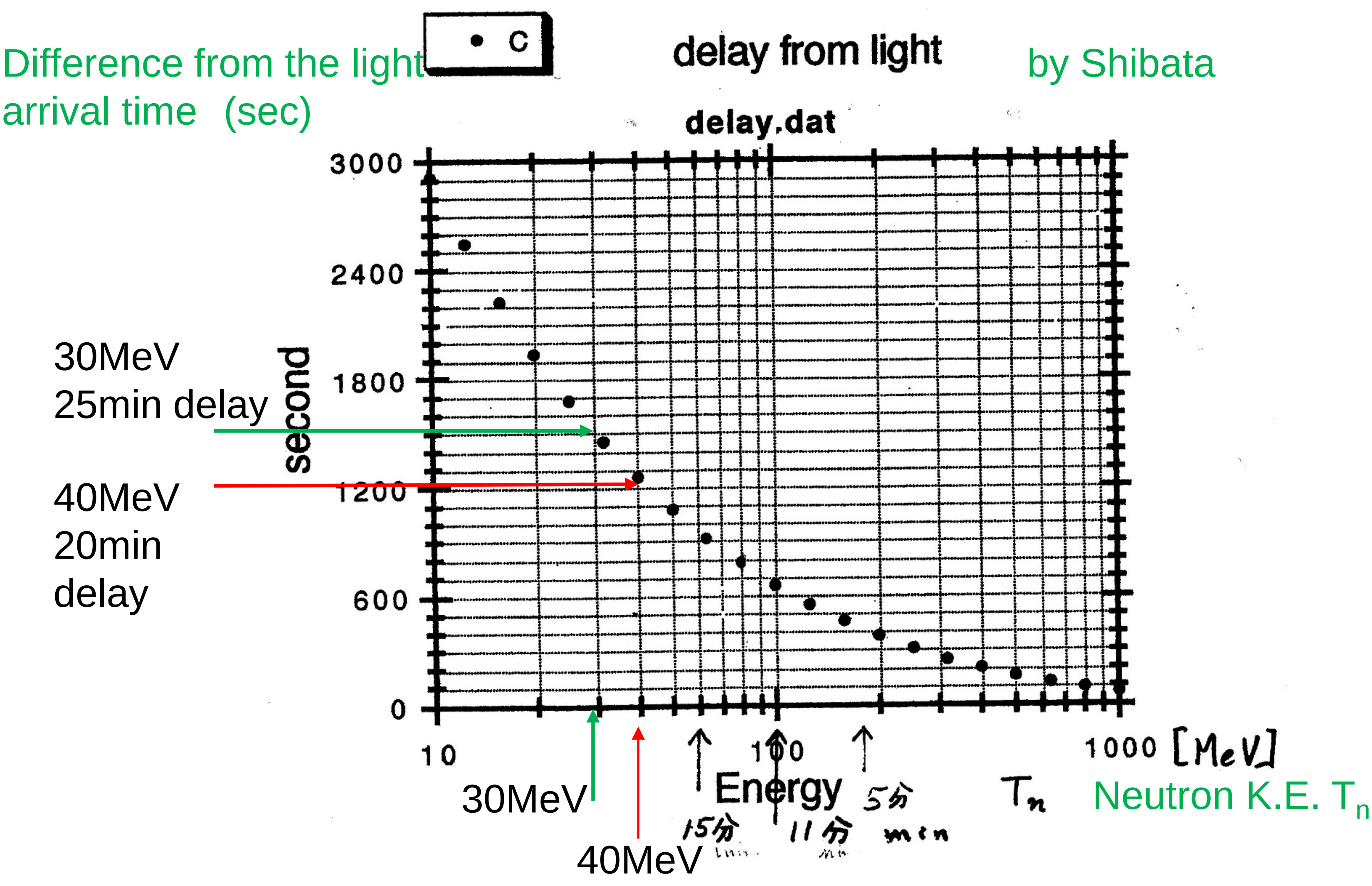
Assumption on neutron production

We assumed the production time of solar neutrons at 17:47:00UT, when the derivative shows the maximum.

And the energy was determined by the flight time method.

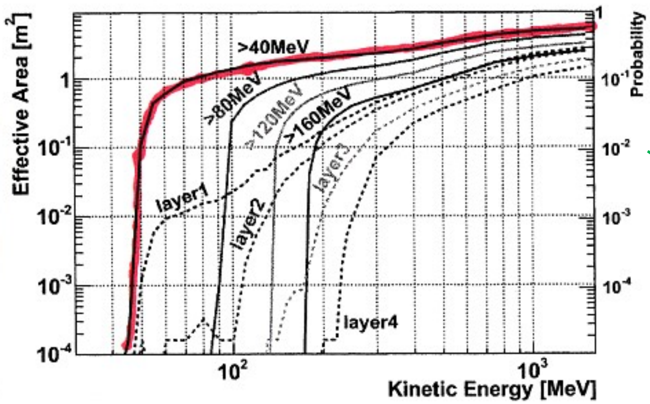


Relation between energy (En) and flight time

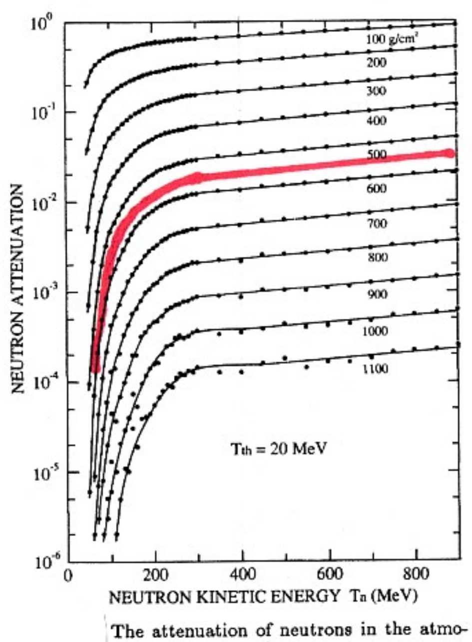


After, we apply two correction factors in order to get the flux at the top of the atmosphere.

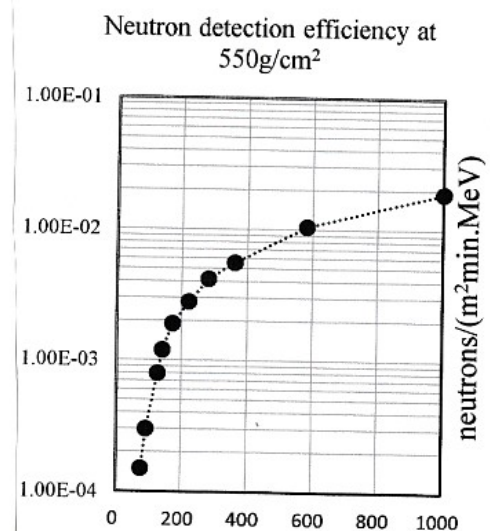
Detection efficiency (Watanabe)



Attenuation in the atmosphere (Shibata)



Combined correction factor

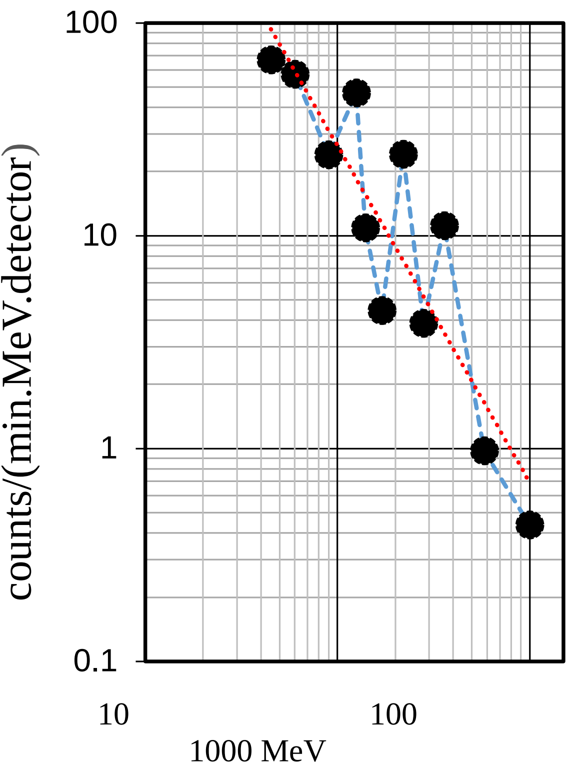


The stream of the conversion

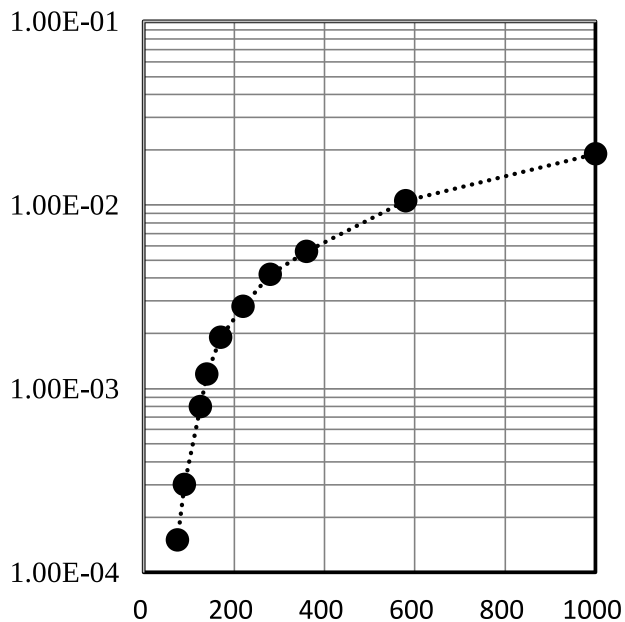
Ground

Top of Atmosphere

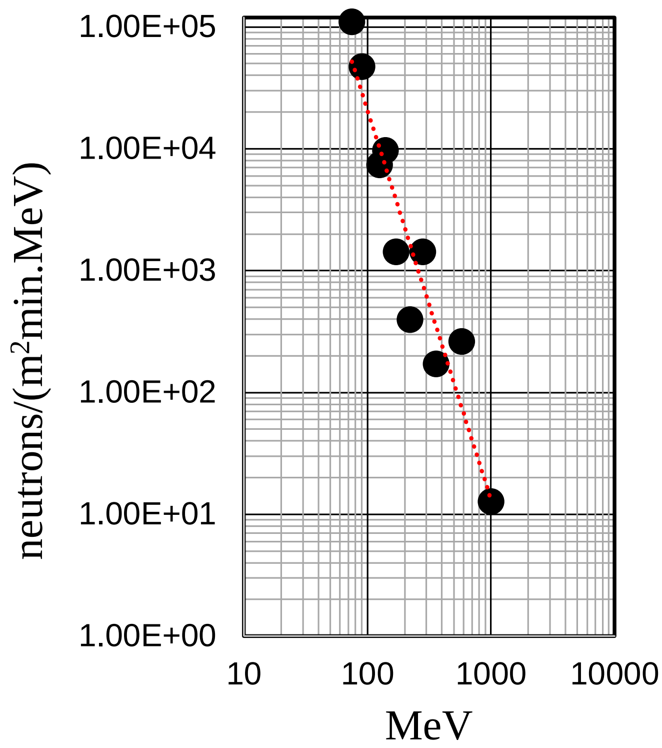
2004.11.7 Bolivia differential neutrons spectrum



Neutron detection efficiency at 550g/cm^2



Differential energy spectrum at the top of atmosphere



Raw data

Correction data

Final spectrum

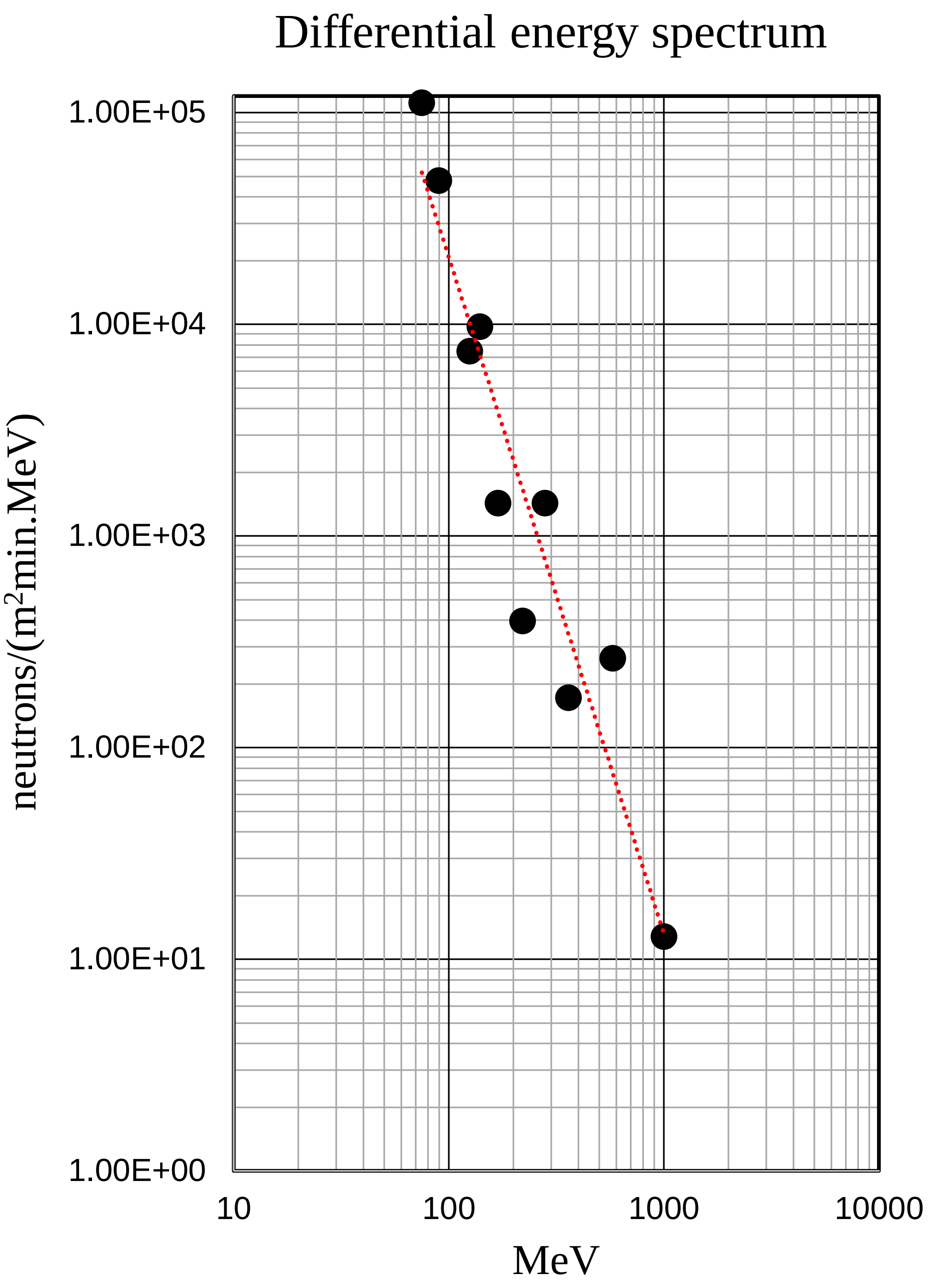
4. Energy spectrum

Differential energy spectrum of solar neutrons observed in November 7, 2004 at Chacaltaya can be expressed by a simple power law with the power index of -3.3

Assumption:15:47 UT start

Red line presents

$E_n^{-3.3} dE_n$



5. How to explain the signals recorded by Mt. Sierra Negra SNT?

In order to understand this problem, we have performed a simulation based on the GEANT4 code.

We have investigated the expected observed ratio of the flux between anti-counter (>2MeV) and S1 channel (>30MeV). We also calculated the attenuation of neutron intensity with energy higher than 30 MeV and gamma-ray intensity to the proton incident.

(>2MeV (anti counter)) / (> 30MeV (S1 channel)

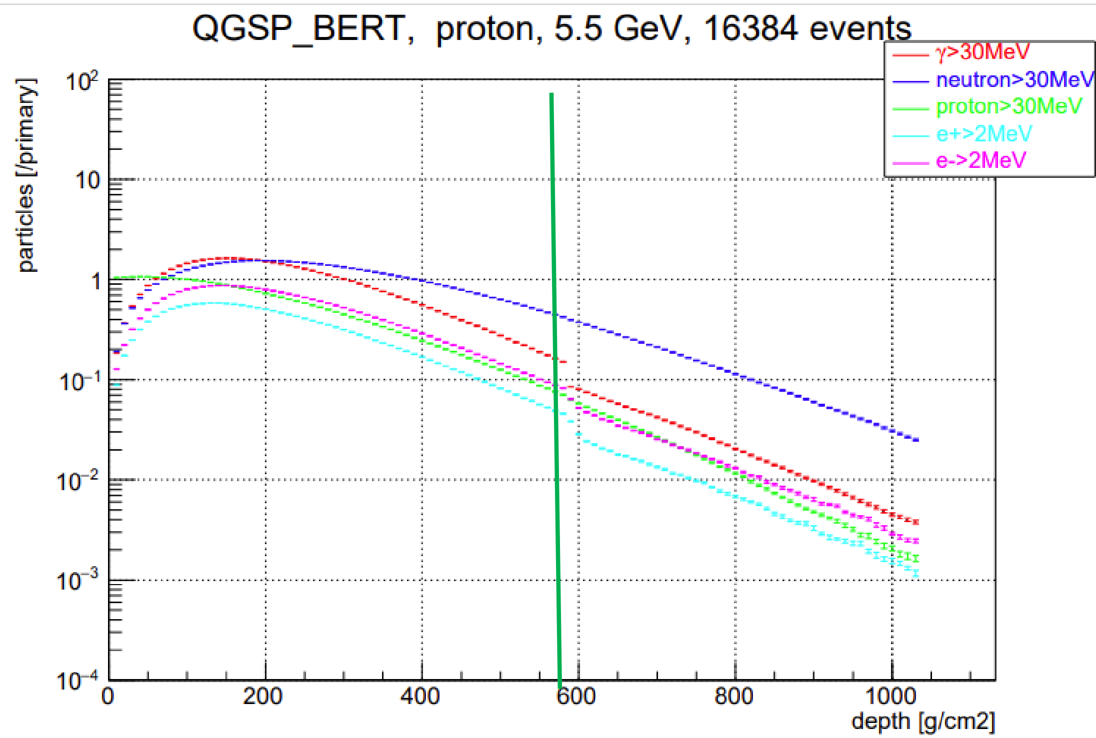
n / γ (>30MeV)

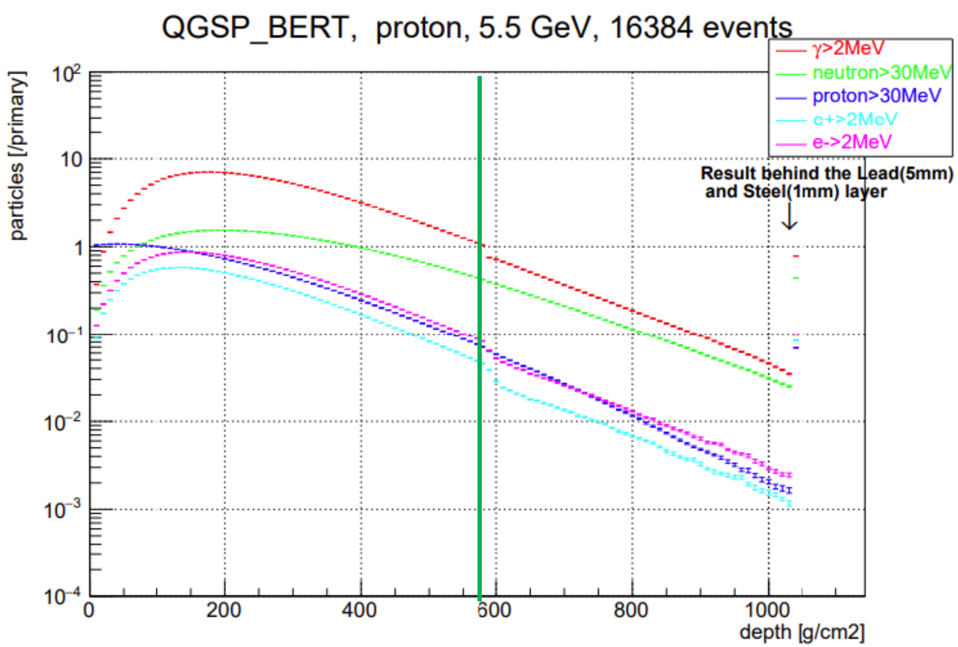
Next slides show the results.

The results are very consistent with the observed results that incident particles over Sierra Negra must be protons with the energy of 4~7 GeV.

GEANT4 simulation results

Right side slide shows proton → incident and produced high energy gamma rays (red) and neutrons (blue line) (Eγ and *n* >30MeV).





←Left side slide shows proton incident and produced low energy gamma rays (red line) that hit the anti-counter (Eγ>2MeV).

6. Summary of simulation and observation

- The simulation can explain the observed results:
  the ratio (>2MeV γ ; anti-all)/(>30MeV n ;S1)=(2.0±0.7).
  Therefore the incident particles may be protons with the energy
  around ~5 GeV.

- A plausible interpretation on this event is that
  high energy neutrons decay in flight within 10^7km and these
  solar neutron decay protons (SNDP) arrived over
  Mt. Sierra Negra.

- The detection of SNDP at the ground level is
  since Oct.19,1989 event. So this event is
  the second example of the SNDP detected at the ground.

- Thank you for listening. Details please read the text.

See you in Osaka!

7. Discussions--- Ratio of the flux between two data

Neutron intensity at the top of the atmosphere (Chacaltaya)
→ 0.1/(m^2.min.MeV) @5GeV

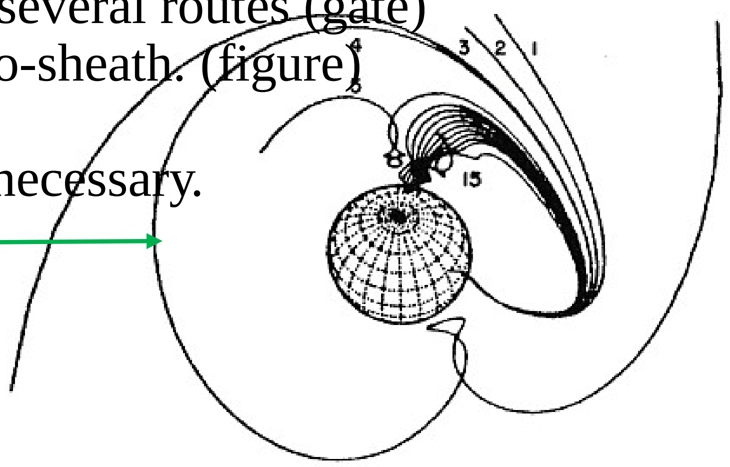
Proton intensity at the top of the atmosphere (Sierra Negra)
→ (0.23 ± 0.02)/ (m^2.min.MeV) @~5GeV

The fluxes are nearly equal, however we must take into account the decay factor of ~5GeV neutrons. The decay rate within 10^7 km is~0.0077 or ~1/130. Therefore the flux is about ~200 times higher than the expected flux from simple optical geometry acceptance hypothesis.

If the effective acceptance area for protons is ~1,000m^2, then, we can explain the flux of Sierra Negra by SNDP hypothesis: they were originating from high energy neutrons.

On the other hand, for protons, there might be several routes (gate) to reach over Mt. Sierra Negra from the magneto-sheath. (figure)

A confirmation by simulations may be further necessary.
(See some of the trajectory calculated by Smart, Shea and Flückiger in 2000)



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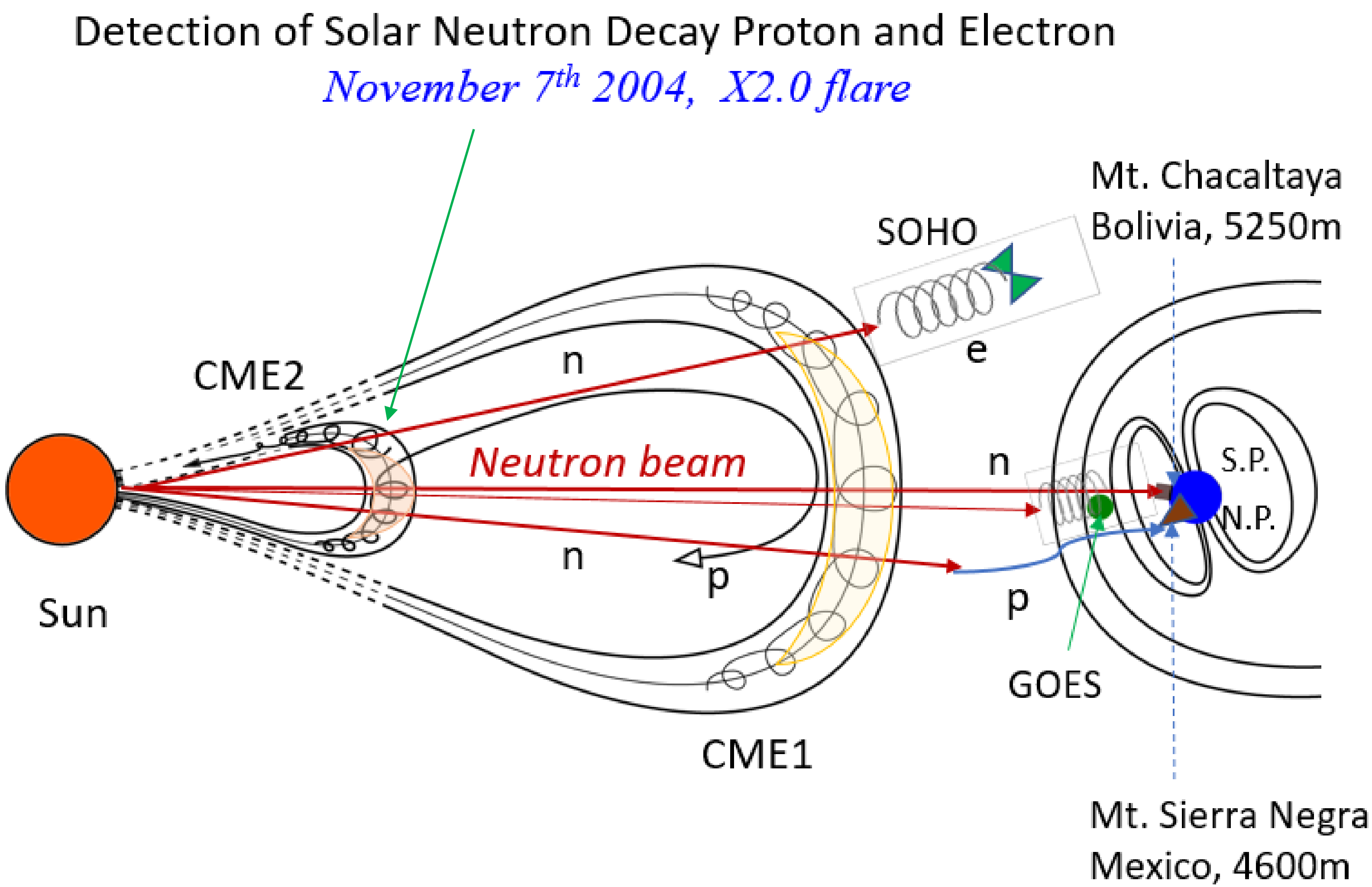
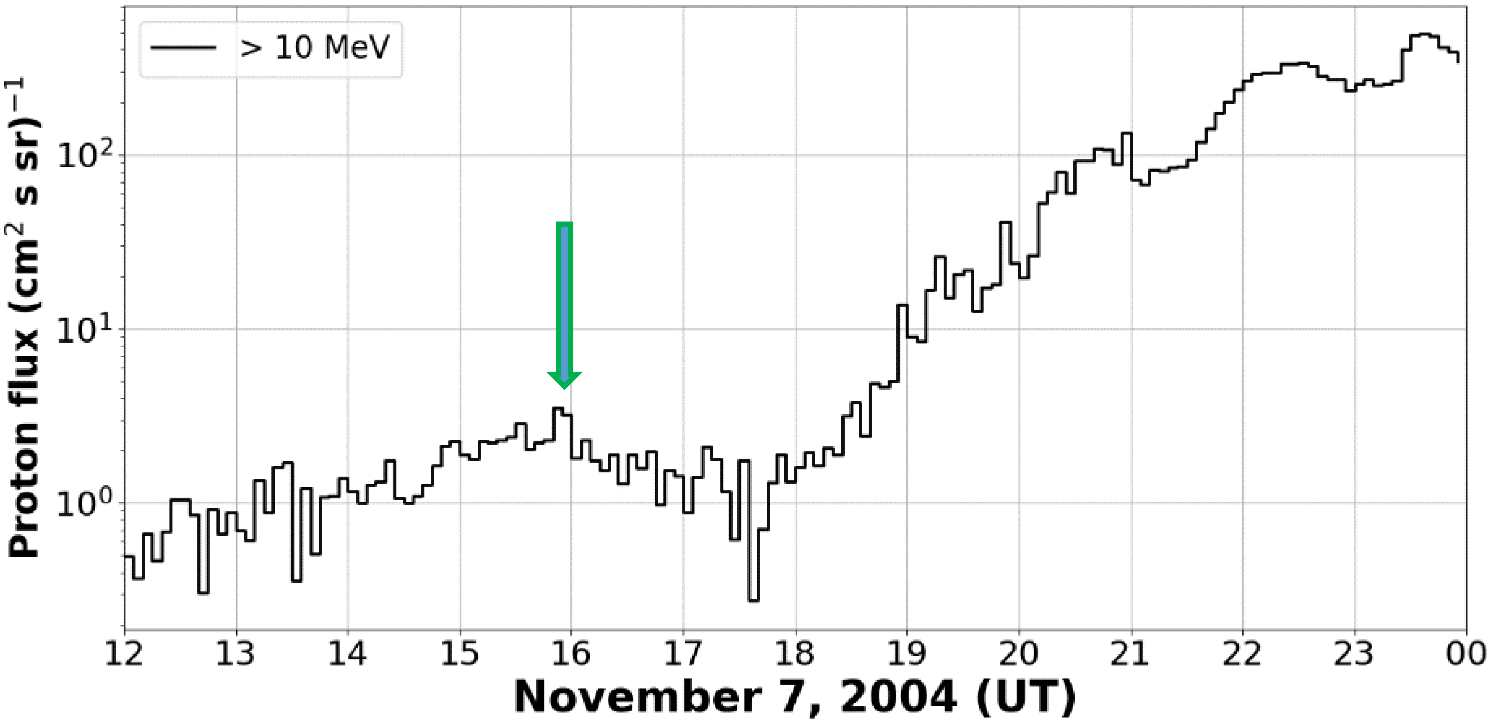
8. Figure of Heliosphere



9. GOES data

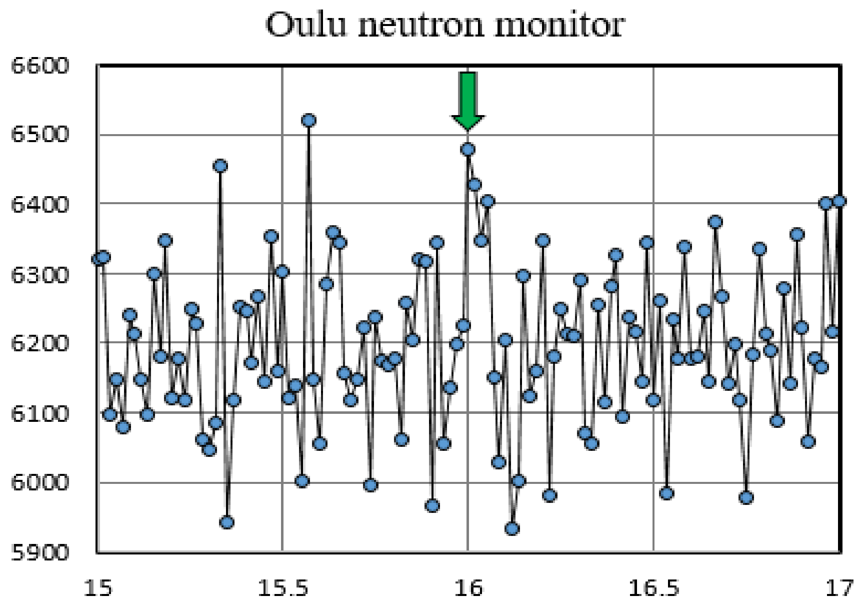
GOES11 proton >10MeV

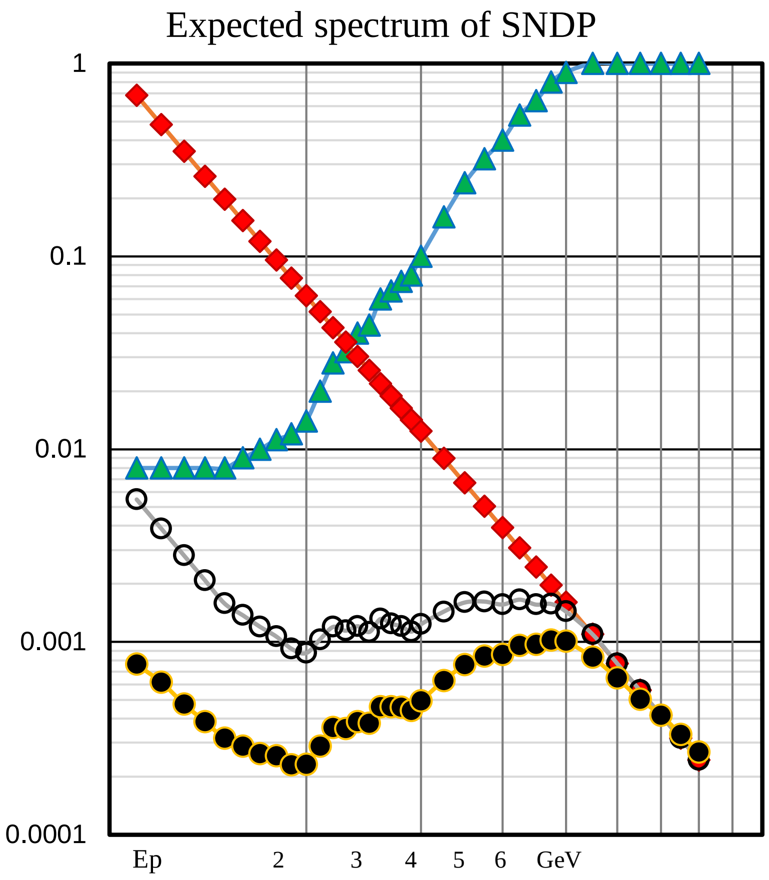
2004.11.7



今回のevent継続時間は~10分である。
1982.6.3 eventは12時間続いた。

Oulu data and rigidity



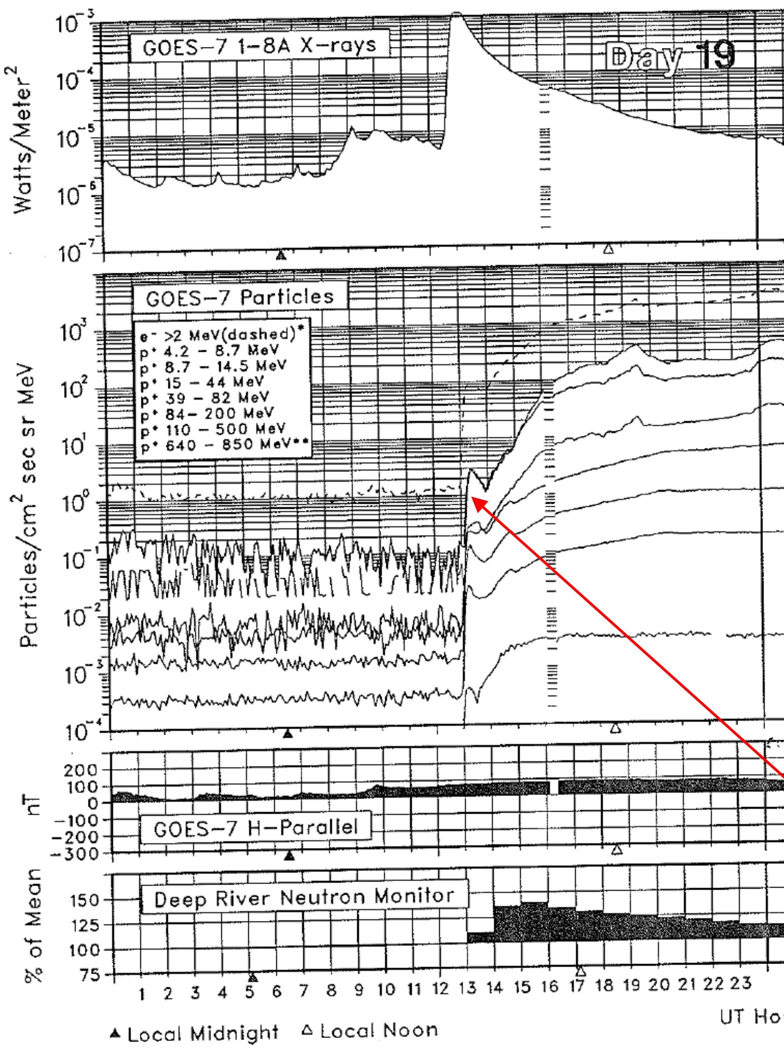


10. Examples of past SNDP (and SNDE)

They are very rare event！

GOES

SOLAR-TERRESTRIA
October



1982 June 3

EVENSON, MEYER, AND PYLE ISEE3 Vol. 274

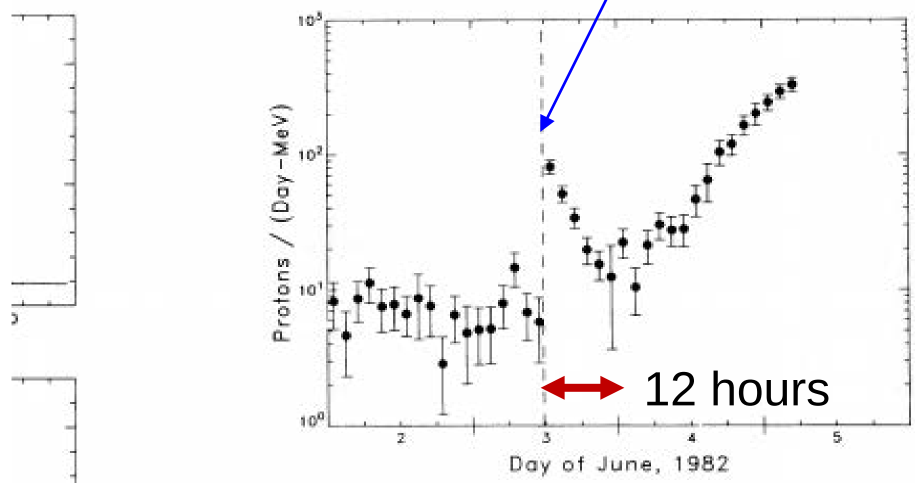


FIG. 3.—The flux of 25–45 MeV protons observed at *ISEE 3*. Two-hour averages are plotted. The gamma-ray arrival time is indicated by a dashed line.

←satellite ground→

1989 Oct. 19

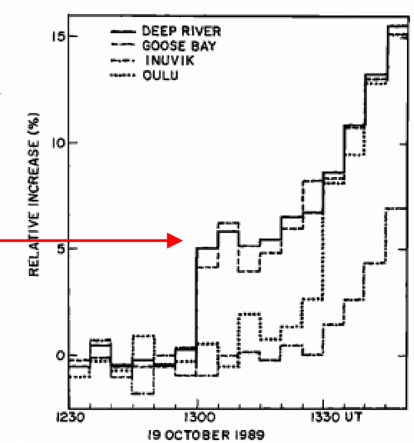
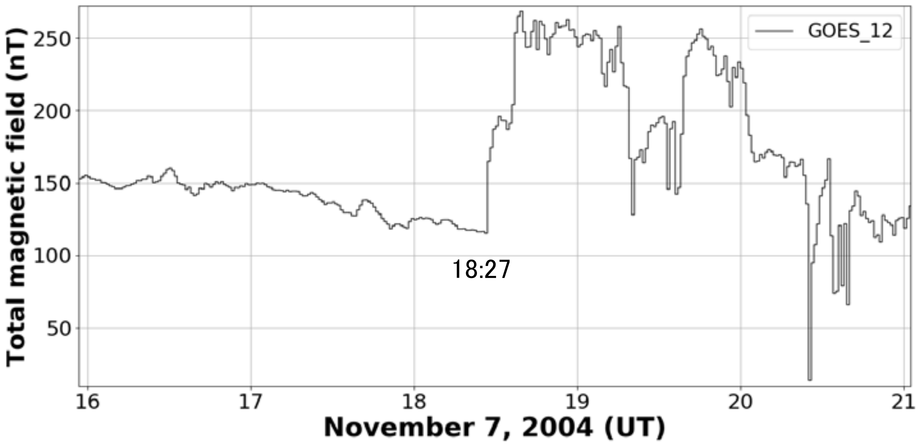


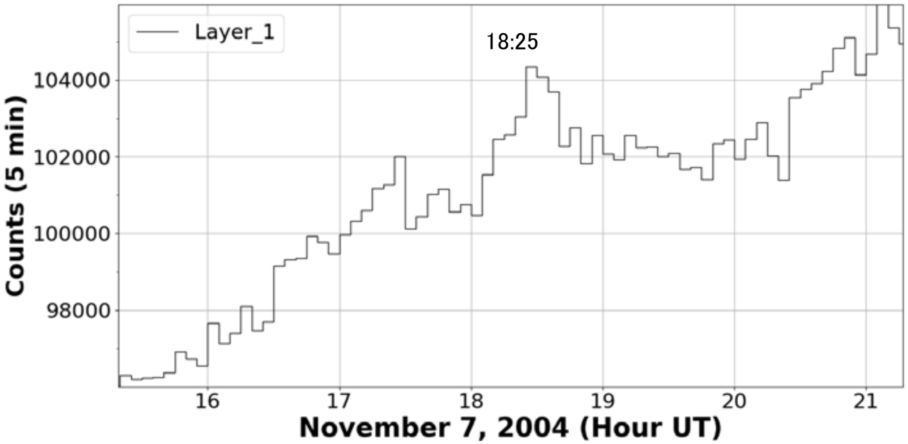
Fig. 2. Relative cosmic ray increase during the onset of the 19 October 1989 relativistic solar particle event observed by the Inuvik, Deep River, Goose Bay and Oulu neutron monitors. The intensity is a percentage above the hourly average background recorded between 1100-1200 UT.

Arrival time of CME at the Earth

GOES recorded IP shock at 18:27 UT.



SNT Mexico recorded an increase at Layer1 between 18:25 and 18:40 UT. SNT Bolivia also recorded an increase at same time in 40MeV-All channel.



By Shea and Smart
vertical axis
Geomagnetic latitude