Search for Supernova Relic Neutrino at Super-Kamiokande

Outline

- Introduction
- Data set & Data reduction
- MC simulation for signal and BG
- Spectrum fitting
- Result
- Summary

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for the Super-Kamiokande collaboration

Supernova Relic Neutrino (SRN)

- Supernova Relic Neutrino(SRN) is diffuse supernova neutrino background from all past supernova.

◎ Motivation

SRN Measurement will enable us to investigate the history of past Supernova. For example, the flux of SRN would show the star formation rate and supernova rate in galaxies.

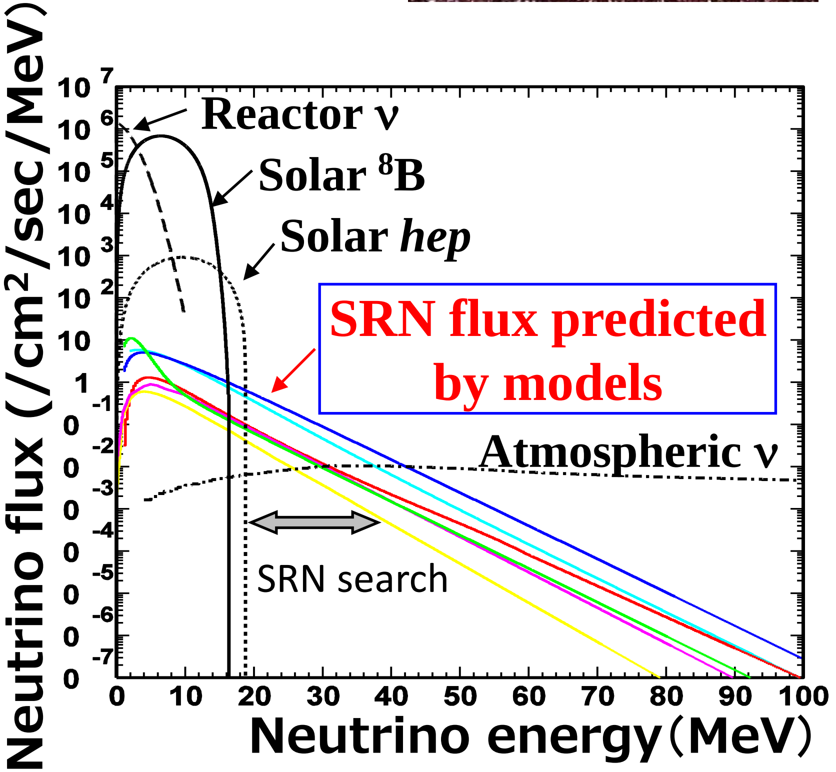
◎ Interaction in SK

The main interaction for SRN search in the SK detector is charged current quasi-elastic interaction **(inverse β decay).**

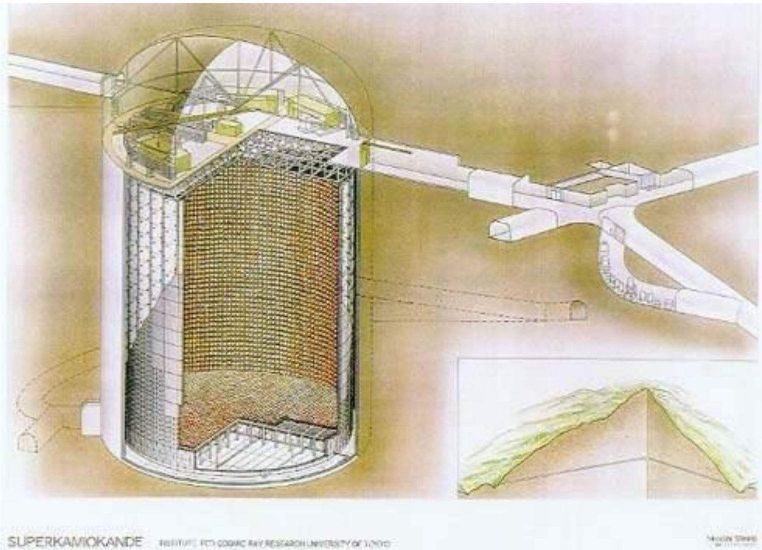
$$\bar{\nu}_e + p \rightarrow e^+ + n$$

◎ Energy region for SRN search

SRN is dominant neutrino **in 18 - 40 MeV**



Detector and Data set



Super-Kamiokande (SK)

SK is a large water Cherenkov detector for ν detection experiment. It is located at Kamioka mine in Japan.

This analysis is conducted using two terms of SK data.

	SK-I	SK-II
Data taking term	Apr. 1996 → Jul. 2001	Dec. 2002 → Oct. 2005
Live time	1496 days	791 days
Number of PMTs	11146 PMTs	5182 PMTs
Fiducial volume	22.5 kt	
Analysis E region	18 -82 MeV	

Data reduction

Data reduction was applied to reject **backgrounds** in the following steps:

1, Normal Spallation cut

The spallation BG is reduced by a likelihood method that uses timing and track information of the muons preceding the candidate events.

2, Cherenkov angle cut

Positrons with E>18MeV have a Cherenkov angle of $\theta c \sim 42$ degrees. To remove **muons and multiple gamma-rays**, remove events with

$\theta c < 38^\circ$ or $\theta c > 50^\circ$

3, Solar direction cut

To remeve **solar neutrino events**, the events in the direction of the sun are removed. ($E<25MeV$ && $Cos\theta_{sun} > 0.75$)

4, Tight Spallation cut

In addition to the normal spallation cut, tighter criteria is applied in order to enhance the rejection efficiency of **spallation BG**. So, we remove events which occur within 0.15 sec from the last muon.

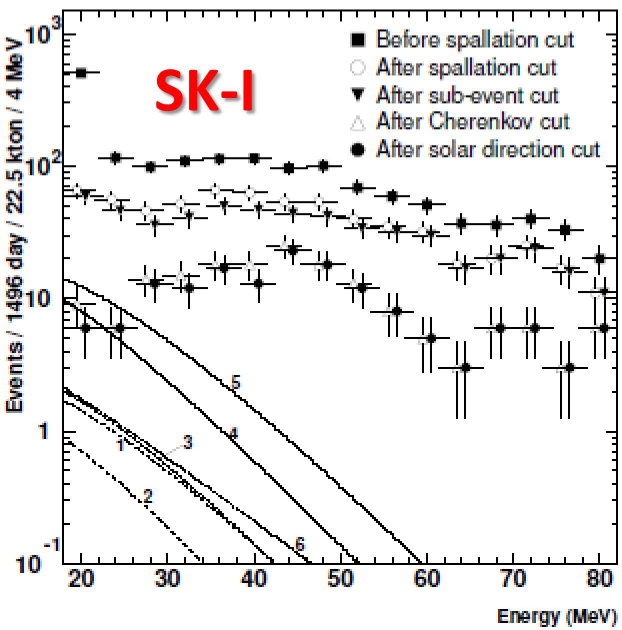
Data reduction

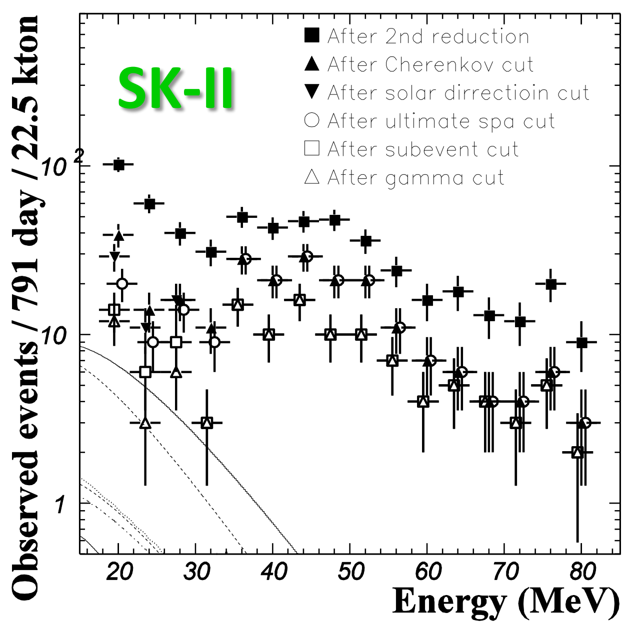
5, Sub-event cut

Some **decay-e** survive in this analysis but are tagged by preceding muons. In order to remove those backgrounds we remove the events which has time correlating events before or after the candidate events. By careful reevaluation of SK-I data number of events is reduced from 271(SK-I published data*) to 218 event.

6, Gamma ray cut

Some **γ ray events** originating from outside of fiducial volume have possibility of being reconstructed within fiducial volume of SK. We remove the events whose expected travel distance of γ ray is < 4.5m.





Number of events after all cut :

218 event in SK-I
(0.14 event/day)

115 event in SK-II
(0.14 event/day)

* : M.Malek et al. Phys. Rev. Lett 90, 061101 (2003)

Remaining Background

Still remaining BG are following atmospheric ν BG.

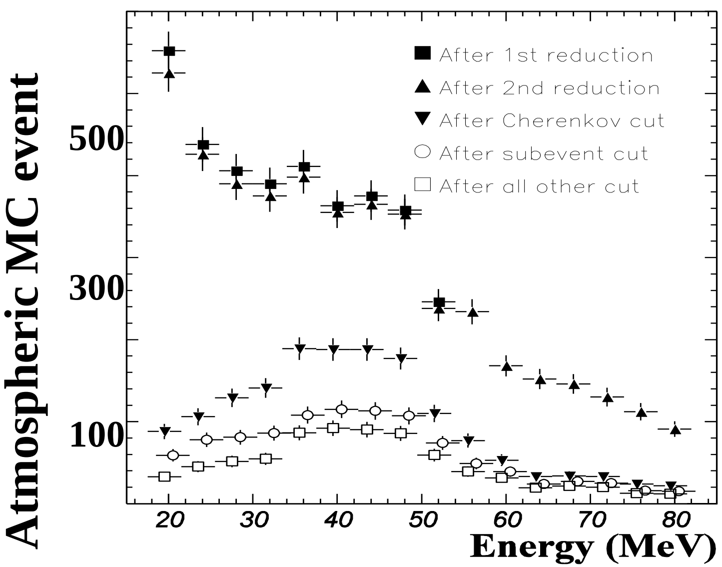
① **decay-e from invisible atmospheric ν_μ (invisible μ-e decay)**

$$\nu_\mu + N \rightarrow \mu + N' \quad (\mu \; energy \; is < Cherenkov \; threshold)$$

$$\rightarrow e + \nu_e + \nu_\mu$$

② **atmospheric ν_e**

$$\nu_e + n \rightarrow e^- + p \,, \quad \overline{\nu}_e + p \rightarrow e^+ + n$$



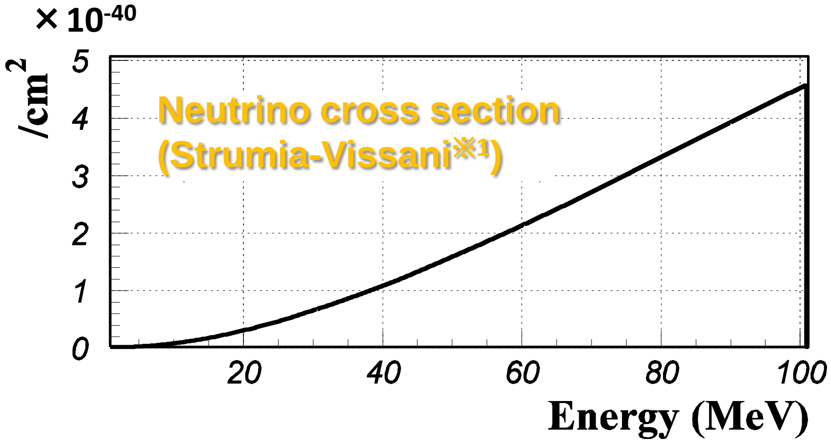
Reduction step of atmospheric ν MC

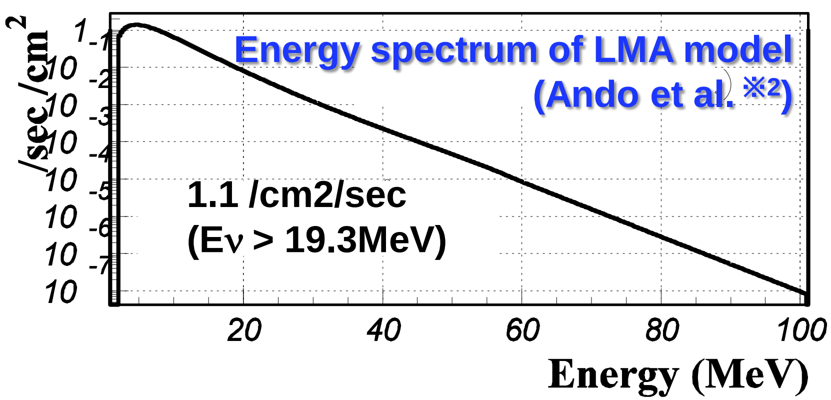
- These BG cannot be rejected by current analysis. So, these are considered with spectrum fitting.
- The spectrum shape of these two BG are obtained by atmospheric ν MC simulation.
- 100years' (SK-I) and 60years' (SK-II) MC is generated and data reductions are applied.

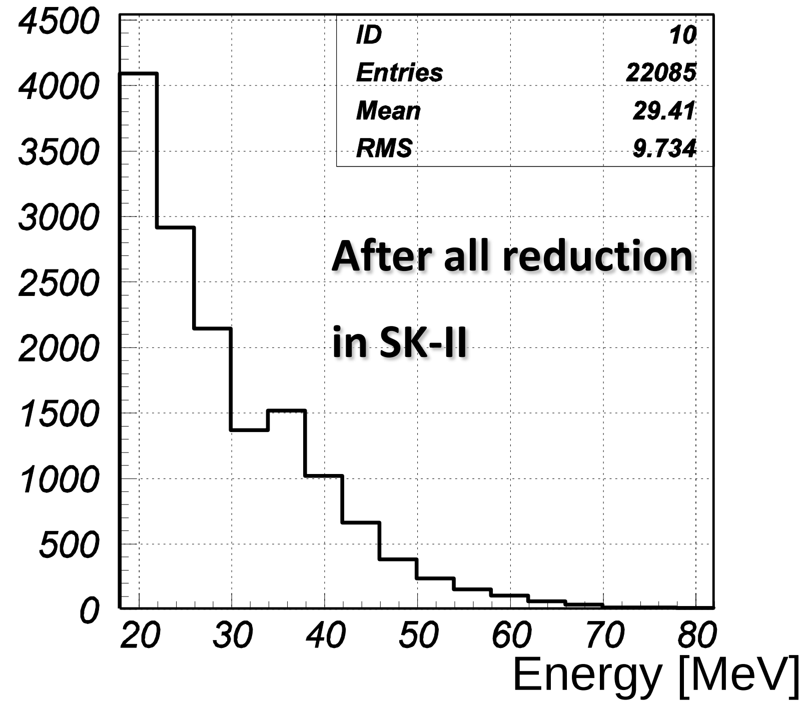
SRN MC simulation

The SRN spectrum are obtained by SRN MC simulation, using SRN model flux and cross section.

100,000 events are generated in full volume and >10MeV







Expected number of SRN event

SK-I : 5.7 event /1496days /22.5kt

SK-II: 2.9 event /791days /22.5kt

※1 : A.Strumia and F.Vissani, Phys.Lett. B564 (2003)

※2 : S.Ando et al. , Astropart. Phys. 18 307 (2003)

Spectrum fitting in SK-I

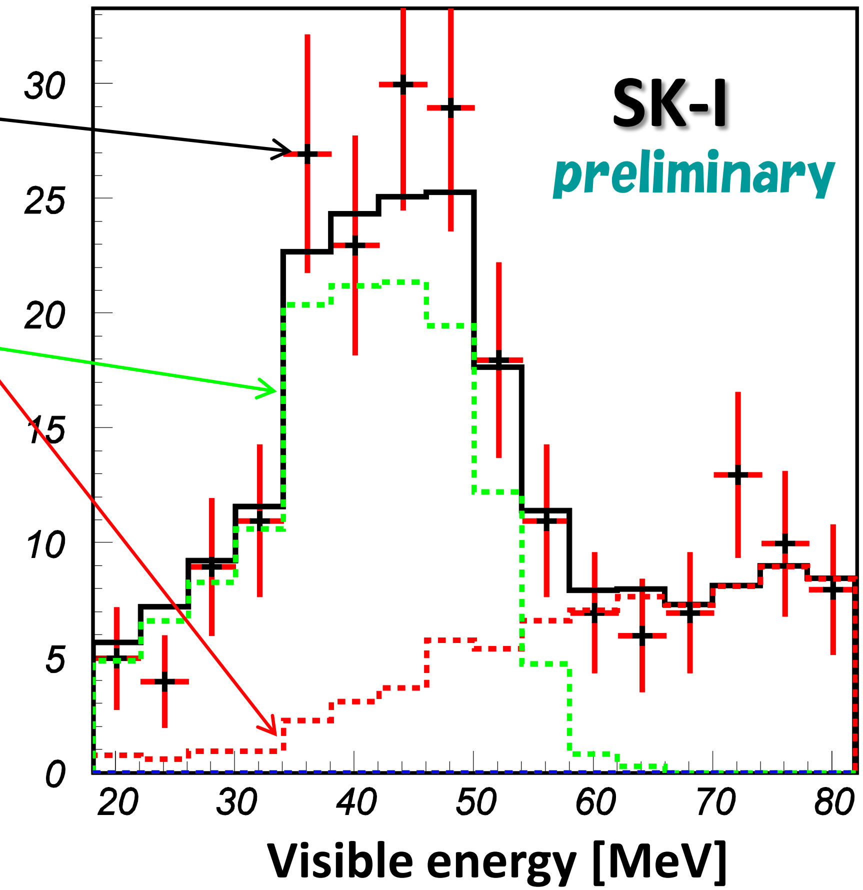
$$\chi^2 = \sum_i \frac{\left[N_{data}(i) - (\alpha \times N_{relic}(i) + \beta \times N_{\nu_e}(i) + \gamma \times N_{\nu_\mu}(i)\right]^2}{\sigma_{data}^2 + \sigma_{MC}^2 + \sigma_{systematic}^2}$$

$N_{data}(i)$: *real Data spectrum*

$N_{relic}(i)$: *SRN MC spectrum*

$N_{\nu_e}(i)$: *atmospheric* ν_e *spectrum*

$N_{\nu_\mu}(i)$: *atmospheric* ν_μ *spectrum*



free parameter

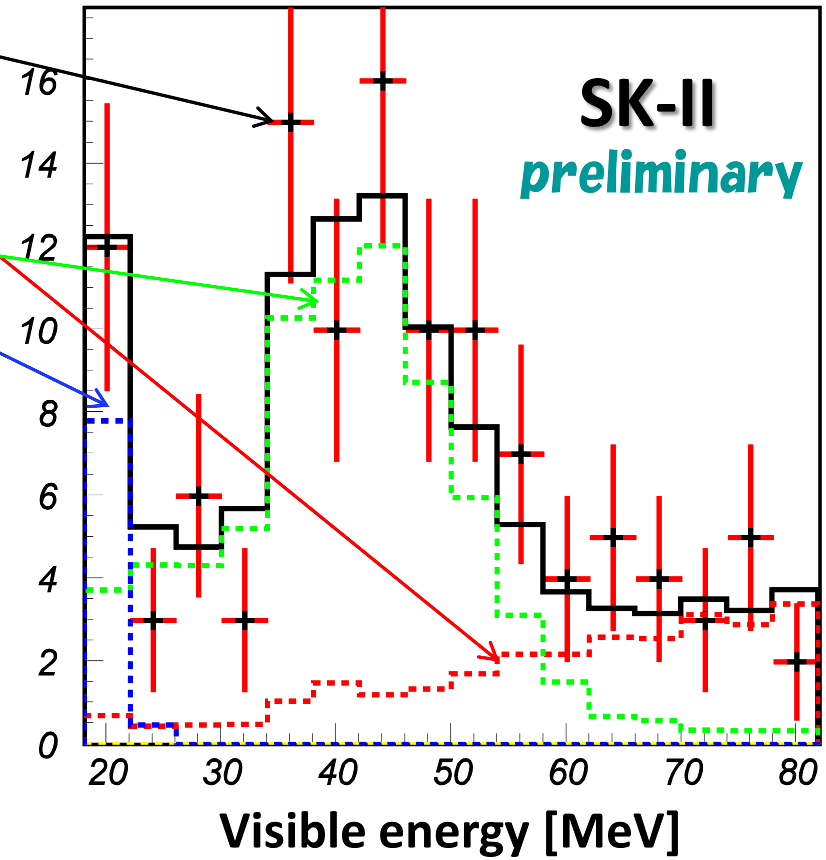
- α = 0.0 : factor of SRN
- β = 1.30±0.2 : factor of ν_e
- γ = 0.45±0.1 : factor of ν_μ

χ^2 = 7.2 / 13 d.o.f

Spectrum fitting in SK-II

$$\chi^2 = \sum_i \frac{\left[N_{data}(i) - (\alpha \times N_{relic}(i) + \beta \times N_{\nu_e}(i) + \gamma \times N_{\nu_\mu}(i) + N_{spal}(i))\right]^2}{\sigma_{data}^2 + \sigma_{MC}^2 + \sigma_{systematic}^2}$$

- $N_{data}(i)$: real Data spectrum
- $N_{relic}(i)$: SRN MC spectrum
- $N_{\nu_e}(i)$: atmospheric ν_e spectrum
- $N_{\nu_\mu}(i)$: atmospheric ν_μ spectrum
- $N_{spa}(i)$: number of spallation event※



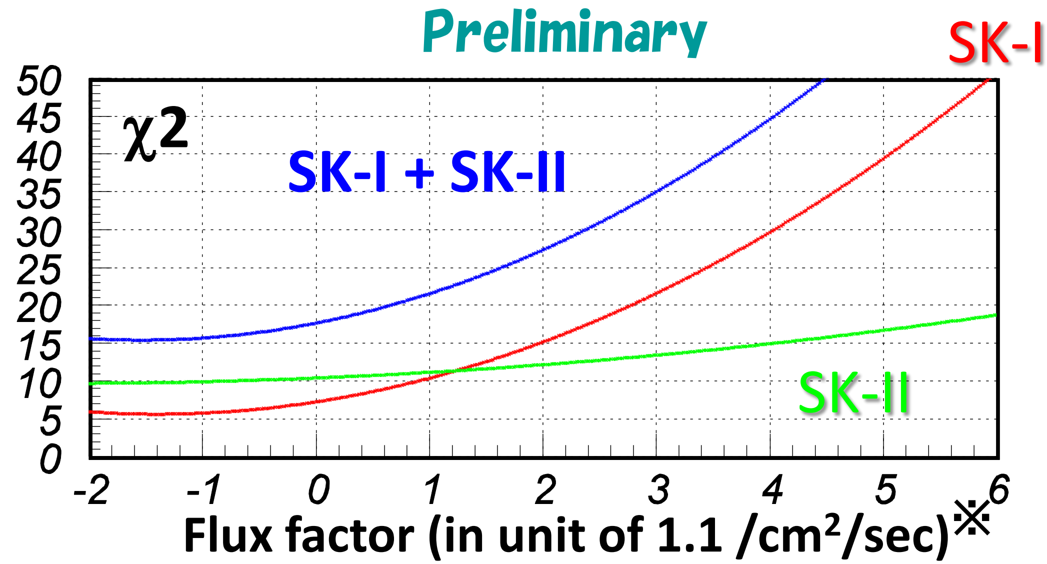
free parameter

- $\alpha = 0.0$: factor of SRN
- $\beta = 0.76 \pm 0.2$: factor of ν_e
- $\gamma = 0.51 \pm 0.1$: factor of ν_μ

$\chi^2 = 10.4 \ / \ 13$ d.o.f

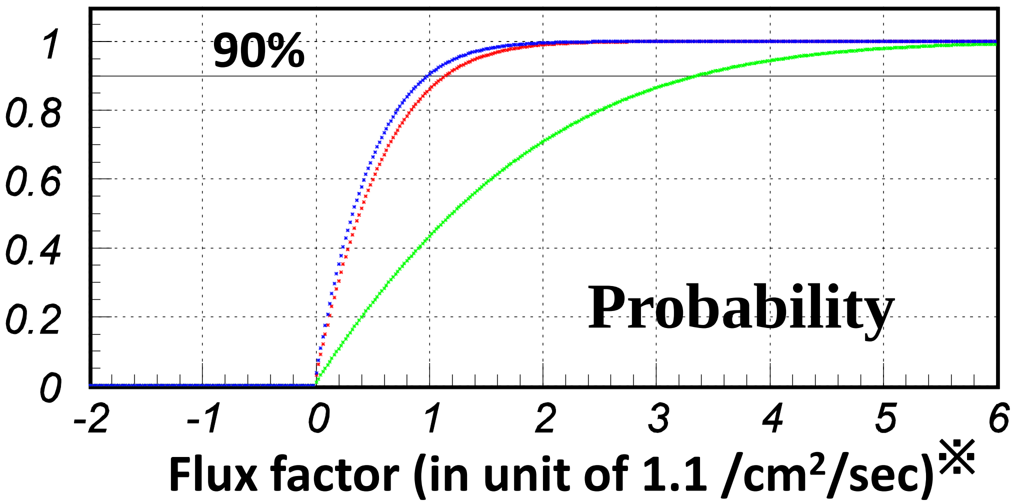
※In SK-II, spallation BG is remaining in the first energy bin due to worse energy resolution. Number of remaining spallation is estimated from quality of rejected spallation events.

Flux limit calculation



$$\chi^2_{Combine} = \chi^2_{SK-I} + \chi^2_{SK-II}$$

$$Probability = \int_{\alpha} A \times \exp\left(-\frac{\chi^2}{2}\right)$$



preliminary

90% C.L. Flux limit

SK-I : < 1.25 /cm² /sec

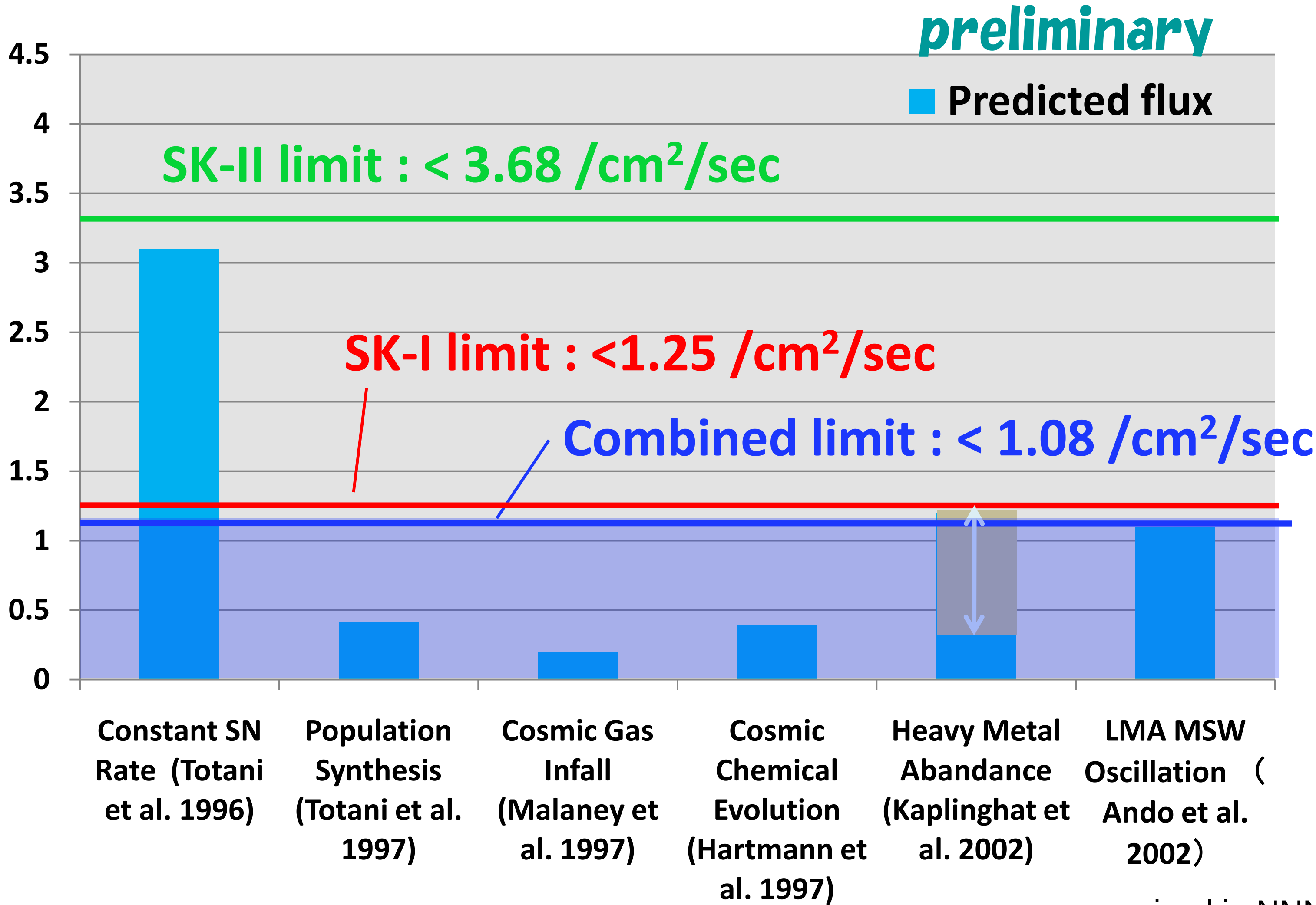
SK-II : < 3.68 /cm²/sec

SK-I + SK-II

< 1.08 /cm² /sec

※ Assuming LMA model (flux factor=1 → flux=1.1 /cm2/sec)

SK flux limit VS predicted flux



revised in NNN05

Summary

- A search for SRN is conducted at Super-Kamiokande.
- Using SK-I (1496days) and SK-II (791days) data, 90% flux limit is obtained to be **<1.08/cm^2/sec** (preliminary).

◎Future plan

We plan to reduce the background by tagging the gamma ray emitted when neutron ,produced by inverse beta decay, is captured.

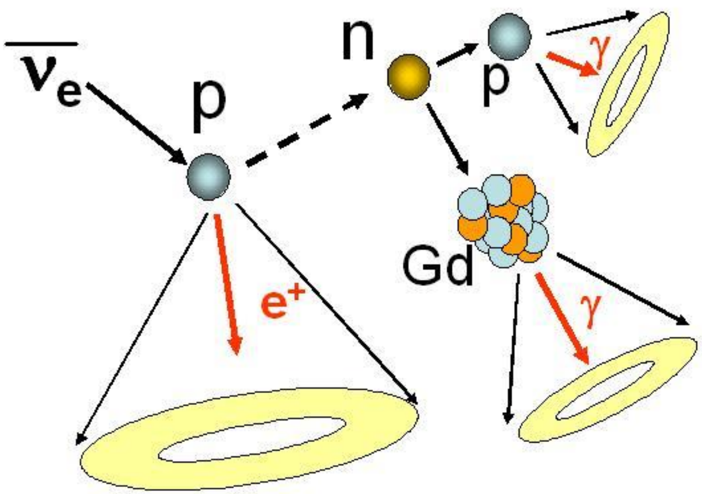
→ see Watanabe-san's poster

Backup

Systematic error estimation

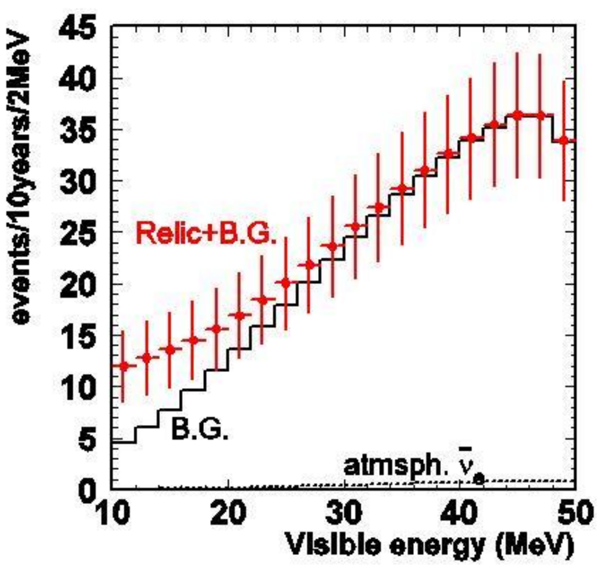
$$\chi^2 = \sum \frac{(N_{data}(i) - N_{BG}(i))^2}{\sigma_{data}^2 + \sigma_{MC}^2 + \sigma_{sys}^2}$$

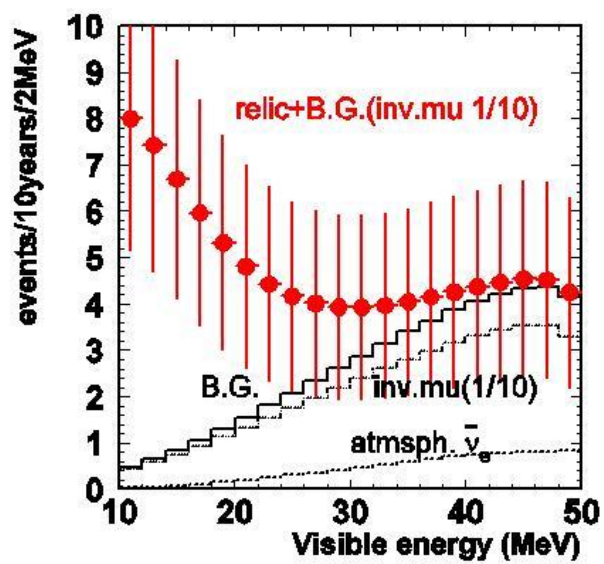
Systematic errors	※same as solar analysis
Energy resolution※	±0.3
1st reduction※	±1.0
2nd reduction※	±3.0
Cherenkov angle cut	±3.0
Gamma cut※	±1.0
Spallation dead time※	±0.4
Remaining spallation event	±4.0% in 1st bin
Vertex shift※	±1.1
Angular resolution※	±3.0
Live time※	±0.1
Total	**±4.8**



n+p→d + γ
2.2MeV γ-ray

n+Gd → ~8MeV γ-ray



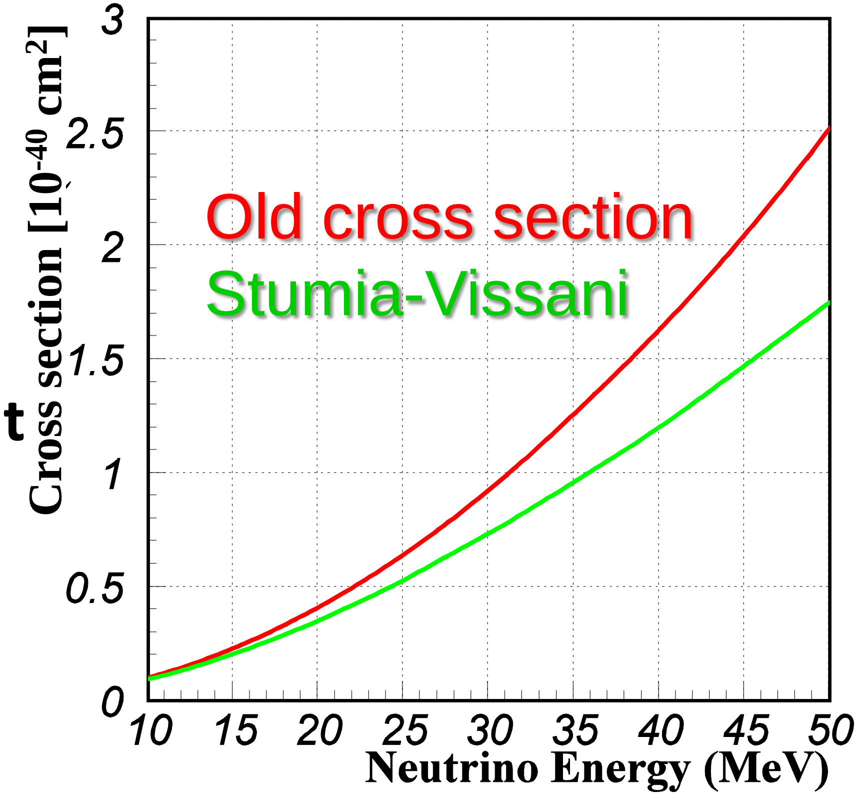


SK-I Relic MC improvement

Cross section of anti-electron neutrino is very important to obtain signal spectrum. In SK-I analysis, following formula is used to calculate cross section.

$$\sigma(E\nu) = 9.52 \times 10^{-44} Ee \cdot Pe$$

Newest cross section value※ is ~10% smaller (@20MeV) than older one.



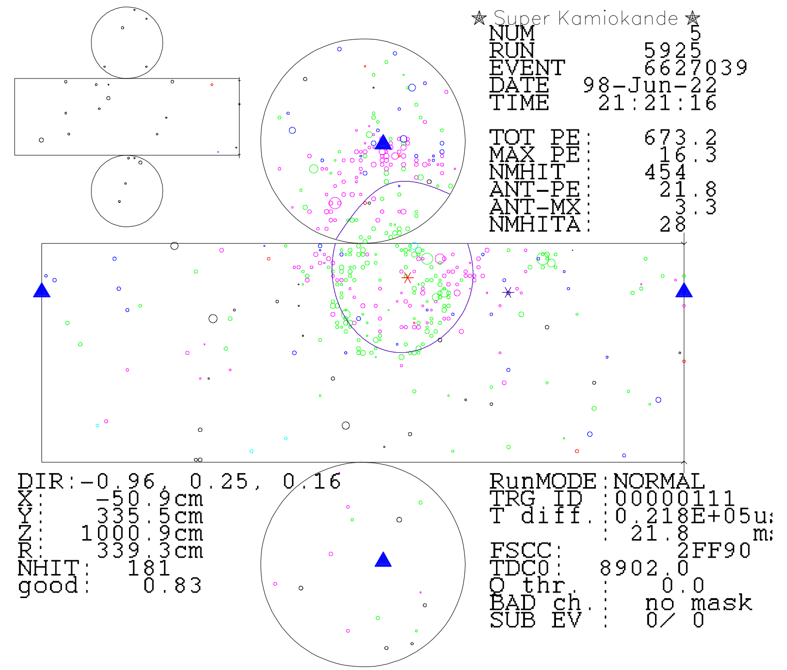
Flux limit of SK-I should be worse about ~10% than <1.2 /cm2 /sec.

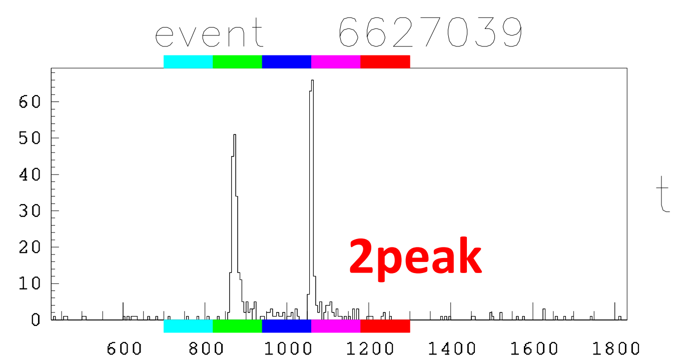
※A.Strumia - F.Vissani Phy. Lett. B564 (2003)

Data reduction improvement in SK-I

Some decay electrons survive in this analysis but are tagged by preceding muons or preceding gamma ray emission.

- Sub-event cut in SK-I removed the event which has 2peak in timing hist.





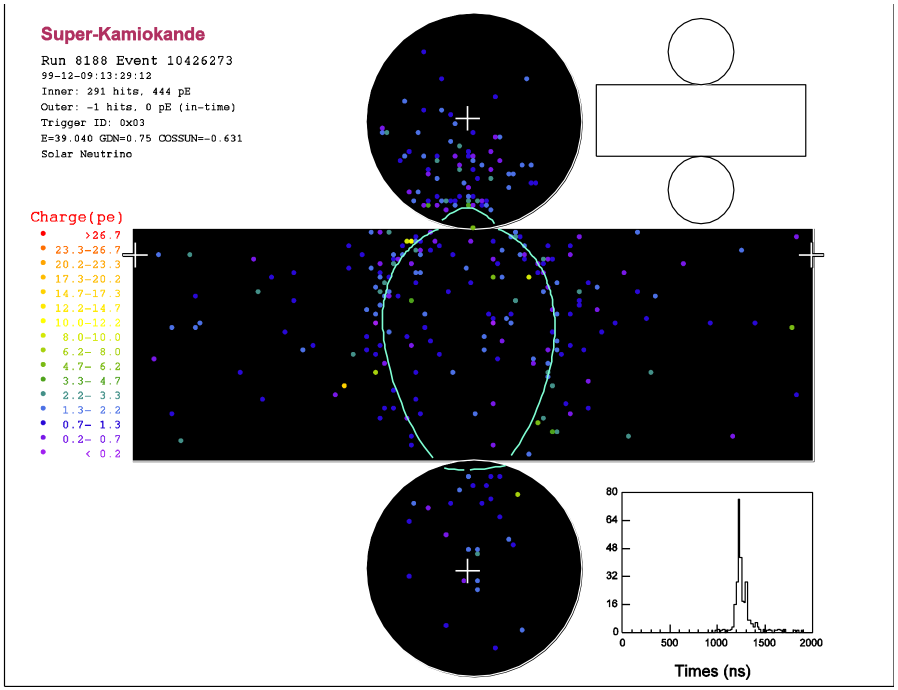
Nakahata-san removed the events which has time correlating events before or after the candidate events.※

※ See Nakahata-san's presentation at collaboration meeting in May, 2004.

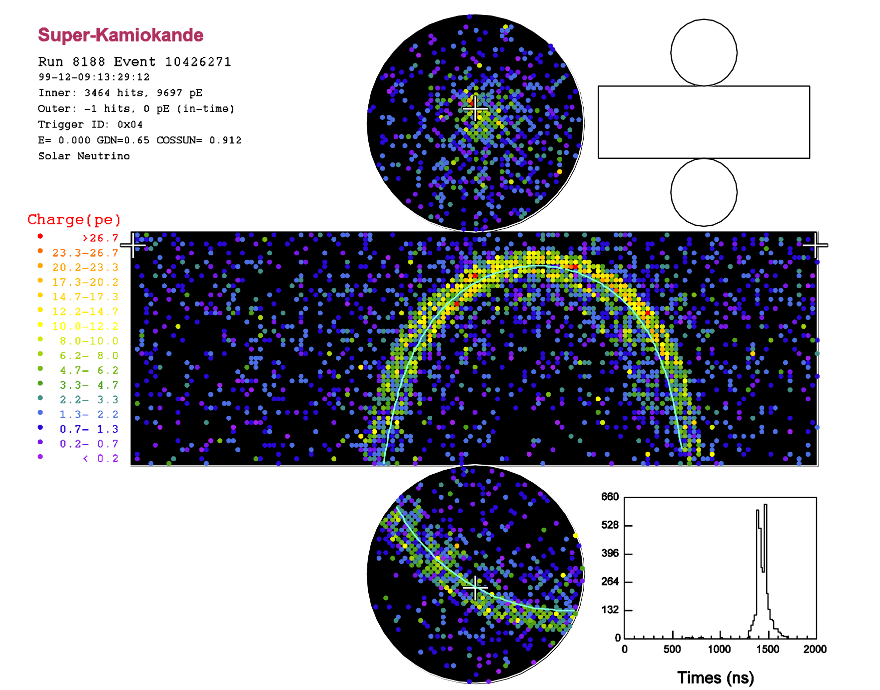
Advanced Sub-event cut in SK-I

Example: (Run 8188, EV 10426273)

Relic candidate



Previous event(1.4 μsec before)



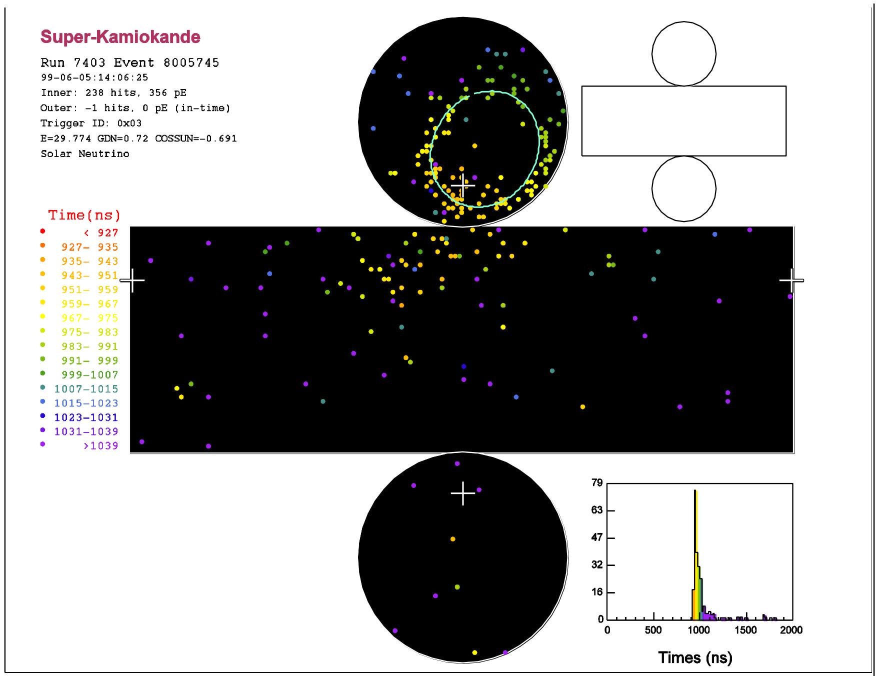
If muon is exist before relic candidate events, these events are removed.

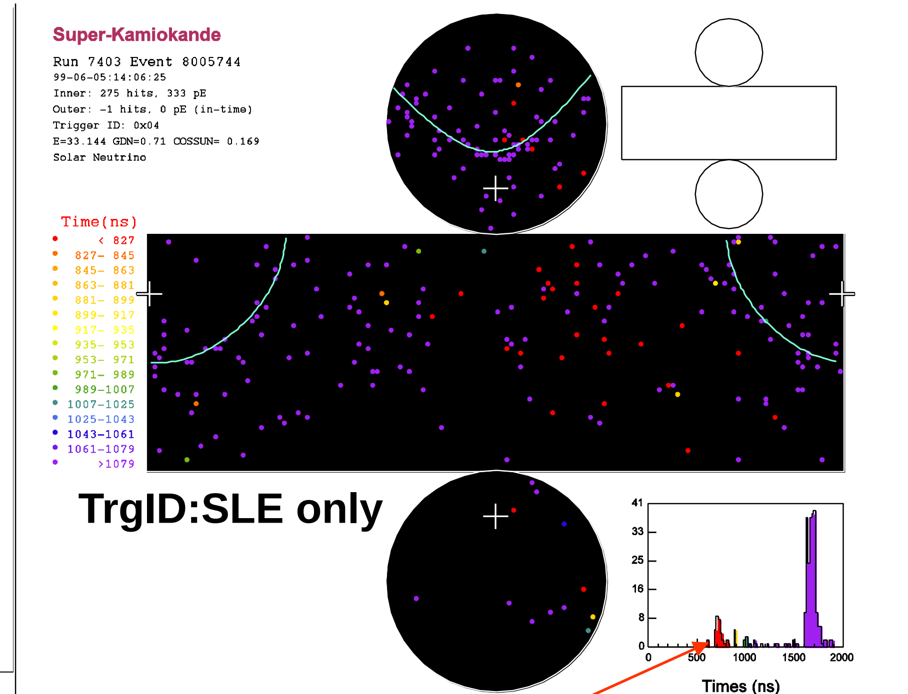
Advanced Sub-event cut in SK-I

Example: (Run 7403, EV 8005745)

Relic candidate

Previous event (1.0 μsec before)





Pre-pre-activity !

Example of gamma ray emission from atmospheric ν_μ interaction ($\nu_\mu + {}^{16}O \rightarrow \mu^+ + {}^{16}N + \gamma$)

Spallation cut

Normal spacut

Dead time = 20%

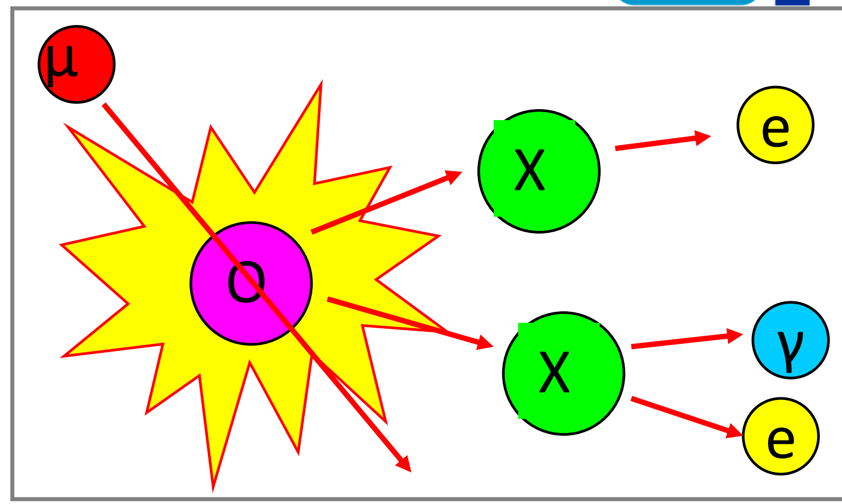
Tight spacut

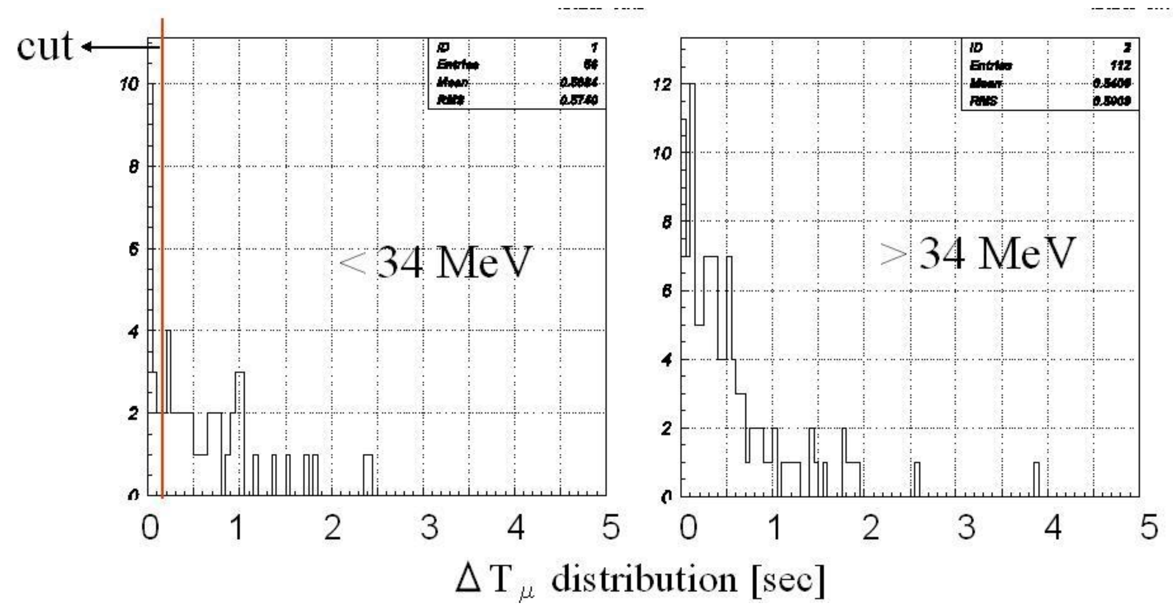
Additional Dead time = 16%

$\Delta T < 0.15$ [sec]

&&

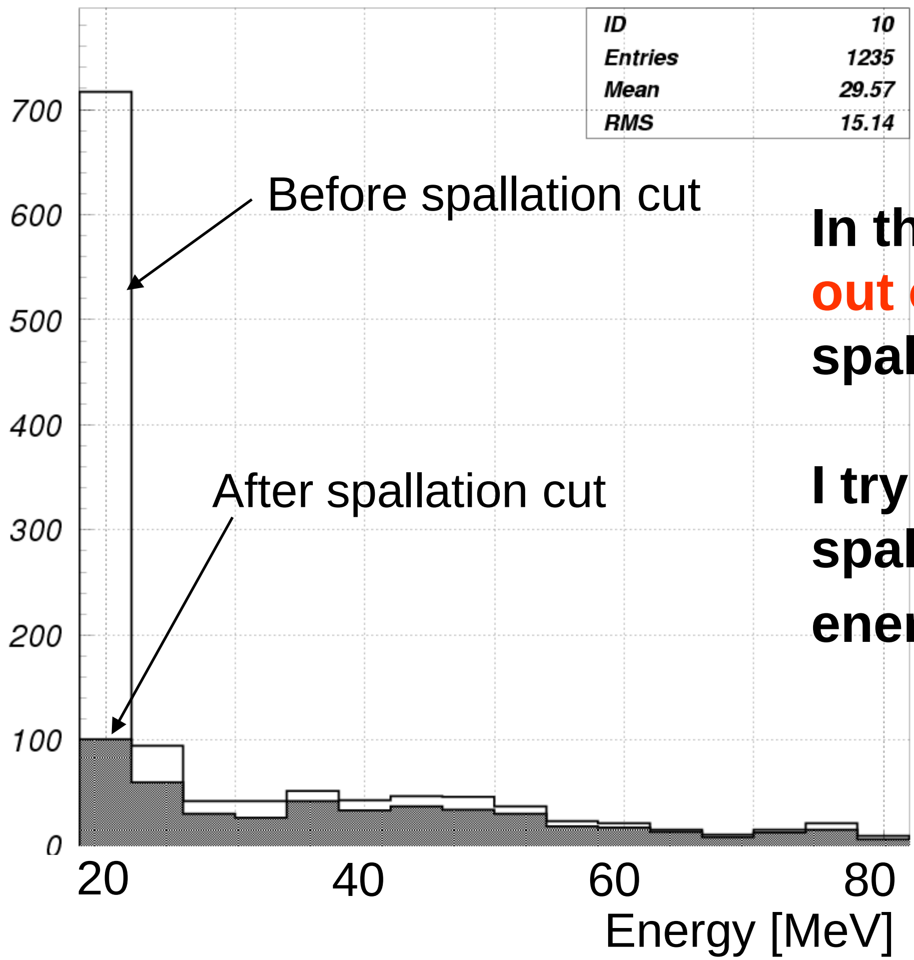
$E < 34$ [MeV]





ΔT : time diff from the last muon

Spallation background study



In the first bin (18~22MeV), 616 events out of 718 events are rejected by spallation cut !! (~85%)

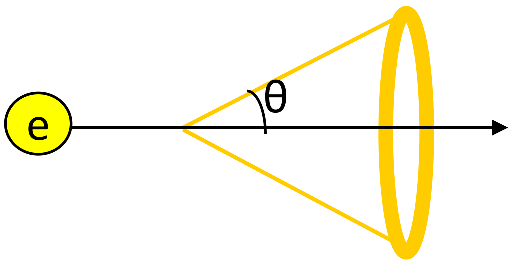
I try to estimate number of remaining spallation events after the cut in this energy bin.

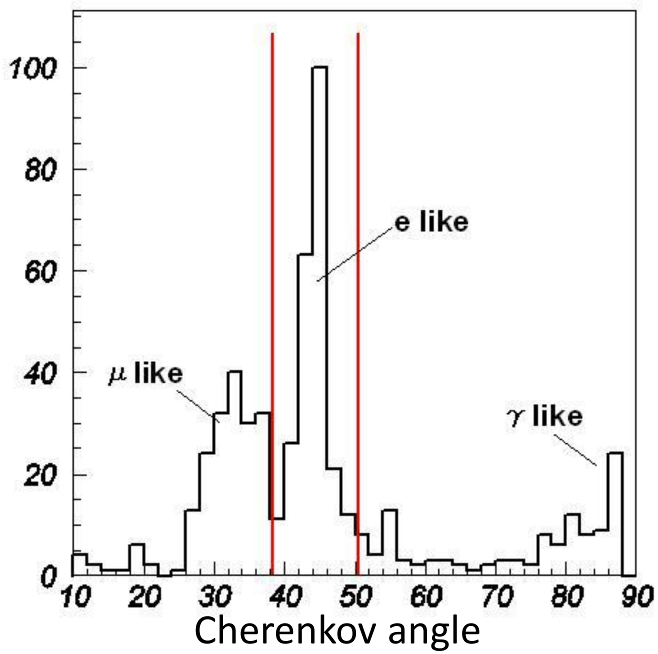
To do it, I obtain ΔT distribution of the true spallation event!!

ΔT : time difference from the last muon

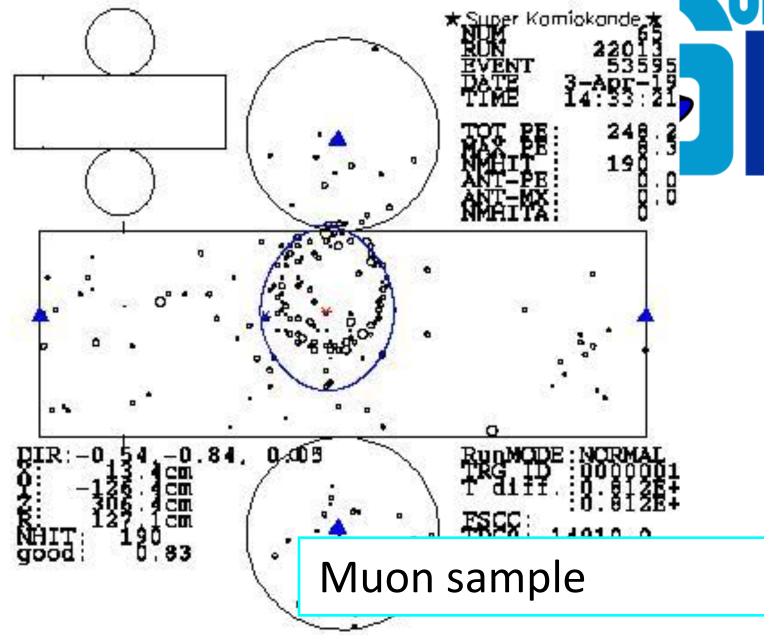
Cherenkov angle cut

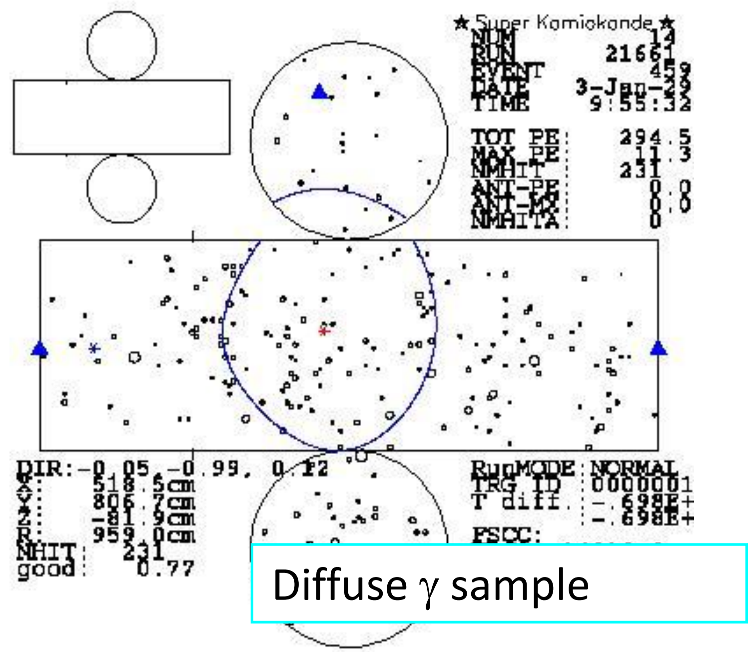
Cherenkov angle θ





$38^\circ < \theta < 50^\circ$

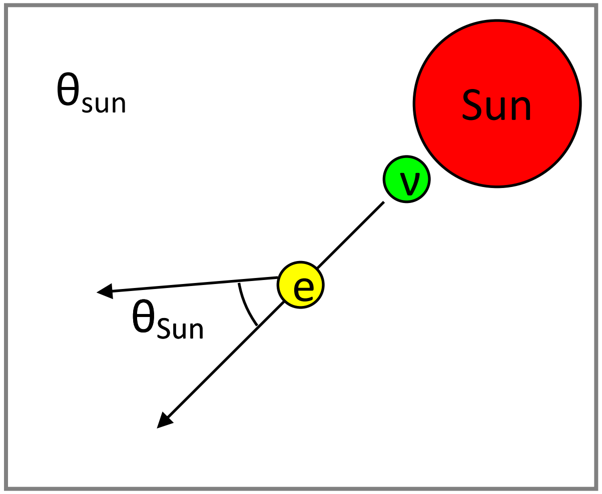




Solar direction cut

Remove solar neutrino

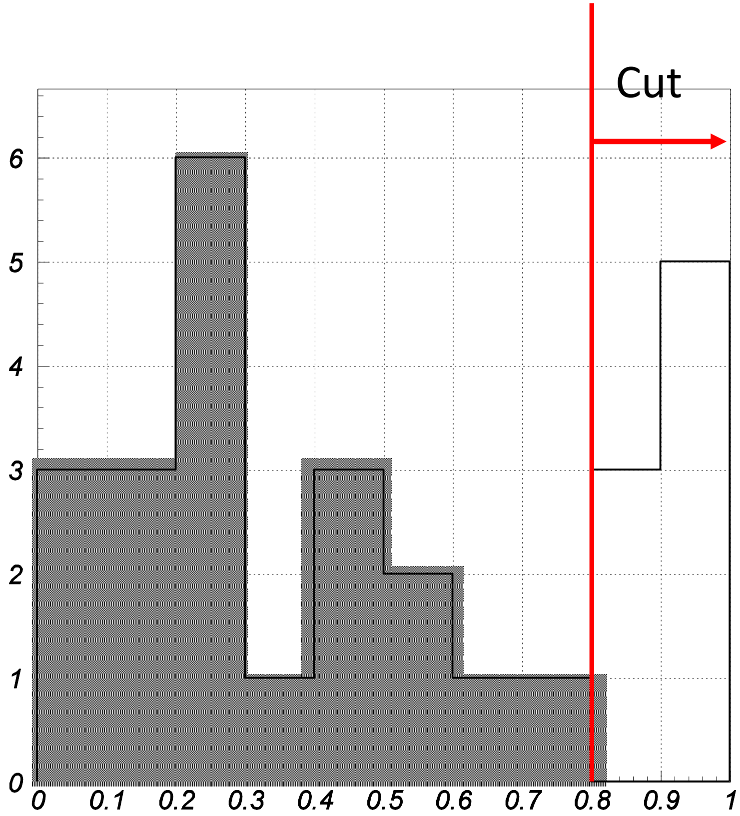
$$\nu_e + e \rightarrow \nu_e + e$$



$\cos\theta_{Sun} < 0.75$

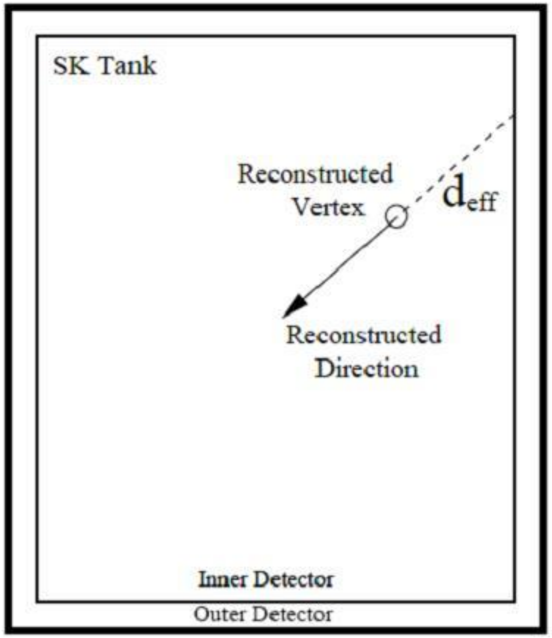
&&

E<25 [MeV]

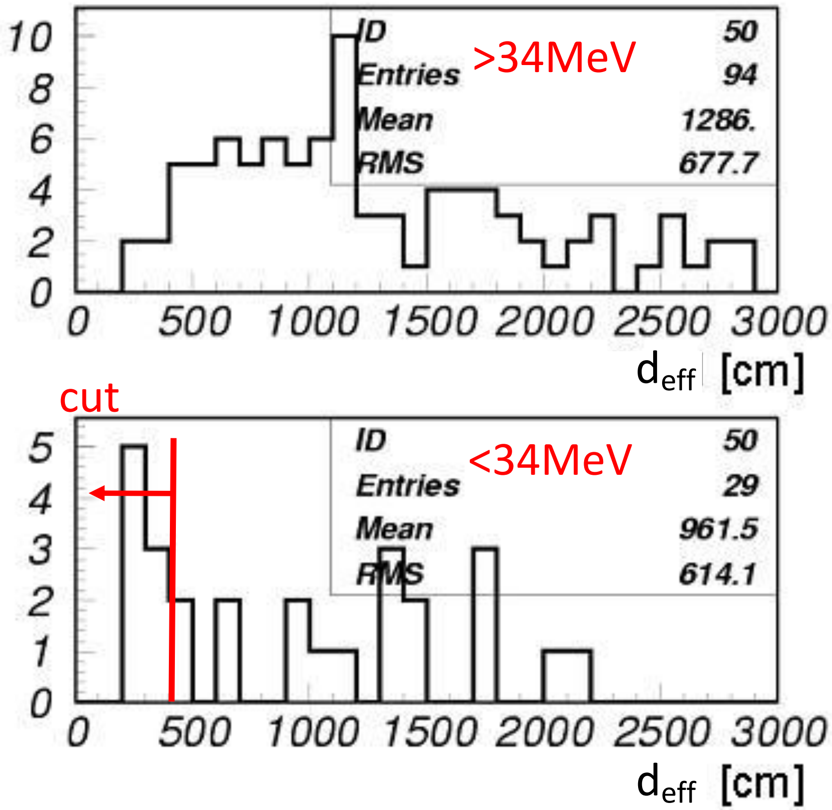


$\text{Cos}\theta_{sun}$ distribution < 25 MeV

Gamma ray cut



Definition of d_{eff}



d_{eff} > 400[cm]
&&
E < 34[MeV]