

Supernova relic neutrino search and atmospheric neutral current at Super-Kamiokande

Linyan WAN for Super-Kamiokande collaboration

Tsinghua University

2018/07/06



Supernova and CCSN neutrino

- Supernova burst is a titanic explosion in the last evolutionary stages of a massive star's life.
- Happening 2~3 per century in our galaxy.
- Shed light on star evolution and heavy element synthesis.

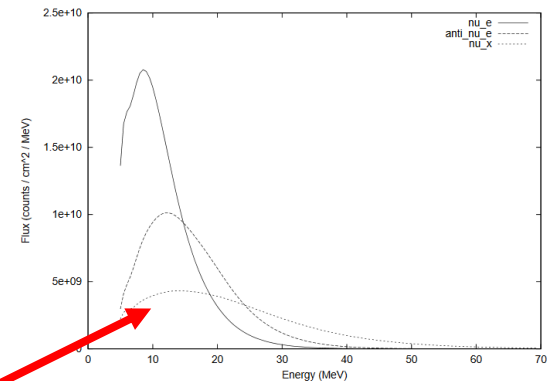


□ Core collapse supernova radiates energy mostly by neutrinos.

Type by light spectrum		Burst model	Main energy output
SN I	SN Ia	Thermal runaway	Kinetic energy
	SN Ib	Core Collapse (SuperNova)	Neutrino (99%)
SN II			

Supernova Relic Neutrino

- Are cumulative neutrino fluxes from all **past** core-collapse supernova bursts, inside and outside Milky Way.
- Expected energy range ~ 10 MeV.
- Are also called **Diffused Supernova Neutrino Background**.
- Can be detected using terrestrial neutrino detectors of large fiducial volume, such as liquid scintillator or water.



$$\frac{dF_\nu}{dE_\nu} = \frac{c}{H_0} \int_0^{z_{max}} R_{SN}(z) \frac{dN_\nu(E'_\nu)}{dE'_\nu} (1+z) \frac{dz}{\sqrt{\Omega_m (1+z)^3 + \Omega_\Lambda}}$$

Time-space transformation

Super-Kamiokande

1996 ~ so far

20" PMT

OD: 1,885 PMTs

ID: 11,129 PMTs

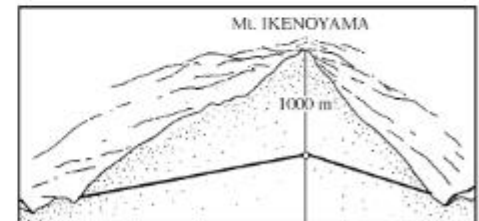
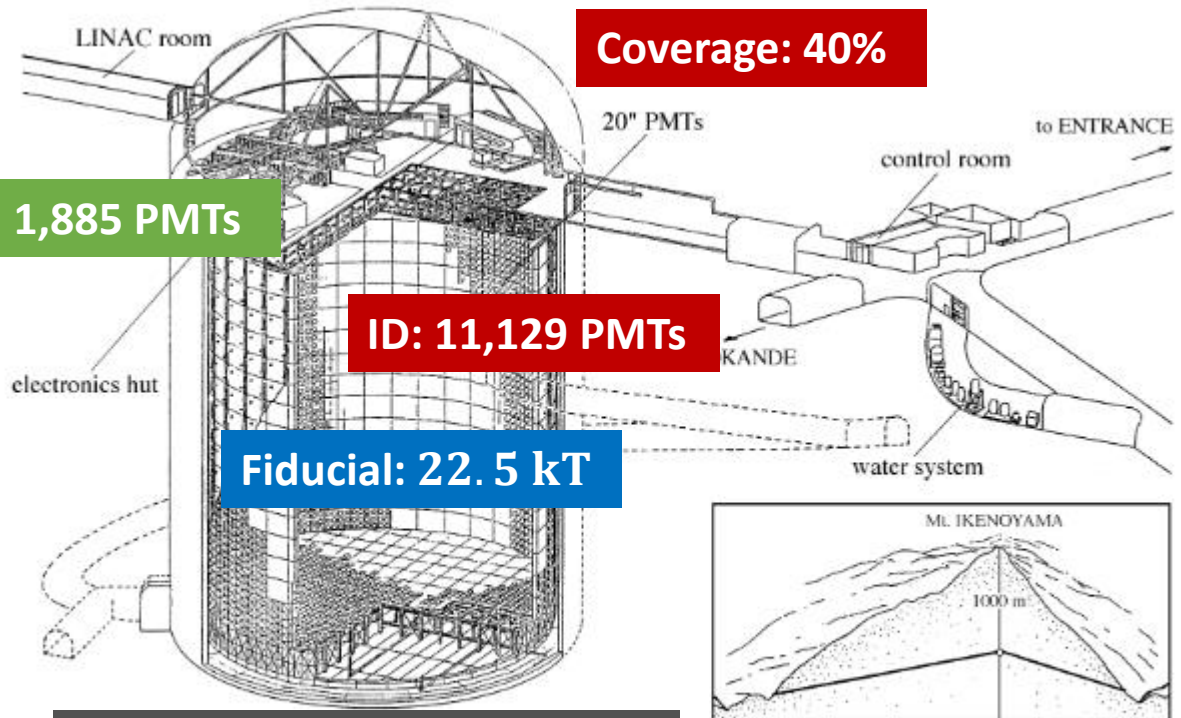
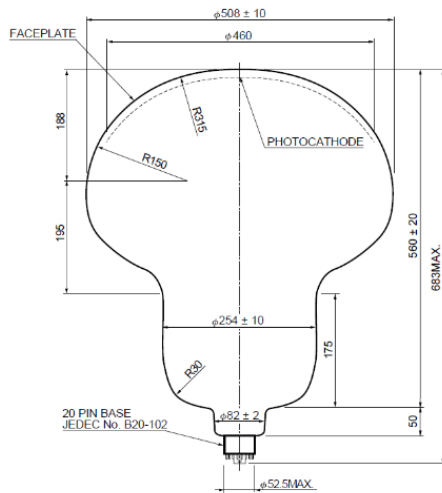
Fiducial: 22.5 kT

Coverage: 40%

$D \times H = 39.3 \text{ m} \times 41.4 \text{ m}$

SUPERKAMIOKANDE INSTITUTE FOR COSMIC RAY RESEARCH UNIVERSITY OF TOKYO

2,700 w.m.e
overburden



NIKKEN SEKKI

Super-Kamiokande

□ Water Cherenkov:

$$\cos \theta_c = \frac{1}{\beta n(\lambda)}$$

Enable particle identification

□ Energy Threshold:

$$E_{thr}(e^{+/-}) \approx 0.77 \text{ MeV}$$

$$E_{thr}(\mu^{+/-}) \approx 157 \text{ MeV}$$

□ Direction:

Reconstruct from Cherenkov ring

□ Water Transparency:

~ 120 m by decay electron

PMT
Implosion

PMT
Refitting

Electronics
Upgrade

1996~2001

SK I

40% Coverage

2001~2005

SK II

40%→19%

2006~2008

SK III

19%→40%

2009~2016

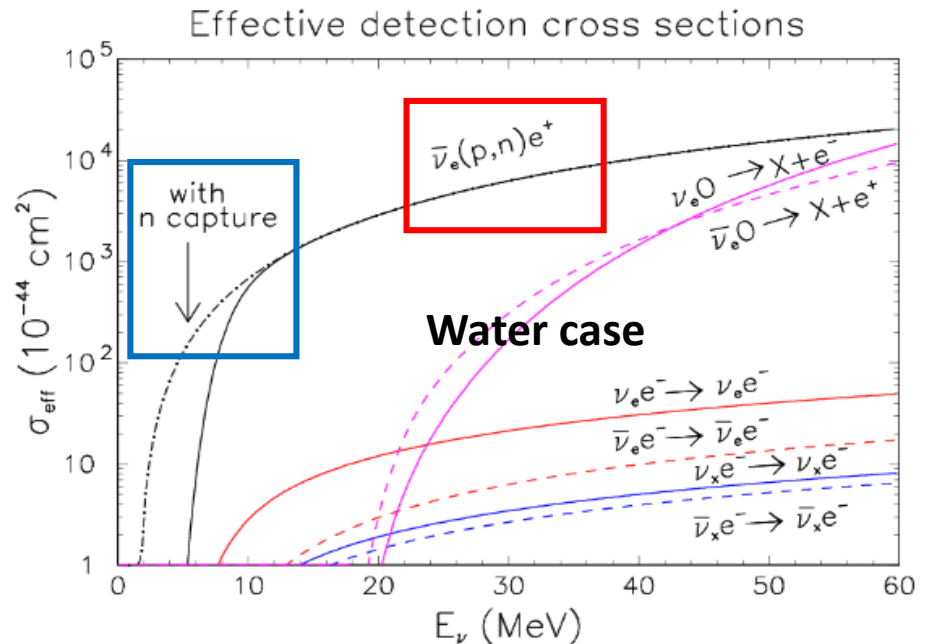
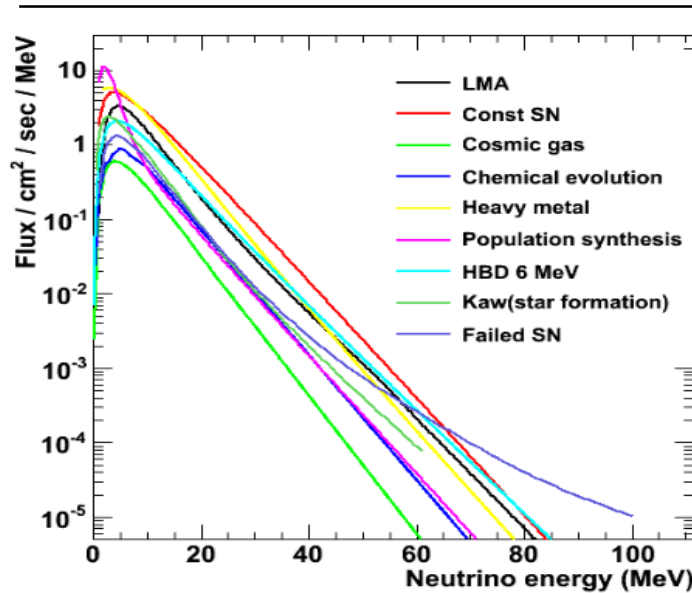
SK IV

Lower trigger threshold

Neutron Tagging

Shape
Analysis
Data
Set

Inverse beta decay



- Inverse Beta Decay
 $\bar{\nu}_e + p \rightarrow n + e^+$

An SRN detector should detect the IBD positron (and gamma).

- Neutron Capture
 $n + p \rightarrow D + \gamma$

- H Capture $\tau \approx 200 \mu\text{s}$ $E_\gamma = 2.2 \text{ MeV}$
- Gd Capture $\tau \approx 30 \mu\text{s}$ $E_\gamma \approx 8.0 \text{ MeV}$

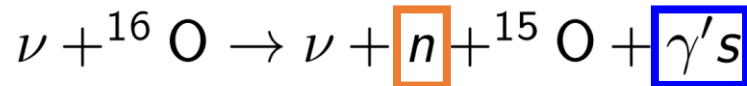
Neutron tagging

- Without neutron tagging, **spallation background** dominates **below 16 MeV**.
- Neutron tagging has been enabled in **SK-IV** by the improvement of FEE and trigger scheme. However, it is difficult in water due to the inefficiency to detect 2.2 MeV γ .
- Using a **multi-variate analysis** of discrimination variables including **hit pattern, hit time, charge, and vertex information**, an Ntag algorithm is constructed with **20%~30%** efficiency at different energy.

Neutral-current background

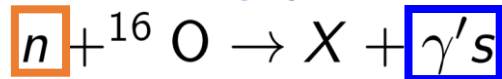
Neutral Current Quasi-Elastic (NCQE) on oxygen:

Primary process:

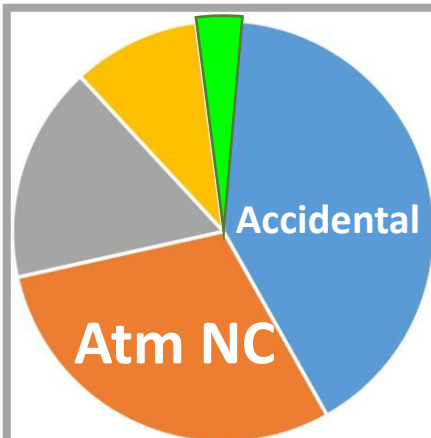


De-excitation γ 's as a signature to detect NCQE (1-10 MeV).

Secondary process:

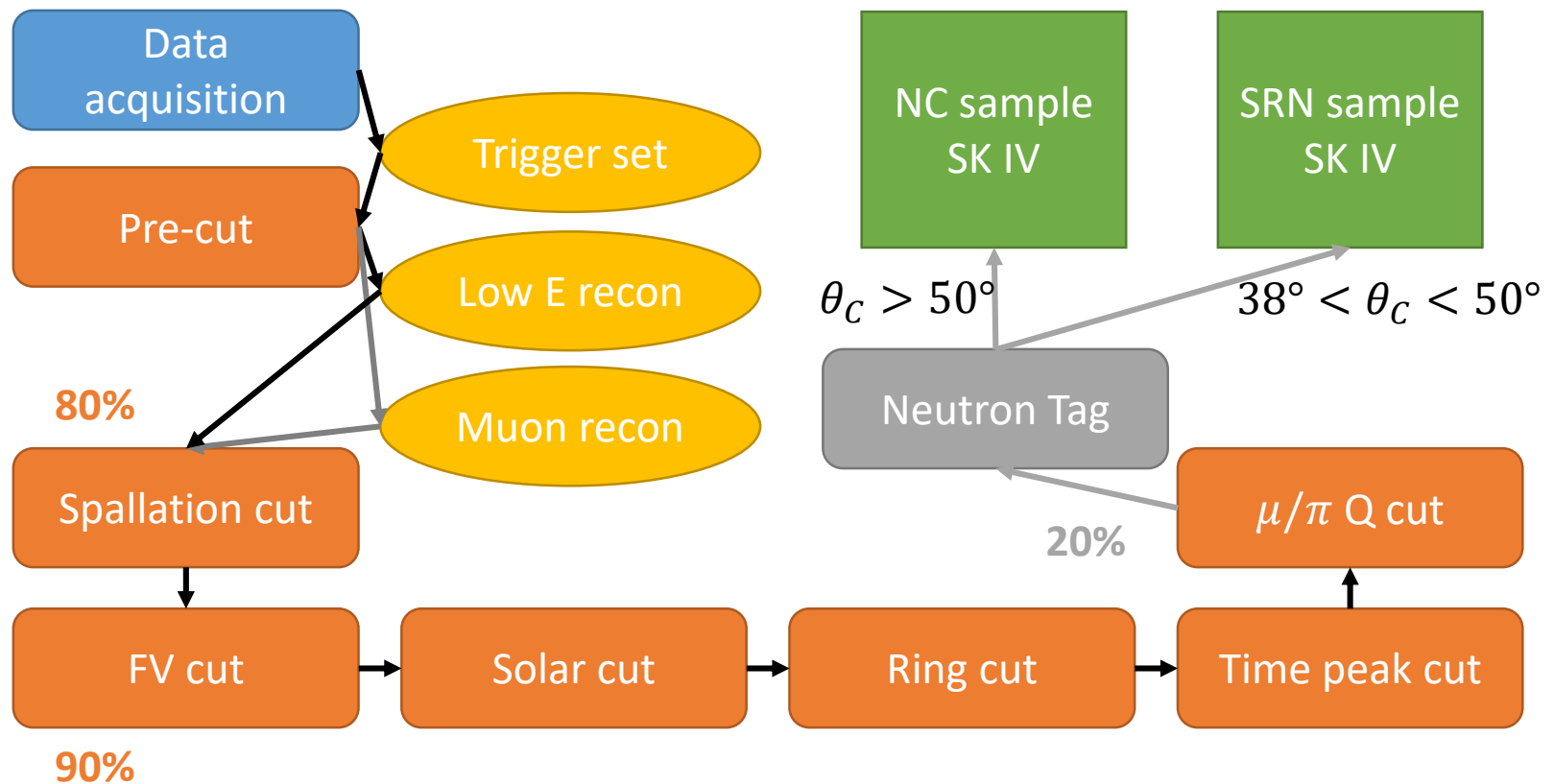


Emitted nucleon can be captured and emit 2.2 MeV gamma or further collide on another nucleus.



- Accidental can be removed in SK-Gd.
- Atmospheric NC is irreducible, dominated by NCQE.
- SRN signal.

Atmospheric NCQE data reduction

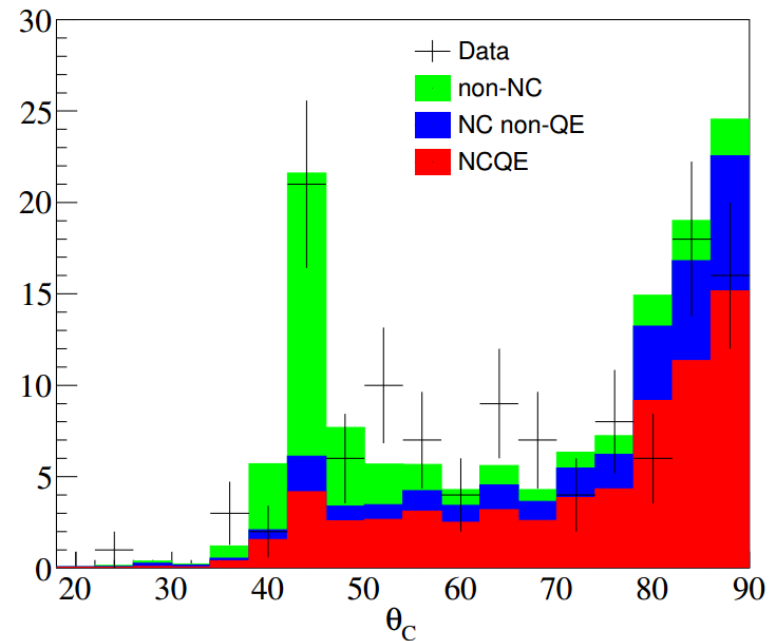


Cherenkov angle distribution

NCQE signals are γ 's and tend to cluster in isotropic regions **above 50°** ;

NC non-QE's are mainly **pion** channels, and the signals are de-excitation γ 's after pion absorption;

Non-NC backgrounds are mainly **electron-like** events peaking at **42°** , including **reactor neutrinos**, **9Li** , and **atmospheric CC**.

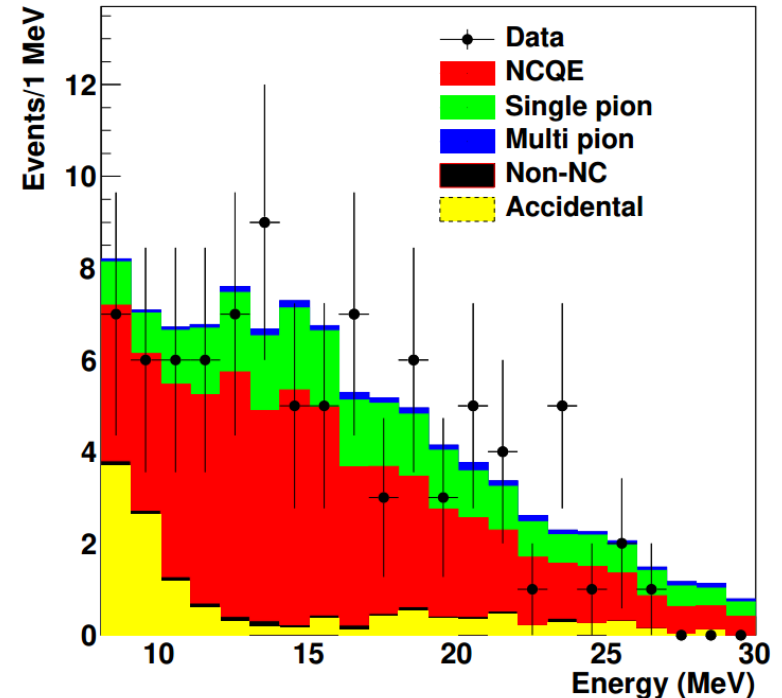


Atmospheric NCQE MC & data

The final sample consists of **89 events** and is validated by a neutron capture time fitting.

The expected number of events is:

- ▣ **NCQE: 58.0**
- ▣ **Single pion: 23.1**
- ▣ **Multi pion: 2.4**
- ▣ **Non-NC w/ neutron: 1.3**
- ▣ **Accidental: 13.7**



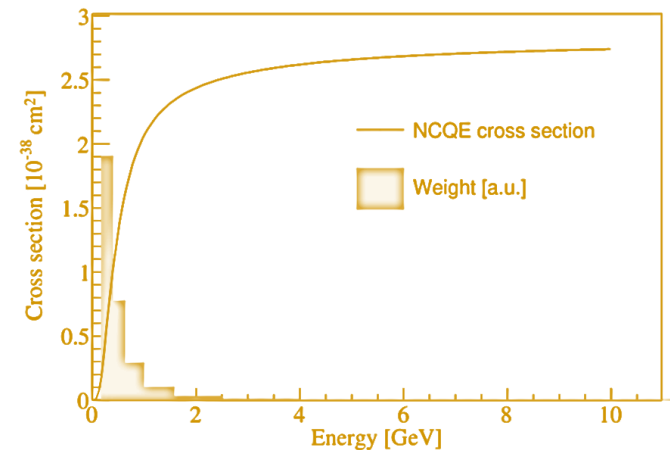
In total, **98.5 events expected** against **89 events observed**, within 1σ statistical uncertainty.

Cross-section calculation

$$\begin{aligned} \langle \sigma_{\text{NCQE}}^{\text{theory}} \rangle &= \frac{\int_{160 \text{ MeV}}^{10 \text{ GeV}} \sum_{i=\nu, \bar{\nu}} \phi_i(E_\nu) \times \sigma_i(E_\nu)_{\text{NCQE}}^{\text{theory}} dE_\nu}{\int_{160 \text{ MeV}}^{10 \text{ GeV}} \sum_{i=\nu, \bar{\nu}} \phi_i(E_\nu) dE_\nu} \\ &= 1.14 \times 10^{-38} \text{ cm}^2 \end{aligned}$$

$$\begin{aligned} \langle \sigma_{\text{NCQE}}^{\text{observed}} \rangle &\approx \frac{N_{\text{tot}}^{\text{obs}} - N_{\text{acc}}^{\text{obs}} - N_{\text{others}}^{\text{obs}} - N_{\text{NCOthers}}^{\text{exp}}}{N_{\text{NCQE}}^{\text{exp}}} \times \langle \sigma_{\text{NCQE}}^{\text{theory}} \rangle \\ &= \frac{89 - 13.7 - 1.3 - (23.1 + 2.4 + 0.0)}{58.0} \times 1.14 \times 10^{-38} \text{ cm}^2 \\ &= (0.95 \pm 0.12_{\text{stat.}}) \times 10^{-38} \text{ cm}^2 \end{aligned}$$

The cut-off at 160 MeV and 10 GeV is due to present atmospheric neutrino flux measurement. Related systematics have been considered.



Systematics

- Flux uncertainty from SK-IV measurement.
- Ratio & γ emission evaluated from theoretical disagreement between models.
- Data reduction and neutron drift from MC.
- Neutron tagging from calibration data.

ν_{atm} flux	18%	
$\nu/\bar{\nu}$ ratio	5%	
	NCQE	NC others
Cross-section		18%
Primary γ 's	10%	3%
Secondary γ 's	13%	13%
Data reduction		3%
Neutron drift		10%
Neutron tagging		10%
Others		0.7%

Table: Uncertainties in NCQE measurement

- The average NCQE cross-section from atmospheric neutrinos on oxygen is measured to be

$$(0.95 \pm 0.12 \text{ (stat.)}_{-0.32}^{+0.49} \text{ (sys.)}) \times 10^{-38} \text{ cm}^2.$$

Conclusion

- We observed 89 events in the NC sample after data reduction and neutron tagging, against 98.5 events expected.
- The atmospheric neutrino average NCQE cross-section is measured to be
$$\left(0.95 \pm 0.12 \text{ (stat.) }^{+0.49}_{-0.32} \text{ (sys.)}\right) \times 10^{-38} \text{ cm}^2$$
- The uncertainty is dominated by systematic, which could improve in future experiment (SK & HK for flux, ND280 etc. for NC other X-sec, RCNP for primary and secondary, SK-Gd for ntag efficiency).

Backup

Efficiency

