Super-Kamiokande
(on the activities from 2000 to 2006 and future prospects)

M. Nakahata
for Neutrino and astroparticle Division

- Super-Kamiokande detector
- Atmospheric neutrinos
- Solar Neutrinos
- Proton decay search
- Supernova neutrinos
### Super-Kamiokande collaboration

<table>
<thead>
<tr>
<th>Institute</th>
<th>Country</th>
<th>Number</th>
<th>Institute</th>
<th>Country</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICRR, Univ. of Tokyo</td>
<td>Japan</td>
<td>28</td>
<td>State Univ. of New York, Stony Brook</td>
<td>USA</td>
<td>7</td>
</tr>
<tr>
<td>Boston Univ.</td>
<td>USA</td>
<td>11</td>
<td>Niigata Univ.</td>
<td>Japan</td>
<td>1</td>
</tr>
<tr>
<td>BNL</td>
<td>USA</td>
<td>1</td>
<td>Okayama Univ.</td>
<td>Japan</td>
<td>4</td>
</tr>
<tr>
<td>Univ. of California, Irvine</td>
<td>USA</td>
<td>11</td>
<td>Osaka Univ.</td>
<td>Japan</td>
<td>2</td>
</tr>
<tr>
<td>California State Univ.</td>
<td>USA</td>
<td>3</td>
<td>Seoul National Univ.</td>
<td>Korea</td>
<td>2</td>
</tr>
<tr>
<td>Chonnam Univ.</td>
<td>Korea</td>
<td>4</td>
<td>Shizuoka Univ.</td>
<td>Japan</td>
<td>1</td>
</tr>
<tr>
<td>Duke Univ.</td>
<td>USA</td>
<td>4</td>
<td>Shizuoka Univ. of Welfare</td>
<td>Japan</td>
<td>1</td>
</tr>
<tr>
<td>Gifu Univ.</td>
<td>Japan</td>
<td>1</td>
<td>SungKyunKwan Univ.</td>
<td>Korea</td>
<td>2</td>
</tr>
<tr>
<td>Univ. of Hawaii</td>
<td>USA</td>
<td>3</td>
<td>Tohoku Univ.</td>
<td>Japan</td>
<td>1</td>
</tr>
<tr>
<td>Indiana Univ.</td>
<td>USA</td>
<td>1</td>
<td>Tokai Univ.</td>
<td>Japan</td>
<td>3</td>
</tr>
<tr>
<td>KEK</td>
<td>Japan</td>
<td>8</td>
<td>Univ. of Tokyo</td>
<td>Japan</td>
<td>1</td>
</tr>
<tr>
<td>Kobe Univ.</td>
<td>Japan</td>
<td>1</td>
<td>Tokyo Institute of Technology</td>
<td>Japan</td>
<td>1</td>
</tr>
<tr>
<td>Kyoto Univ.</td>
<td>Japan</td>
<td>2</td>
<td>Tsinghua Univ.</td>
<td>China</td>
<td>3</td>
</tr>
<tr>
<td>LANL</td>
<td>USA</td>
<td>1</td>
<td>Warsaw Univ.</td>
<td>Poland</td>
<td>1</td>
</tr>
<tr>
<td>Louisiana State Univ.</td>
<td>USA</td>
<td>2</td>
<td>Univ. of Washington</td>
<td>USA</td>
<td>4</td>
</tr>
<tr>
<td>Univ. of Minnesota</td>
<td>USA</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miyagi Kyoiku Univ.</td>
<td>Japan</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>28</strong></td>
<td><strong>Nagoya Univ.</strong></td>
<td>Japan</td>
<td>3</td>
</tr>
</tbody>
</table>

(*) Number of participants.

33 institutes, 122 physicists

**ICRR member:**
- Staff: 17 (faculty: 8, research assistant: 9)
- PD: 4
- Students: 7

Total 28
# History of Super-Kamiokande Detector

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>Start</td>
<td>Number of ID PMTs (photocoverage)</td>
</tr>
<tr>
<td>1997</td>
<td></td>
<td>Main results</td>
</tr>
<tr>
<td>1998</td>
<td>SK-I</td>
<td>11,146 (40%)</td>
</tr>
<tr>
<td>1999</td>
<td></td>
<td>Evidence for Atmospheric $\nu$ osc.</td>
</tr>
<tr>
<td>2000</td>
<td></td>
<td>Tau $\nu$ favor over sterile $\nu$ in atm. osc.</td>
</tr>
<tr>
<td>2001</td>
<td>Accident</td>
<td>Evidence for Solar $\nu$ osc.</td>
</tr>
<tr>
<td>2002</td>
<td>Partial Reconstruction</td>
<td>LMA by solar $\nu$ global analysis</td>
</tr>
<tr>
<td>2003</td>
<td>SK-II</td>
<td>5,182 (19%)</td>
</tr>
<tr>
<td>2004</td>
<td></td>
<td>Atmospheric $\nu$ L/E</td>
</tr>
<tr>
<td>2005</td>
<td></td>
<td>K2K final results</td>
</tr>
<tr>
<td>2006</td>
<td>Full reconstruction</td>
<td>Atmospheric $\nu$ tau appearance</td>
</tr>
<tr>
<td>2007</td>
<td>SK-III</td>
<td>11,129 (40%)</td>
</tr>
<tr>
<td>2008</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Accident and partial reconstruction

Accident on Nov.12, 2001. 6777 ID, 1100 OD PMTs were destroyed.

All PMTs were packed in acrylic and FRP cases to prevent shock-wave.

Reconstructed using remaining 5182 ID PMTs. OD was fully reconstructed (April-September 2002).

| ID: Inner detector |
| OD: Outer detector |
Full Reconstruction (October 2005 – April 2006)

~6000 ID PMTs were produced from 2002 to 2005 and were mounted from Oct.2005 to Apr.2006.

All those PMTs were packed in acrylic and FRP cases.

Mount PMTs on a floating floor.

Pure water was supplied and SK-III data taking has been running since July 11, 2006.
Atmospheric neutrinos

Main Physics

<table>
<thead>
<tr>
<th>Study of muon-neutrinos oscillations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oscillation parameters ((\theta_{23}, \Delta m^2_{23}, \theta_{13}))</td>
</tr>
<tr>
<td>Oscillation mode ((\nu_\mu \rightarrow \nu_\tau, \nu_\mu \rightarrow \nu_{\text{sterile}}))</td>
</tr>
<tr>
<td>Oscillation signature ((L/E) dependence)</td>
</tr>
</tbody>
</table>
SK-I+II atmospheric neutrino data

CC $\nu_e$  CC $\nu_\mu$

SK-I + SK-II

Sub-GeV $\mu$-like $P < 400$ MeV/c

Sub-GeV $\mu$-like $P > 400$ MeV/c

Multi-GeV $\mu$-like

Multi-GeV e-like

Number of Events

$\cos \theta$

No osc.

Osc.

Looking at the data, we see that:

SK-I: 92 kton yr
SK-II: 49 kton yr
Total: 141 kton yr

SK-I: hep-ex/0501064 + SK-II 804 days
$\nu_\mu \rightarrow \nu_\tau$ 2 flavor analysis

SK-I + SK-II

1489 days (SK-I) + 804 days (SK-II)

Best Fit: $\Delta m^2 = 2.5 \times 10^{-3} \text{ eV}^2$
$\sin^2 2\theta = 1.00$
$\chi^2 = 839.7 / 755 \text{ dof (18\%)}$

$1.9 \times 10^{-3} \text{ eV}^2 < \Delta m^2 < 3.1 \times 10^{-3} \text{ eV}^2$
$\sin^2 2\theta > 0.93$ at 90\% CL
Oscillation results 1998 vs. (SK-I+SK-II)

1998

535 days

90 % CL

SK-I + SK-II

90% CL

99% C.L.

90% C.L.

68% C.L.

90% CL of 1998
L/E analysis

oscillation
\[ P_{\mu\mu} = 1 - \sin^2 2\theta \sin^2 (1.27 \frac{\Delta m^2 L}{E_v}) \]

decoherence
\[ P_{\mu\mu} = 1 - \frac{1}{2} \sin^2 2\theta \cdot (1 - \exp(-\gamma_0 L/E)) \]

decay
\[ P_{\mu\mu} = (\cos^2 \theta + \sin^2 \theta \cdot \exp(-\frac{m L}{2\tau E}))^2 \]

Should observe this dip!

→ Further evidence for oscillations
→ Better determination of oscillation parameters, especially $\Delta m^2$
Selection criteria

Select events with high L/E resolution

(Δ(L/E) < 70%)

Events are not used, if:

- horizontally going events
- low energy events

Similar cut for: FC multi-ring μ-like,

OD stopping PC, and

OD through-going PC
SK-I+II L/E analysis and non-oscillation models

\[ \chi^2(\text{osc}) = \frac{83.9}{83 \text{ dof}} \]
\[ \chi^2(\text{decay}) = \frac{107.1}{83 \text{ dof}} \]
\[ \chi^2(\text{decoherence}) = \frac{112.5}{83 \text{ dof}} \]

Oscillation gives the best fit to the data. Decay and decoherence models disfavored by 4.8 and 5.3 \( \sigma \), resp.
Oscillation to $\nu_\tau$ or $\nu_{\text{sterile}}$?

$\mu$-like data show zenith-angle and energy dependent deficit of events, while e-like data show no such effect.

$\nu_\mu \rightarrow \nu_\tau$ or $\nu_\mu \rightarrow \nu_{\text{sterile}}$

**Propagation**

- $\nu_\mu \rightarrow \nu_\tau$: No matter effect
- $\nu_\mu \rightarrow \nu_s$: With matter effect

For $\sin^2 2\theta = \sim 1$, matter effect suppresses oscillation at higher energy.

**Interaction**

- $\nu_\mu \rightarrow \nu_\tau$: With Neutral Current
- $\nu_\mu \rightarrow \nu_s$: W/O Neutral Current

Check upward-going NC events
Testing $\nu_\mu \rightarrow \nu_\tau$ vs. $\nu_\mu \rightarrow \nu_{\text{sterile}}$

- High E PC events (Evis > 5 GeV)
- Up through muons

- Matter effect

- Neutral current
  - Multi-ring e-like, with Evis > 400 MeV

Pure $\nu_\mu \rightarrow \nu_{\text{sterile}}$ excluded

(PRL 85, 3999 (2000))
Limit on oscillations to $\nu_{\text{sterile}}$

$$\nu_\mu \rightarrow (\sin^2 \xi \cdot \nu_{\text{sterile}} + \cos^2 \xi \cdot \nu_\tau)$$

If pure $\nu_\mu \rightarrow \nu_\tau$, $\sin^2 \xi = 0$

If pure $\nu_\mu \rightarrow \nu_{\text{sterile}}$, $\sin^2 \xi = 1$

SK-1 data

Consistent with pure $\nu_\mu \rightarrow \nu_\tau$

SK collab. draft in preparation
Search for CC $\nu_\tau$ events (SK-I)

CC $\nu_\tau$ events

$\nu_\tau$

$\nu_\tau$

$\tau$

Signature of CC $\nu_\tau$ events
- Higher multiplicity of Cherenkov rings
- More $\mu \not\to e$ decay signals
- Spherical event pattern

Only $\sim 1.0$ CC $\nu_\tau$
FC events/kton yr

(BG (other $\nu$ events)
$\sim 130$ ev./kton yr

Likelihood and neural network analysis
Likelihood / neural-net distributions

Pre-cuts: E(visible) > 1.33 GeV, most-energetic ring = e-like

Down-going (no $\nu_\tau$)  Up-going

Likelihood

Neural-net

Zenith-angle
Zenith angle dist. and fit results

Likelihood analysis

scaled $\tau$-MC

$\nu_{\mu}$, $\nu_{e}$, & NC background

Data

Fitted # of $\tau$ events

138 $\pm$ 48(stat) $+15/-32$(syst)

Expected # of $\tau$ events

78 $\pm$ 26(syst)

Zero tau neutrino interaction is disfavored at 2.4$\sigma$.  

NN analysis

Neural Network

$\tau$+BG

BG

Data

Hep-ex/0607059
Future: Search for Non-zero $\theta_{13}$

One mass scale dominance approx.
$\Delta m^2_{12} \sim 0$, $\Delta m^2_{13} \sim \Delta m^2_{23} = \Delta m^2$

$$P(\nu_\mu \rightarrow \nu_e) = \sin^2 \theta_{23} \cdot \sin^2 2\theta_{13} \cdot \sin^2 \left( \frac{1.27 \Delta m^2 L}{E} \right)$$

only 3 parameters

$P(\nu_\mu \rightarrow \nu_e)$ at SK

Simulation (4.5 Mton·yr)
1+multi-ring, e-like, 2.5~5 GeV/c

Electron appearance

Using finely binned data, look for enhancement at certain energies and angles due to electron neutrino resonance in earth.
Future: Search for non-zero $\theta_{13}$

Sensitivity of 20 years’ SK data

If $\theta_{13}$ is close to CHOOZ limit, non-zero $\theta_{13}$ can be observed by atmospheric neutrinos.
Summary of Atmospheric neutrino analysis

- Activities from 2000 to 2006
  - Allowed parameter region was improved:
    - $1.9 \times 10^{-3} \text{ eV}^2 < \Delta m^2 < 3.1 \times 10^{-3} \text{ eV}^2$
    - $\sin^2 2\theta > 0.93$ at 90% CL
  - L/E dependence of neutrino oscillation was observed.
  - $\nu_\mu \rightarrow \nu_\tau$ favors over $\nu_\mu \rightarrow \nu_{\text{sterile}}$
  - Tau appearance with $2.4 \sigma$ level.

- Future prospects
  - Search for non-zero $\theta_{13}$. If $\theta_{13}$ is close to CHOOZ limit, it could be observed by atmospheric neutrinos.
Solar neutrinos

Main Physics

High statistics measurement of $^8$B solar neutrinos to
(1) solve “solar neutrino problem”
(2) measure oscillation parameters ($\theta_{12}, \Delta m^2_{12}$)
Solar neutrino measurement in SK

- $^8$B neutrino measurement by $\nu + e^- \rightarrow \nu + e^-$
- Sensitive to $\nu_e$, $\nu_\mu$, $\nu_\tau$: $\sigma(\nu_\mu(e^-)) = \sim 0.15 \sigma(\nu_e(e^-))$
- High statistics $\sim 15$ev./day with $E_e > 5$MeV
- Real time measurement. Studies on time variations.
- Studies on energy spectrum.
- Precise energy calibration by LINAC and $^{16}$N.

Typical event

- Timing information $\rightarrow$ vertex position
- Ring pattern $\rightarrow$ direction
- Number of hit PMTs $\rightarrow$ energy

$E_e = 9.1$MeV
$\cos \theta_{\text{sun}} = 0.95$
Super-Kamiokande-I solar neutrino data
May 31, 1996 – July 13, 2001 (1496 days)

$\nu + e^- \rightarrow \nu + e^-$

22400$\pm$230 solar $\nu$ events
(14.5 events/day)

$^8$B flux : $2.35 \pm 0.02 \pm 0.08 \times 10^6$/$cm^2$/sec

Data

\[
\frac{\text{Data}}{\text{SSM(BP2004)}} = 0.406 \pm 0.004 \pm 0.014
\]

(Data/SSM(BP2000) = 0.465 $\pm$0.005 $\pm$0.016/$-0.015$)
Evidence for solar neutrino oscillation by SK and SNO (June 2001)

SK $\phi_{ES} = 2.32 \pm 0.03 + 0.08/-0.07$ [x10$^6$/cm$^2$/s] $\phi_{ES} = \phi_e + 0.15 \phi_{\mu,\tau}$
SNO $\phi_{CC} = 1.75 \pm 0.07 + 0.12/-0.11$ $\phi_{CC} = \phi_e$

Obtained total flux: $\phi_{exp} = 5.5 \pm 1.4$ (cf. $\phi_{SSM(BP2000)} = 5.05+1.0/-0.8$)

Data as of June 2001
SK: 1258 days of SK-I
SNO: 241 days of pure D2O (CC only)
Energy spectrum of SK-I

SK-I 1496day 22.5kt

$(\tan^2 \theta, \Delta m^2)$

SMA (0.0016, 6.9x10^{-6})

LMA (0.38, 7.2x10^{-5})

Just-So (0.26, 7.9x10^{-11})

Energy correlated systematic error
SK-I day/night difference

\[ A_{\text{DN}} = \frac{\text{Day-Night}}{\text{Day} + \text{Night}/2} \]

Expected D/N asymmetry

SK 1496d 5.0-20 MeV 22.5 kt

All

Day
Night

A_{\text{DN}} = 0.021\pm0.020^{+0.013}_{-0.012}
Excluded region by energy spectrum and day/night

Super-Kamiokande 1496 days

Zenith Spectrum $\nu_e \rightarrow \nu_{\mu/\tau}$ (95% C.L.)

Allowed region combined with all solar neutrino data

- Rates: Homestake (Cl), GALLEX (Ga), SAGE (Ga), SK (H2O), SNO CC+NC (D2O)
- Zenith spectra from SK: energy spectra of electrons at 7 zenith angle bins (day + 6 nights)

LMA is favored with 99 % CL.

Plot as of May 2002

Plot after KamLAND first result
SK-II solar neutrino analysis

Event direction
SK-II 791 days 7-20MeV
signal = 7239 $^{+154}_{-152}$ (stat.)

Energy spectrum
flux = 2.38 $^{0.05}_{-0.05}$ (stat.) $^{+0.16}_{-0.15}$ (sys.) $\times 10^6$/cm$^2$/sec
SK-I result: 2.35 +/-0.02(stat.) +/-0.08(syst.)

Consistent with SK-I
Future prospects: precise spectrum measurement

Is there spectrum distortion?

$\nu_e$ survival probability

Recoil electron spectrum

~10% spectrum distortion expected from LMA

But, SK-I spectrum is almost flat.

Data: SK-I
Future prospects: expected sensitivity of SK-III

Expected spectrum in SK-III

5 years data assumed

Energy correlated systematic error

BG is 70% reduced as SK-I below 5.5MeV
Energy correlated systematic error is half as SK-I
5 years

Statistical significance

<table>
<thead>
<tr>
<th>sin²(θ)</th>
<th>Δm² (eV²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.22</td>
<td>7.2 x 10⁻⁵</td>
</tr>
<tr>
<td>0.28</td>
<td>10 x 10⁻⁵</td>
</tr>
<tr>
<td>0.28</td>
<td>7.2 x 10⁻⁵</td>
</tr>
<tr>
<td>0.28</td>
<td>4.8 x 10⁻⁵</td>
</tr>
<tr>
<td>0.35</td>
<td>6.3 x 10⁻⁵</td>
</tr>
</tbody>
</table>

Assumption:
Correlated systematic error: x 0.5
4.0-5.5MeV background : x 0.3 of SK-I
(> 5.5MeV is same as SK-I)
Summary of Solar neutrino analysis

Activities from 2000 to 2006
- The flat energy spectrum and small day/night value of SK favored LMA solution.
- LMA solution was obtained by solar global analysis (SK, SNO, radiochemical) with 99% CL.
- SK-II data is consistent with SK-I data.

Future prospects
- Precise measurement of energy spectrum. ~10% distortion is expected for the LMA solution.
  By lowering background in lower energy region, it should be observed in 5-7 years.
Proton decay search

Physics

Forces Merge at High Energies

Grand Unification
$G \supset SU(2) \otimes U(1) \otimes SU(3)$

Quark+lepton

Establish GUT
Proton decay search \((p \to e^+ \pi^0)\)

No candidate was observed.

Life time limit \((p \to e^+ \pi^0) > 8.4 \times 10^{33}\) years
Proton decay search \((p \rightarrow \nu K^+)\)

\(\mu^+\) shape method

\[ P_{rot} = \frac{1}{2} |Q_{\pi^+}| \]

\(K^+ \rightarrow \pi^+ \pi^0\) method

Combine those methods,
Lifetime: \(>2.3 \times 10^{33}\) years
Sensitivity of future SK

\[ p \rightarrow e^+\pi^0 \]

\[ p \rightarrow \nu K^+ \]

**Sensitivity for \( p^5e\pi^0 \) (90\% CL)**

- SK $\square$ 20 yrs $\rightarrow$ 450ktyr
- BG = 1~2 events

**Sensitivity for \( p^5\nu K^+ \) (90\% CL)**

- SK current limit (90\% CL)
  - 141ktyr, $8.4 \times 10^{33}$ yrs

**Combined sensitivity**

- \( \mu \) spectrum
- Prompt $\gamma$

$\square /B \rightarrow 2 \square 10^{34}$ yrs
(SK 20yrs, 90\% CL)

$\square /B \rightarrow 4 \square 10^{33}$ yrs
(SK 20yrs, 90\% CL)
Supernova neutrinos

Physics

- High statistics supernova events at neutrino burst (~8000 events at 10kpc) to investigate detailed mechanism of supernova burst.
- Supernova relic neutrinos (SRN) to study star formation in the universe.
**Supernova burst search (online)**

Data Acquisition system

Online host computer

A few minutes later

Supernova watch computer

If a candidate is found

**ALARM**

Notify to shift person

Send signal to SNEWS

Check vertex distribution and event pattern

**Selection criteria:**
- \( \geq 25 \) ev. within 10 sec.
- \( \text{Rmean} > 7.5 \text{m} \)

Rmean: averaged distance between event vertices. This cut reject spallation and flasher backgrounds.

SNEWS: (SuperNova Early Warning System)

Current members: SK, SNO, AMANDA/Ice Cube, LVD

Alarm rate was about once per \(~10\) days. (specification of SNEWS).

They were due to PMT flashers and multiple spallation events.

No real galactic supernova was found during SK-I and SK-II.
Search for supernova relic neutrinos

Population synthesis (Totani et al., 1996)
Constant SN rate (Totani et al., 1996)
Cosmic gas infall (Malaney, 1997)
Cosmic chemical evolution (Hartmann et al., 1997)
Heavy metal abundance (Kapplinghat et al., 2000)
LMA v oscillation (Ando et al., 2002)

SRN predictions

Atmospheric v

Spallation B.G. below ~18 MeV
Search for supernova relic neutrinos in SK-I

Energy spectrum (>18MeV)

SK SRN Flux Limits vs. Theoretical Predictions (E > 19.3 MeV)

SK-I flux limit: < 1.2 /cm²/sec

SK limit is close to the model predictions!
Future: Possibilities of $\bar{\nu}_e$ tagging

- **Possibility 1**
  - $n + p \rightarrow d + \gamma$
  - 2.2MeV $\gamma$-ray
  - $\Delta T \approx 200 \textsec$
  - Number of hit PMT is about 6 in SK-III

- **Possibility 2**
  - $n + \text{Gd} \rightarrow \sim 8\text{MeV} \gamma$
  - $\Delta T = \text{several 10th } \textsec$
  - Add 0.2% GdCl$_3$ in water (ref. Vagins and Beacom)

$\bar{\nu}_e$ could be identified by delayed coincidence.
Possibility of SRN detection


No B.G. reduction

Hard to distinguish

Statistically <1σ excess
(10yrs, \( E_{\text{vis}} = 18-30 \text{ MeV} \))

~1.2σ for SK20yrs

B.G. reduction by neutron tagging

Assuming 90% of invisible muon B.G. can be reduced by neutron tagging.

Assuming 80% detection efficiency.

Signal: 22.7, B.G. 13.1(\( E_{\text{vis}} = 15-30 \text{ MeV} \))

Signal: 44.8, B.G. 14.7(\( E_{\text{vis}} = 10-30 \text{ MeV} \))
Summary of proton decay

- **Activities from 2000 to 2006**
  - Lifetime lower limit was obtained:
    - $p \rightarrow e^+\pi^0 > 8.4 \times 10^{33}$ yrs
    - $p \rightarrow \nu K^+ > 2.3 \times 10^{33}$ yrs
- **Future prospects**
  - $p \rightarrow e^+\pi^0 > 2 \times 10^{34}$ yrs, $p \rightarrow \nu K^+ > 4 \times 10^{33}$ yrs for 20 yrs data

Summary of supernova neutrinos

- **Activities from 2000 to 2006**
  - Supernova burst search has in online and offline analyses. No candidate was found.
  - SRN Flux limit: $< 1.2 \text{ /cm}^2\text{/sec}$ for $E > 18 \text{ MeV}$ by SK-I data. It is close to theoretical predictions.
- **Future prospects**
  - Improved search for SRN neutrinos by neutron tagging.