Astroparticle Physics in Hyper-Kamiokande

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for the Hyper-Kamiokande Proto-Collaboration
Agenda

• Status of Hyper-K
• Supernova Burst Neutrinos
• Supernova Relic Neutrinos
• Solar Neutrinos
• Dark Matter
3rd Generation Water Cherenkov Detector

Kamiokande
1983–1996

Super-Kamiokande
1996–today (and beyond)

Hyper-Kamiokande
~2026–???

Koshiba, 2002

Kajita, 2015

???, 20??
Status of Hyper-K

- Proto-Collaboration formed in 2015
  - now: 300 people in 15 countries


Timeline for 1st tank (2nd tank up to 6 years later)

http://hyperk.org/?p=215
After considering other locations within Japan, the Kamioka mine was determined to be the most suitable location for the experiment for many reasons. The Kamiokande experiment had been successfully completed and made significant physics contributions; the mine was still in operation with existing facilities (electricity, water, air ducts, drains, communications); its rock structure was well known and very stable. A suitable site was identified within the mine for the new experiment, close to the existing main tunnel; thus it would not be necessary to excavate a new tunnel, whose cost would be a substantial fraction of the total budget.

The Super-Kamiokande project was approved by the Japanese Ministry of Education, Science, Sports and Culture in 1991 for total funding of approximately $100 M. The US portion of the proposal, which was primarily to build the OD system, was approved by the US Department of Energy in 1993 for $3 M. In addition the US has also contributed about 2000 20 cm PMTs recycled from the IMB experiment.

Excavation of the cavity started in 1991, and detector construction was completed by December, 1995. Super-Kamiokande was successfully commissioned and began operations on April 1, 1996, as scheduled. By May 1, 1996, minor initial problems with the DAQ were cleared up and data taking began in earnest. While earlier data are valid, the large number of interrupted runs collected in April, 1996 are normally discarded for convenience in physics analyses except for analyses of upward-going muons.

Fig. 3 shows the construction timeline. A general view of the detector and other facilities is shown in Fig. 4. In the inset at the right bottom corner, a sectional view of Mt. Ikenoyama is shown, with Super-Kamiokande almost directly under the peak where the tunnels merge.

The cavity which houses the 50 kton tank is located near the mine’s main horizontal truck tunnel, which is 1800 m long at approximately 350 m altitude above mean sea level, as shown in Fig. 5. The Atotsu tunnel, named after the river near its entrance, provides access to the tank top, with its electronics huts and calibration equipment, as well as the experiment control room, a separate cavity housing the water purification system, toilet facilities, and a parking area for mine vehicles. A branch tunnel winds downward around the tank and provides access to the pressure hatch at the tank bottom. Additional halls for the electron LINAC located above and behind the main tank cavity and for equipment storage are also provided.

The main tunnel also provides access to other experiments at the Kamioka Observatory such as KamLAND. As a safety backup the experimental areas can also be reached by mine train from the mine company’s surface facilities in Higashi–Mozumi village.
Changes for Low-E Physics

- lower overburden $\rightarrow$ higher $\mu$ flux (e.g. solar: $2.7 \times$ spallation background compared to SK)
  - 2nd tank in Korea with SK-like overburden

- new PMTs with $2 \times$ timing resolution and $2 \times$ photon detection efficiency
  - **better energy/vertex reconstruction** $\rightarrow$ lower bkgd & enhanced physics capabilities

- **lower energy threshold**

- R&D is still ongoing
  - (e.g. mPMTs – MoU with KM3NeT)

- build on experiences of SK-Gd

![Graph showing time resolved detection efficiency]

SK: 7.3 ns
HK: 4.1 ns
Supernova $\nu$ Burst

- at 10 kpc: \textbf{50 k – 80 k events} per tank (hierarchy-dependent) \textbf{in $\sim 10$ s}

- precise event-by-event \textbf{time & energy} information

- \textbf{directionality}: $\sim 1^\circ$ (via $\nu_e$-scattering)

- most sensitive to $\bar{\nu}_e$ ($\sim 90\%$ inverse beta decay on H)

$\rightarrow$ detailed information on SN explosion mechanism (e.g. Standing Accretion Shock Instability – SASI)
SN in Nearby Galaxy

- 2100–3150 events in LMC (SN1987a-like)
- 9–13 events in Andromeda
- ≥1 event out to few Mpc

→ important test for SN simulations
Supernova Relic Neutrinos

- $\nu$ from all SN integrated over the history of the universe
- encode history of star formation
- information on dim SNe & black hole formation

>5$\sigma$ detection possible

$\rightarrow$ measure spectrum!
Solar Neutrinos

- Day/Night asymmetry (Earth matter effect)
- \(5\sigma\) observation in \(~3\) years
- distinguish solar (\(\nu_e\)) & reactor (\(\bar{\nu}_e\)) values of \(\Delta m^2_{21}\)
  \(\rightarrow\) CPT violation?

\[
\sin^2 \theta_{12} = 0.312 \pm 0.025 \\
\Delta m^2_{21} = 7.54 \pm 0.19 \\
\sin^2 \theta_{12} = 0.311 \pm 0.014 \\
\Delta m^2_{21} = 4.85 \pm 1.4 \\
\sin^2 \theta_{12} = 0.308 \pm 0.013 \\
\Delta m^2_{21} = 7.50 \pm 0.19
\]
Solar Neutrinos

- transition between vacuum and matter oscillations occurs at ~5 MeV
- 3–5σ observation in 10 years

Various non-standard models

Vacuum oscillation dominant

Matter oscillation dominant

See this ‘up-turn’
Dark Matter

- indirect detection via annihilation/decay to $\nu$
- very good sensitivity at low WIMP masses ($\leq 100$ GeV)

Indirect detection via annihilation/decay to $\nu$ and very good sensitivity at low WIMP masses ($\leq 100$ GeV) are key aspects of dark matter research. The image shows the 90% CL upper limit for WIMP masses and cross sections, indicating the current sensitivities and limits set by experiments such as SK and other collaborations. The graph illustrates the expected relic density from the thermal dark matter scenario compared to the observed relic density inside the Sun.
Other Measurements

- detect solar \textit{Hep} neutrinos \((^3\text{He} + p \rightarrow ^4\text{He} + e^+ + \nu_e)\)
- short-time variations in solar neutrino flux
- solar flares
- gamma ray bursts
- newborn pulsar winds
- \textit{etc.}

... and non-astrophysics:
- determine \(\delta_{\text{CP}}\) and mass hierarchy with beam and atmospheric neutrinos
- proton decay searches
- \textit{etc.}
Summary

- Hyper-K is the next step in the very successful Japan-based neutrino research programme.
- $8 \times (17 \times)$ fiducial volume & high-efficiency PMTs improve low-E astrophysics:
  - galactic SN: $\sim 10^5$ events, detailed info on explosion mechanism
  - $5\sigma$ observation of supernova relic neutrinos (SRN) & first measurement of SRN spectrum
  - solar neutrinos (day/night asymmetry & spectrum upturn, $Hep$ neutrinos, time variation)
  - indirect dark matter searches
  - etc.