Hyper-Kamiokande Physics Opportunities

Submitted by the Hyper-Kamiokande Working Group *
to the 2013 Snowmass Intensity Frontier Neutrino Working Group

January 31st 2013

Abstract

We propose the Hyper-Kamiokande (Hyper-K) detector as a next generation underground water Cherenkov detector [1]. It will serve as a far detector of a long baseline neutrino oscillation experiment envisioned for the upgraded J-PARC beam, and as a detector capable of observing, far beyond the sensitivity of the Super-Kamiokande (Super-K) detector, proton decays, atmospheric neutrinos, and neutrinos from astrophysical origins. The current baseline design of Hyper-K is based on the highly successful Super-K detector, taking full advantage of a well-proven technology. Hyper-K consists of two cylindrical tanks lying side-by-side, the outer dimensions of each tank being $48(W) \times 54(H) \times 250(L)$ m^3. The total (fiducial) mass of the detector is 0.99 (0.56) million metric tons, which is about 20 (25) times larger than that of Super-K. A proposed location for Hyper-K is about 8 km south of Super-K (and 295 km away from J-PARC) at an underground depth of 1,750 meters water equivalent (m.w.e.). The inner detector region of the Hyper-K detector is viewed by 99,000 20-inch PMTs, corresponding to the PMT density of 20% photo-cathode coverage (one half of that of Super-K).

The Hyper-K project is envisioned to be completely open to the international community. The current working group contains members from Canada, Japan, Korea, Spain, Switzerland, Russia, the United Kingdom and the United States. The United States physics community has a long history of making contributions to the neutrino physics program in Japan. In Kamiokande, Super-Kamiokande, K2K and T2K, US physicists have played important roles building and operating beams, near detectors, and large underground water Cherenkov detectors. This set of three one-page whitepapers prepared for the US Snowmass process describes the opportunities for future physics discoveries at the Hyper-K facility with beam, atmospheric and astrophysical neutrinos.

*Project contact: Tsuyoshi Nakaya <t.nakaya@scphys.kyoto-u.ac.jp>

The Hyper-Kamiokande Working Group

Boston University (USA): Contact: E. Kearns
Chonnam National University (Korea): Contact: K.K. Joo
Duke University (USA): Contact: C.W. Walter
Earthquake Research Institute, The University of Tokyo (Japan): Contact: A. Taketa
ETH Zurich (Switzerland): Contact: A. Rubbia
Institute for Nuclear Research (Russia): Contact: Y. Kudenko
Imperial College London (UK): Contact: M.O. Wascko
Kamioka Observatory, ICRR, The University of Tokyo (Japan): Contact: M. Shiozawa
Kavli IPMU, The University of Tokyo (Japan): Contact: M.R. Vagins
KEK (Japan): Contact: T. Kobayashi
Kobe University (Japan): Contact: Y. Takeuchi
Kyoto University (Japan): Contact: T. Nakaya
Lancaster University (UK): Contact: P.N. Ratoff
Los Alamos National Laboratory (USA): Contact: G. Sinnis
Louisiana State University (USA): Contact: T. Kutter
Miyagi University of Education (Japan): Contact: Y.Fukuda
Nagoya University (Japan): Contact: Y. Itow
Okayama University (Japan): Contact: Y. Koshio
Osaka City University (Japan): Contact: K. Yamamoto
Pontifícia Universidade Católica do Rio de Janeiro (Brazil): Contact: H. Nunokawa
Queen Mary, University of London (UK): Contact: F. Di Lodovico
Seoul National University (Korea): Contact: S. B. Kim
STFC Rutherford Appleton Laboratory (UK): Contact: D. Wark
Sungkyunkwan University (Korea): Contact C. Rott
The California State University Dominguez Hills (USA): Contact K. Ganezer
The University of Tokyo (Japan): Contact: M. Yokoyama
Tohoku University (Japan): Contact: K. Inoue
Research Center for Cosmic Neutrinos, ICRR, The University of Tokyo (Japan): Contact: K. Okumura
Tokyo Institute of Technology (Japan): Contact: M. Kuze
TRIUMF (Canada): Contact: A. Konaka
University Autonoma Madrid (Spain): Contact: L. Labarga
University of British Columbia (Canada): Contact: H.A. Tanaka
University of Geneva (Switzerland): Contact: A. Blondel

University of Hawaii (USA): Contact: J.G. Learned

University of Regina (Canada): Contact: M. Barbi

University of Toronto (Canada): J.F. Martin

University of California, Davis (USA): Contact: R.Svoboda

University of California, Irvine (USA): Contact: H.W. Sobel

University of Liverpool (UK): Contact: N. McCauley

University of Oxford (UK): Contact: G. Barr

University of Pittsburgh (USA): Contact: V. Paolone

University of Sheffield (UK): Contact: L.F. Thompson

University of Washington (USA): Contact: R.J. Wilkes

University of Warwick (UK): Contact: G.J. Barker

University of Winnipeg (Canada): B. Jamieson

Virginia Tech (USA): Contact: C. Mariani

York University (Canada): Contact: S. Bhadra

Low-Energy Neutrino Physics and Astrophysics with Hyper-K

Hyper-K represents the next generation of highly-successful water Cherenkov technology for observation of low-energy (less than ∼50 MeV) neutrinos, including solar neutrinos [11, 12, 13], core-collapse supernova neutrinos [14, 15, 16], and potentially dark matter annihilation neutrinos [17].

Solar Neutrinos: Assuming sufficient depth to overcome cosmic-muon-induced spallation background, Hyper-K will observe ∼115,000 elastic solar ^{8}B neutrino-electron scatters per year (above its energy threshold and after event selection efficiency, assuming a livetime of 90%), an unprecedentedly large solar neutrino rate. With tight control of systematic uncertainties, Hyper-K will be very sensitive to the solar day/night effect, *i.e.* the regeneration of ν_e flavor of solar neutrinos passing through the Earth. Within five years, Hyper-K will determine the solar zenith angle variation amplitude to ∼0.5%– expressed here as a day/night asymmetry, defined as (day − night)/(0.5(day + night))– measuring Δm^2_{21} with a precision comparable to that of current reactor antineutrino experiments, and establishing (or refuting) the presence of matter effects on neutrino oscillations with a significance exceeding 4σ [18].

Supernova Neutrinos: Hyper-K is sensitive to neutrinos from Galactic core-collapse supernovae (∼250,000 interactions in ∼10 s at the Galactic center a few times/century), nearby supernovae (∼25 interactions at Andromeda; 1/2 interactions for distances < 4 MPc with ∼ 60%/25% probability every few years) and distant supernovae (∼100 interactions/year, up to $z \sim 1$). With Gd salt doping [19], Hyper-K could also separate $\bar{\nu}_e$ inverse beta reactions from other interactions. A large-statistics Galactic burst offers many unique opportunities (*e.g.* [20, 21] and references therein). From the time, flavor and energy profile of the neutrinos, we can learn about the neutronization burst, shock wave effects, explosion temperatures, and black hole formation. We may gain information on neutrino parameters, in particular mass hierarchy. Spectral swaps between neutrino flavors will enable the study of $\nu - \nu$ interactions. In addition to an early alert for even quite distant supernovae, Hyper-K could also achieve precision pointing to a nearby supernova's direction. Even a few neutrinos from nearby extragalactic supernovae will determine the nature of nearby transients whose mechanism is uncertain [22]. The rate and spectrum of distant supernova neutrinos characterize the properties of typical supernova explosions (luminosity and explosion temperature). For distant supernovae, Gd doping is essential to tag $\bar{\nu}_e$ between 10 and 30 MeV and thereby distinguish supernova neutrinos from atmospheric neutrino backgrounds.

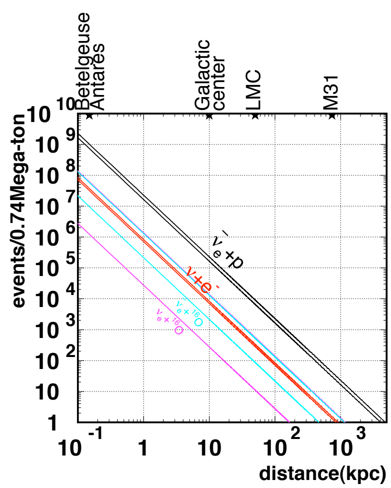

Figure 4: Expected numbers of SN burst events in HK for each interaction as a function of the distance to the SN [1].

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