HYPER-KAMIOKANDE

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on behalf of the Hyper-Kamiokande proto collaboration
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Water Čerenkov Detector

- Cherenkov ring
- Particle identification (> 99% efficiency)
- Momentum reconstruction (energy and direction)
- Large mass $\Rightarrow$ rare process (p decay, $\nu$ physics)
- Well established technology $\rightarrow$ next slide
New physics revealed by WČ detectors

Kamiokande (1983-1996)

- Proton decay search
- Atmospheric neutrino anomaly
- Solar neutrino observation
- Supernova 1987A

⇒ Birth of Neutrino Astrophysics

Super-Kamiokande (1996-)

- Proton decay: exclude SU(5)
- Atmospheric neutrino oscillation
- Solar neutrino oscillation
- Long baseline (K2K / T2K)

⇒ Discovery of Atmospheric Neutrino Oscillations
New physics with Hyper-Kamiokande

- CP violation
- Mass hierarchy
- $\theta_{23}$ octant
- Neutrino astrophysics
- Supernova
- Proton decay
- …?!

x3 J-PARC beam power

x 20 fiducial mass (HK: 180kton x 2)

Improved detector performance

New photosensor
Hyper-Kamiokande Detector Design

Two high performance water Cherenkov detectors
- $74\text{ m} \Phi \times 60\text{ m} H$
  $\Rightarrow 180\text{kton fiducial mass}$
- $40,000 \times 20\text{-inch}$
  new PMTs (next slide)
  $\Rightarrow 40\%$ photocoverage
New Photosensor

Hyper-K PMT developed with Hamamatsu
- Box & Line dynode structure (SK: Venetian Blind)
- \( \times 2 \) photodetection efficiency
- \( \times 2 \) better timing response
- \( \times 2 \) water pressure resistance (>100m equivalent)

⇒ Significant impact to detector design and physics performance
Upgrade of J-PARC neutrino beam

- J-PARC neutrino beam for T2K
  - 30GeV proton synchrotron
  - 410kW with 2.5 sec cycle (as of May 2016)
  - 295km baseline to Super-K
  - 2.5° off-axis $\nu_\mu$ and $\overline{\nu}_\mu$ beam peaked at 0.6GeV to search for CP violation

- J-PARC upgrade plan
  - Upgrade of Main Ring approved
    - $\times 2$ rate with new power supply system
    - T2K: $\sim 900$kW $\Rightarrow$ $\sim 1.3$MW by 2026
    - $\times 3$ beam power for Hyper-K
Hyper-Kamiokande Proto-collaboration

- Proto-collaboration formed in January 2015 with ~250 physicists
  - Defined governance structure and international task/cost sharing
- ICRR and KEK-IPNS signed MoU for promotion of Hyper-Kamiokande
Worldwide R&D

• Alternative options for photo-sensors
  • 50cm High-QE Hybrid Photodetector (HPD)
  • Multi-PMT module
  • Texas 11” PMT for OV

200ton water Cherenkov test detector at Kamioka (EGADS)

• Near Detectors
  • Upgrade plans for 280m detectors
  • Water Cherenkov detectors at 1-2 km proposed
    • Neutrino flux close to Hyper-K
      ⇒ suppression of systematic uncertainties
Hyper-Kamiokande proposed timeline

- Target to start operation with 1\textsuperscript{st} detector from 2026
- Sensitivity evaluated assuming staged construction strategy with the same 2\textsuperscript{nd} detector starts 6 years later
Hyper-K Physics Capabilities
CP violation in neutrino sector

\[ P(\nu_\mu \rightarrow \nu_e) \neq P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) \]

Neutrino mode
\[ \nu_e \]
Antineutrino mode
\[ \bar{\nu}_e \]
295km

J-PARC neutrino beam

Appearance signal at Hyper-K
- 1.3MW×10×10⁷s
  (10years running)

\[ \delta_{CP} = 0 \]
\[ \delta_{CP} = 90° \]
\[ \delta_{CP} = -90° \]
\[ \delta_{CP} = 180° \]
Projected sensitivity to $\delta_{CP}$

With 1.3MW×10×10^7s (10yr)

- CP violation observation
  - $>3\sigma$ for 78% of $\delta_{CP}$
  - $>5\sigma$ for 62% of $\delta_{CP}$
- Measurement of $\delta_{CP}$
  - 21° for $\delta_{CP} = 90°$
  - 7° for $\delta_{CP} = 0°$
Precise measurements of $\Delta m^2_{32}$ and $\theta_{23}$

- Precision of $\Delta m^2_{32}$
  - $\delta(\Delta m^2_{32}) \sim 1.4 \times 10^{-5}$ eV$^2$
    (ref. $\Delta m^2_{21} = (7.5 \pm 0.2) \times 10^{-5}$ eV$^2$)
  - $\Rightarrow$ Sensitivity to mass hierarchy in combination with reactor

- Precision of $\theta_{23}$
  - $\delta(\sin^2 \theta_{23}) \sim 0.006$ (for $\sin^2 \theta_{23} = 0.45$)
  - $\delta(\sin^2 \theta_{23}) \sim 0.015$ (for $\sin^2 \theta_{23} = 0.50$)
  - $\Rightarrow$ Good potential to determine $\theta_{23}$ octant
Atmospheric neutrino

- Matter effects enhance $P(\nu_\mu \rightarrow \nu_e)$ at 2-10GeV
  - Normal hierarchy $\Rightarrow$ neutrino
  - Inverted hierarchy $\Rightarrow$ anti-neutrino
- Resolve mass hierarchy in $\sim 3$ years ($\sin^2\theta_{23}=0.5$) by combination of atmospheric + beam $\nu$

J. Raaf, NNN2013

from HK-LoI (5.6Mt \cdot yr)
Proton decay search

• Probe GUT scale by virtual particle exchange \(\Rightarrow\) proton decay

\[
\Gamma(p \to e^+ \pi^0) \approx \frac{g^4 m_p^5}{M_X^4}
\]

New physics BSM

EW unification

GUT?

\(10^2\text{GeV} > 10^{15}\text{GeV}\)

How to access?

10^2\text{GeV}

\(\sqrt{s} = 318\text{ GeV}\)

\[
\begin{align*}
E_{\text{W, unification}}^2 &> 10^{15}\text{ GeV} \\
\text{How to access?}\ &10^2\text{ GeV}
\end{align*}
\]

\(\tau_p = 1.4 \times 10^{34}\text{ yr} \) (SK limit)

• BG free observation with high photo-coverage + HQE PMT

• 9\(\sigma\) discovery in 10 years for

\[\tau_p = 1.4 \times 10^{34}\text{ yr} \] (SK limit)
Proton decay search: 3σ discovery potential

- Good discovery potential for $\tau_p > 10^{34} \sim 10^{35}$ years (test of SUSY SO(10) etc.)
- Further improvement under study

Limit from SK

High photo-coverage (baseline)

Low photo-coverage

Muon momentum ($p \rightarrow \nu K$ search)
Hyper-Kamiokande neutrino telescope

- Supernova
  - >10^5 events expected from SN at 10kpc
  - Probe core collapse and cooling mechanism
  - 100 supernova relic neutrino events in 10yr
- Solar neutrino observation
  - MSW transition (upturn of solar spectrum)
  - Day/night asymmetry (earth matter effects)
  - Solar hep neutrinos
Summary

- **Wide physics capabilities with Hyper-Kamiokande**
  - Observation/measurement of CP violation in neutrino sector
  - Proton decay search with discovery potential for $10^{34} \sim 10^{35}$ years
  - Neutrino astrophysics
    - Supernova, relic SN, solar neutrino, dark matter search…

- **Towards early approval of the project**
  - Formed Hyper-Kamiokande international proto-collaboration
    - Promotion of the project supported by ICRR and KEK-IPNS
    - Worldwide R&D actively ongoing
  - Baseline design: high photodetector density with new HQE PMTs
  - Design Report submitted to Hyper-K Advisory Committee
  - Aim to put in next SCJ master plan and MEXT roadmap