# Low Energy Neutrino Studies and Backgrounds at Hyper-Kamiokande


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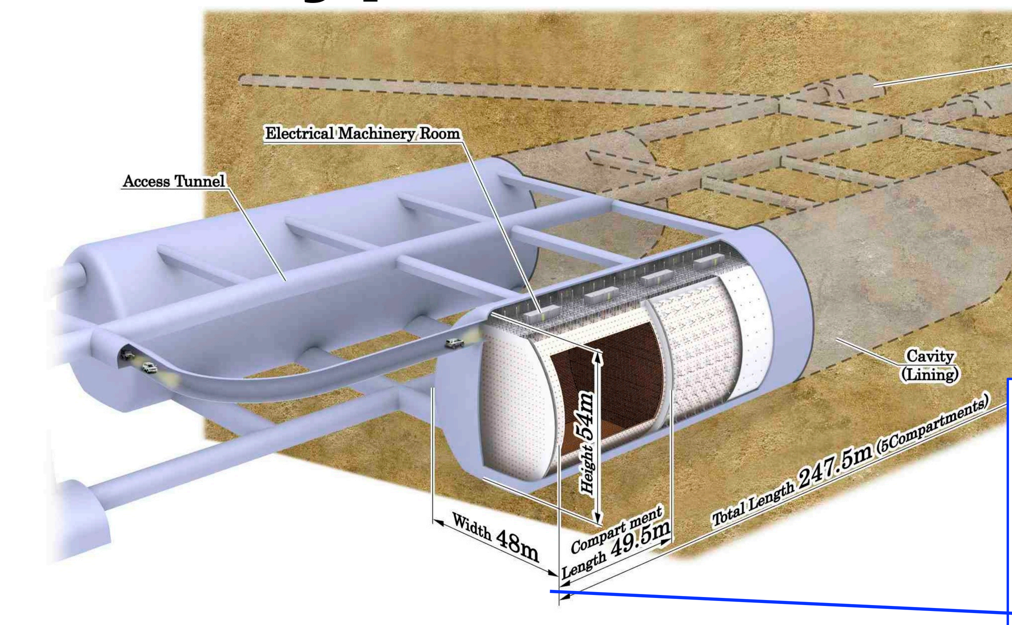
## 1. Hyper-Kamiokande





| Location candidates | Mozumi | Tochibora |
|---|---|---|
| World geographical Coodinate system | 36°25'28.7796"N 137°18'13.9824"E | 36°21'20.105"N 137°18'49.137"E |
| Meters water equivalent on detector | 2,200 m | 1,750 m |

**Hyper-Kamiokande (Hyper-K) is a next generation underground water Cherenkov detector.**

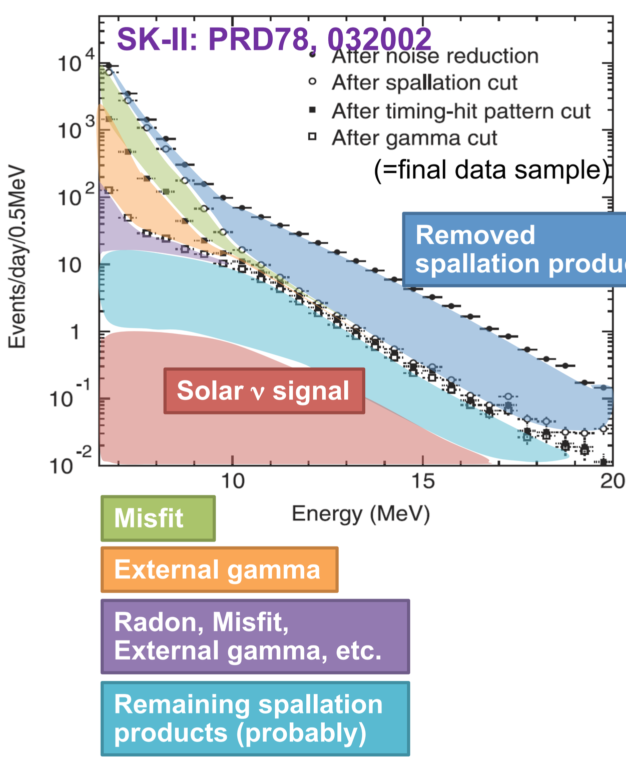
| Detector Design | Super-Kamiokande | Hyper-Kamiokande |
|---|---|---|
| Caverns | 1 cylindrical caverns, No compartments | 2 egg shape caverns, 10 compartments |
| Num. of ID/OD PMTs | 11,129 / 1,885 | ~99,000 / ~25,000 |
| Photo coverage | 40% | ~20% (to be optimized) |
| Total / Fiducial Volume | 50 kt / 22.5 kt | 0.99 Mt / 0.56 Mt |

R&Ds for photo sensor, electronics, detector design, location and physics capability are being performed.

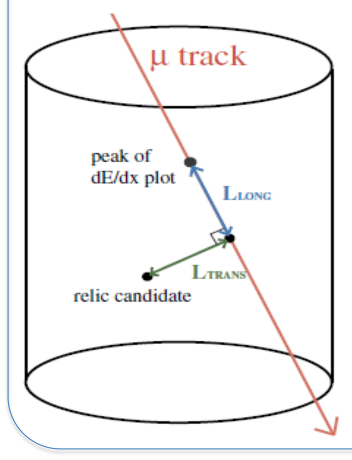
Fruitful physics programs are planned for accelerator, atmospheric and solar neutrinos, proton decays, neutrinos from other astrophysical origins. e.g. CP asymmetry. mass hierarchy, $\theta_{23}$ octant …

## 2. Spallation Background and Location

### 1. Spallation, dominant BG source in low energy, ~10-20MeV




Cosmic-ray μ interact with oxygen nuclei in the water and produce various radio active isotopes. →Spallation

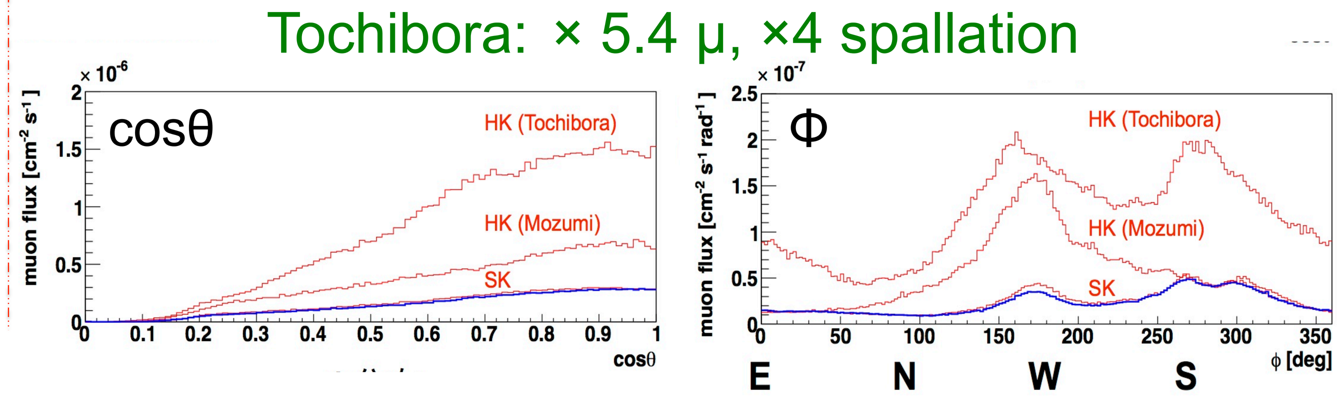


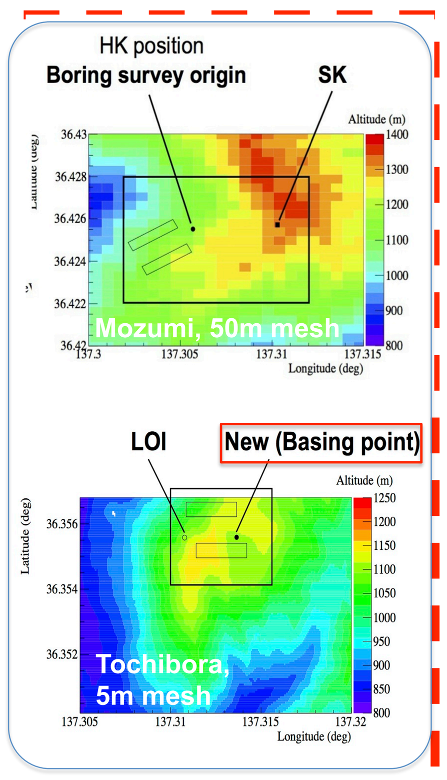

Spallation cut
Likelihood method with
- Peak Charge Q of previous μ
- Time difference from pre. μ
- Transverse Length ($L_{TRANS}$)
- Longitudinal Length ($L_{LONG}$) ← new, PRD85, 052007

More μ, worse separation.

### 2. Muon and spallation simulation[*1]

Simulation studies are performed w/
MUSIC[*2] : Muon flux at locations
FLUKA[*3] : Muon-nuclear interaction
Mozumi: × 2.2 μ, ×2 spallation of SK
Tochibora: × 5.4 μ, ×4 spallation




*1: KamLand Collaboration, PRC81:025807(2010) *2: V.A.Kudryavtsev arXiv:0810.4635 *3: G.Battistoni et.al., AIP Conf. Proc. 896, 31-49

### 3. Effects on signal and background

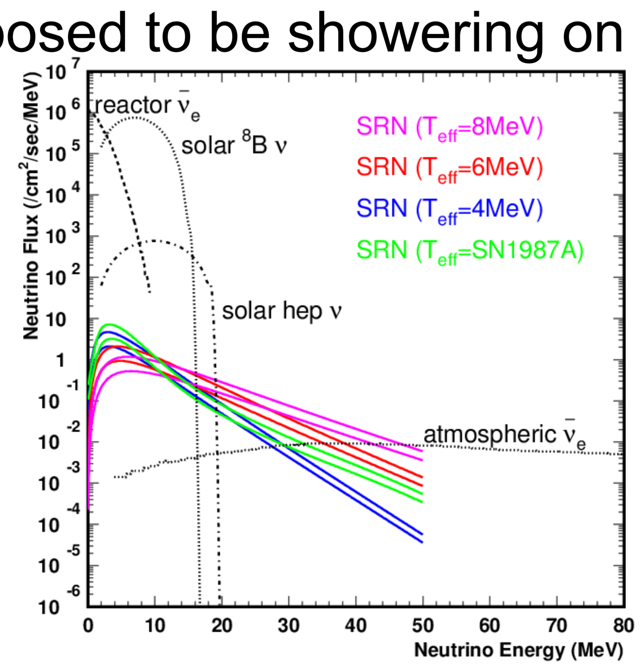
| Spallation cut with LH for E=17.5–20MeV. (20-26MeV) | Cosmic μ × 1 | μ × 2 | μ × 5 |
|---|---|---|---|
| Signal Efficiency, keeping same spallation reduction rate | 79% (90%) | 62% (77%) | 29% (54%) |
| N of spallation background, keeping 80% sig. efficiency | ≡ 1 | 3.6 | 13.2 |

## 3. Supernova Relic Neutrino

**Supernova Relic Neutrino** is diffused supernova neutrinos from all past supernovae. SRN is supposed to be showering on us continuously.

**SRN Flux**

= **Star Formation Rate**
× **Neutrino emission spectrum (supernova models)**
× **Redshift (Hubble's law)**

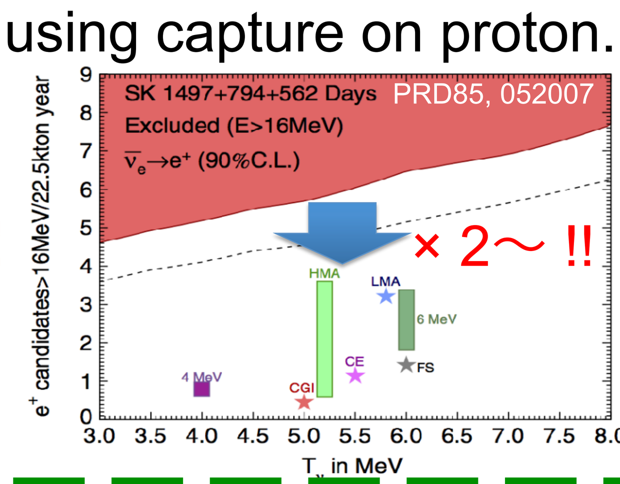



**Current status for SRN search**

SRN has been searched with Super-Kamiokande though inverse beta decay. $\bar{\nu}$ + p → e⁺ + n.

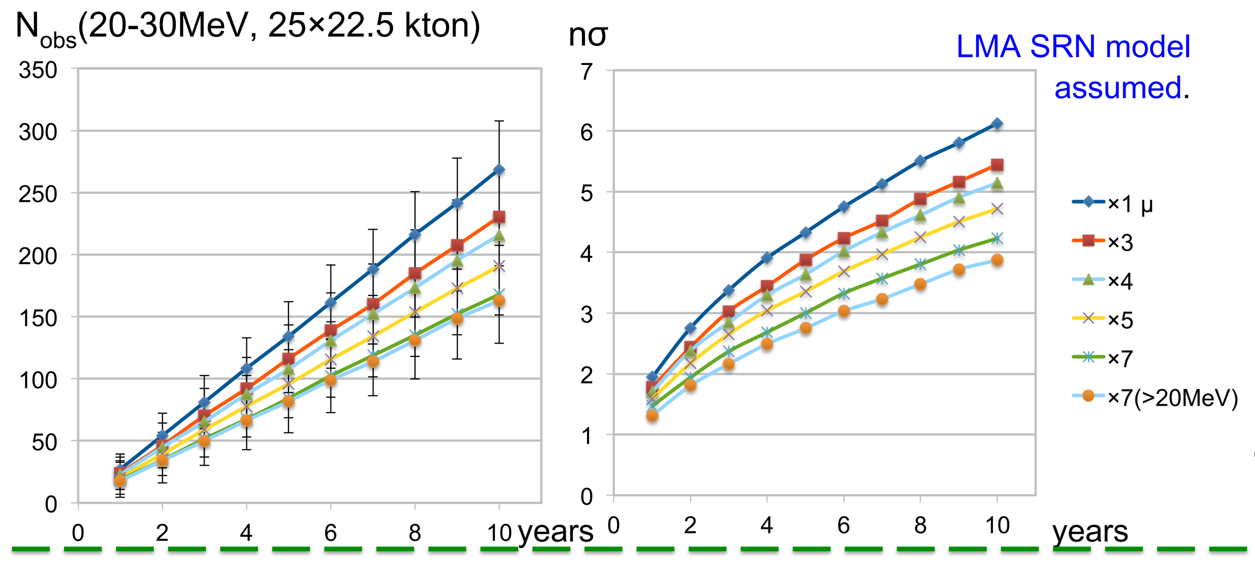
- Single positron search ( PRD85, 052007)
- Positron + neutron tagging search, using capture on proton. (arXiv:1311.3738)

**Close to theoretical assumptions!**




**SRN search with Hyper-K (single positron)**

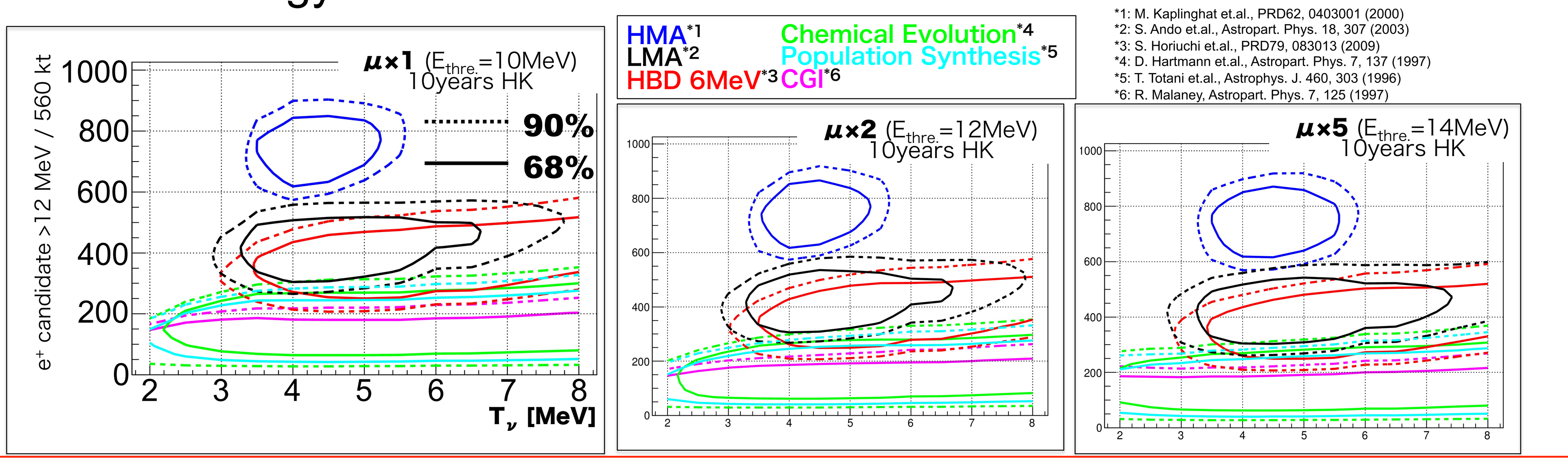
Because of the large mass, Hyper-K is a promising detector for SRN.




6 σ non-0 observation of SRN, with same μ BG as SK.
5 σ for Mozumi-site.
4 σ for Tochibora-site.

**SRN search with Hyper-K+Gd ( positron + Gd(n,g) neutron tagging)**

By adding Gd into Hyper-K, we can reduce several backgrounds and lower the energy threshold. It will lead us SRN model distinction.



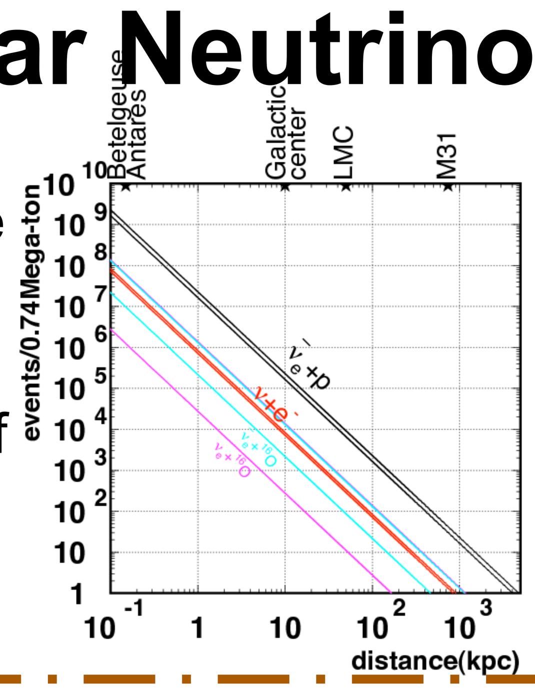

*1: M. Kaplinghat et.al., PRD62, 0403001 (2000)
*2: S. Ando et.al., Astropart. Phys. 18, 307 (2003)
*3: S. Horiuchi et.al., PRD79, 083013 (2009)
*4: D. Hartmann et.al., Astropart. Phys. 7, 137 (1997)
*5: T. Totani et.al., Astrophys. J. 460, 303 (1996)
*6: R. Malaney, Astropart. Phys. 7, 125 (1997)

**LMA can be sepalated from other models with > 90% C.L., except for HBD 6MeV.**

## 4. Supernova Burst and Solar Neutrino

**Supernova Burst Neutrino :** In case of a galactic supernova, very large statistics and time profile will be available. SN at nearby galaxy is also possible. (0.4～0.8 events at 4Mpc.)

**Solar Neutrino :** Recently, SK reported a indication of matter effect in solar neutrino oscillation by day/night rate asymmetry. PRL122,091805(2014)
HK will improve the results, hopefully.




## Summary

Several R&Ds for Hyper-Kamiokande, a next generation underground Cherenkov detector, are being performed.

- Spallation Background for candidate sites
- Supernova Relic Neutrino search with Hyper-K
- Supernova Burst and Solar neutrino study with Hyper-K

are discussed here.

**Hyper-K is a promising detector for low energy neutrino studies.**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