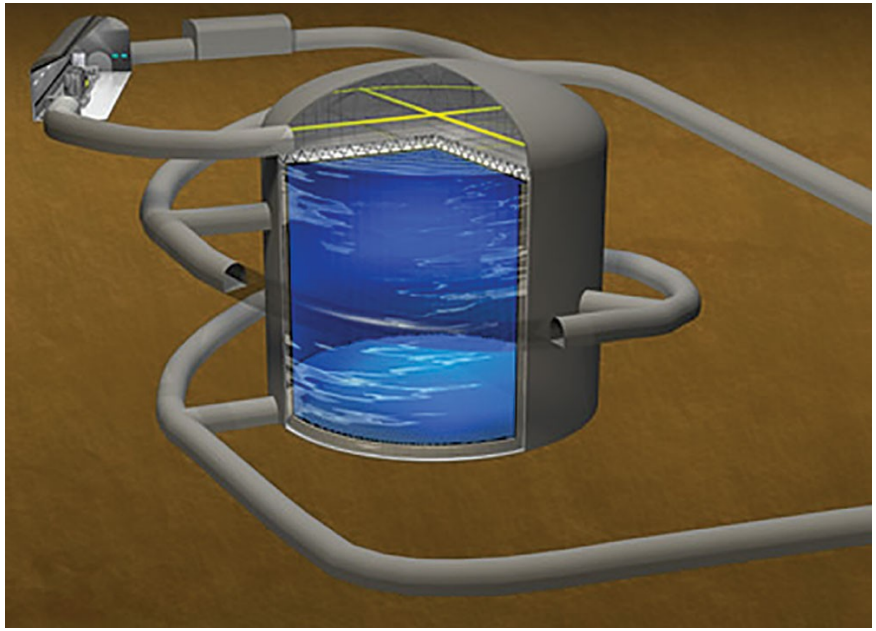
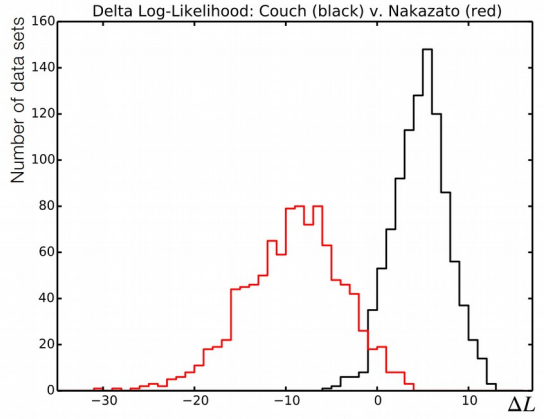
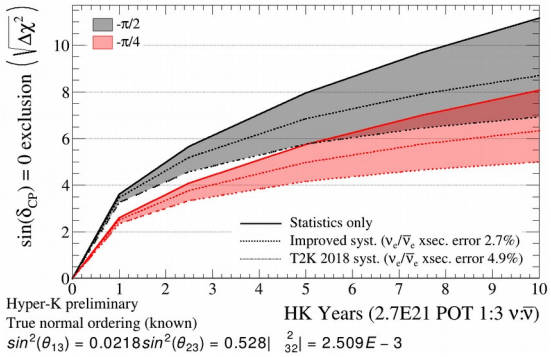
Hyper-Kamiokande:
Status & Plans







Matthew Malek

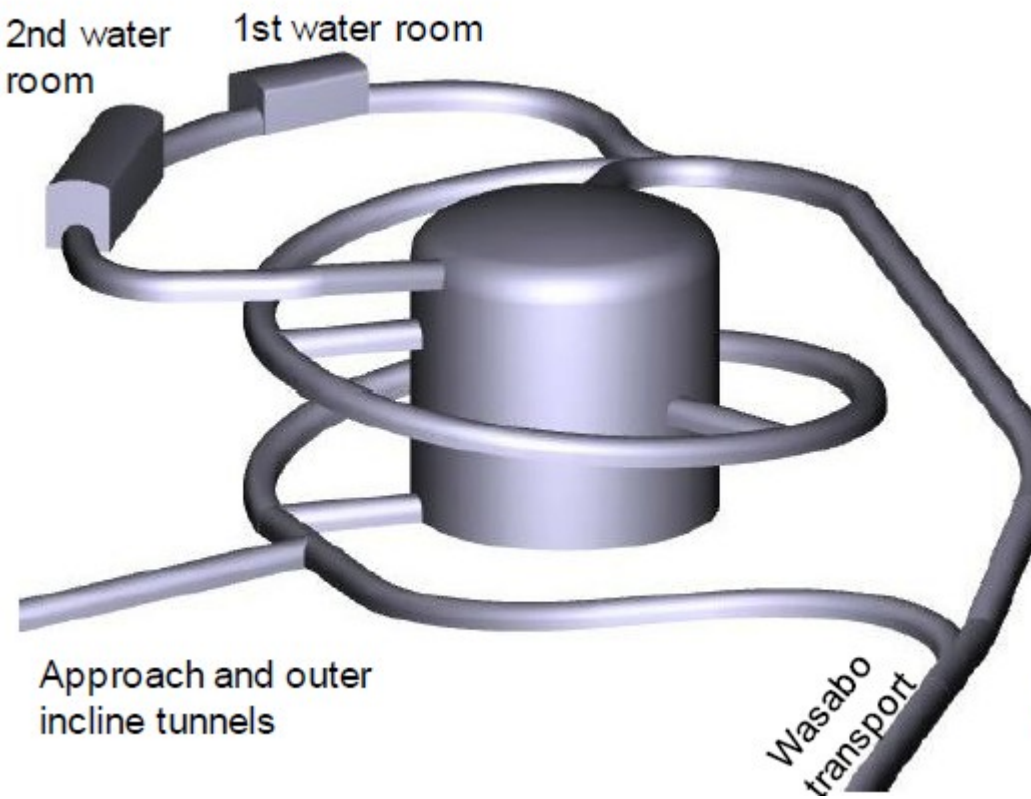
The University of Sheffield

30th International Symposium on Lepton Photon Interactions at High Energies

11th January 2022

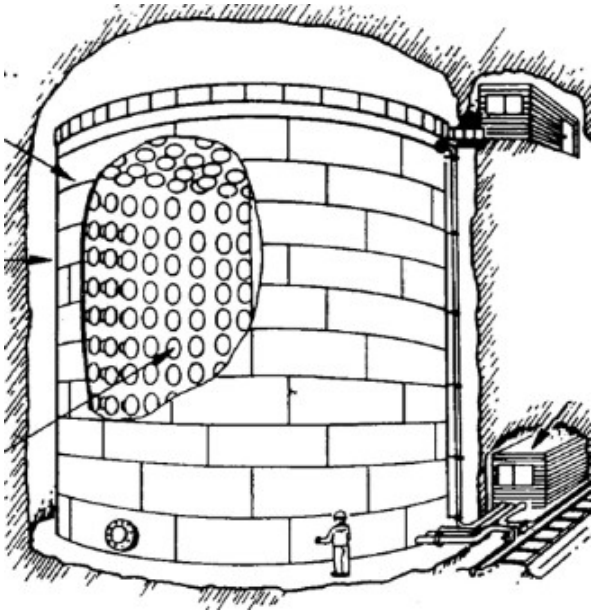
Outline

- **The Hyper-Kamiokande Experiment**
  - Design overview
  - Current status
- **Particle Physics**
  - Neutrino oscillation
  - Proton Decay
- **Astroparticle Physics**
  - Supernovae
  - Dark matter detection



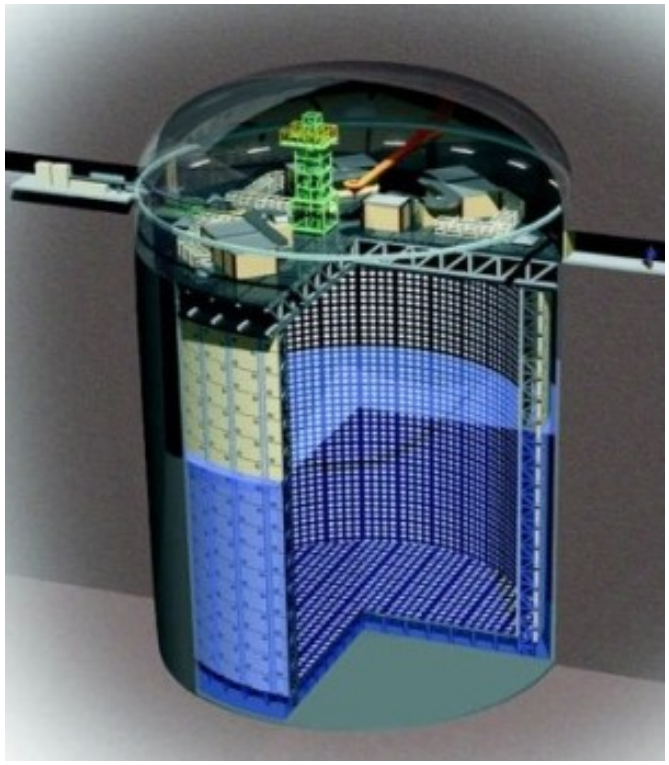
The Kamioka Trilogy

The Kamioka Saga Continues!



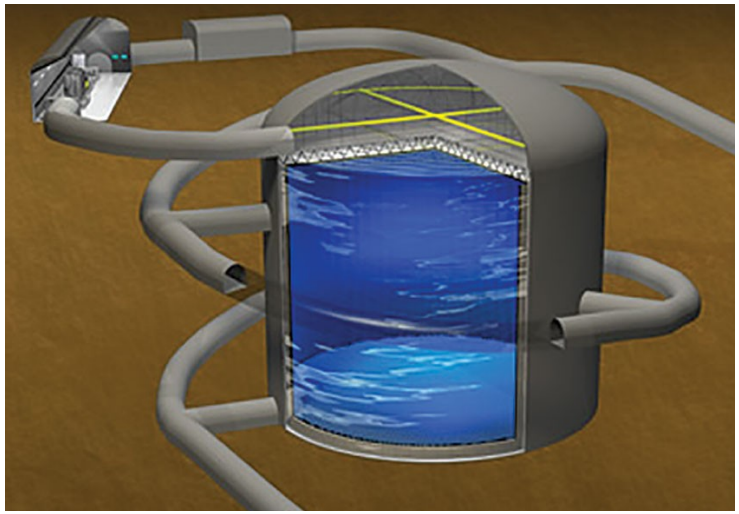
Kamiokande
- 1983 – 1996
- 3 ktonnes total
- 680 tonnes fiducial

Super-Kamiokande
- 1996 – ??



- 50 ktonnes total
- 22.5 tonnes fiducial
  – 33x K

Hyper-Kamiokande
- 2027 – ??
- 260 ktonnes total
- 190 tonnes fiducial
  – 8x Super-K



Hyper-K Fact Sheet

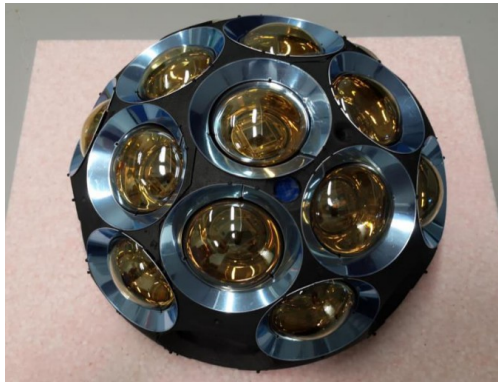
The University Of Sheffield.

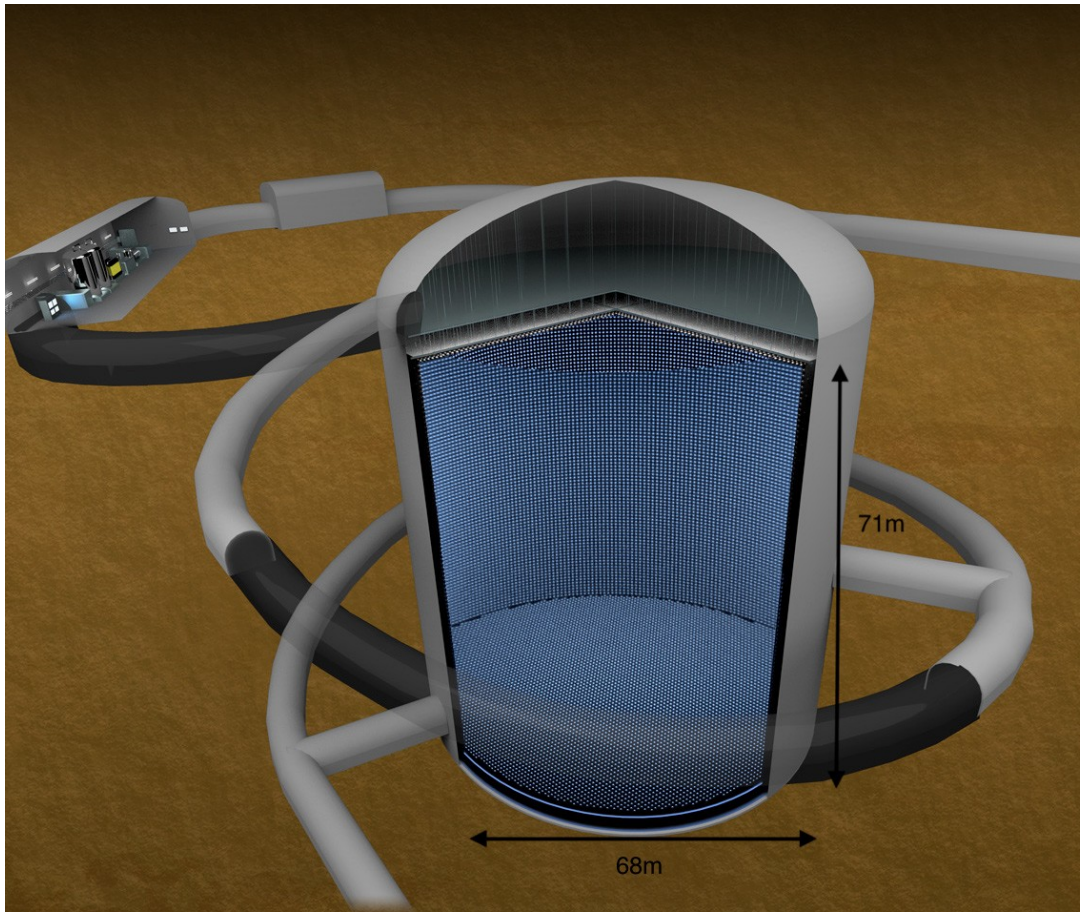
Location:

- Tochibora mine (Mt. Nijugoyama)
- 650m overburden (1755 m.w.e.)

Size:

- 71m (height) x 68m (diameter)
- 260 ktonnes total
- 188 ktonnes fiducial





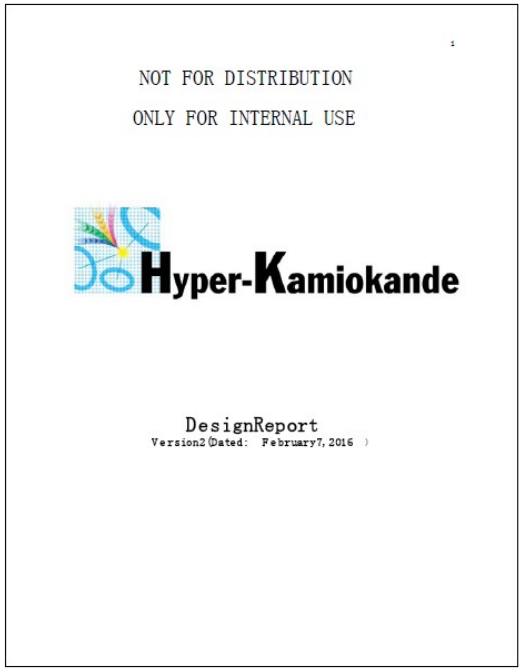
Photosensors:

- 20% photocathode coverage with new 50cm Hamamatsu 'box & line' PMTs
  - 1ns TTS; half that of SK PMTs
  - Quantum efficiency **double** that of SK PMTs.
- Supplemented by additional arrays of 3” multi-PMT (mPMT) assemblies

Hyper-K Status

2015: Proto-Collaboration formed
2016: Design Report submitted
2020: Funding in place
2021: Tunnel excavation started

2027: Begin data taking!

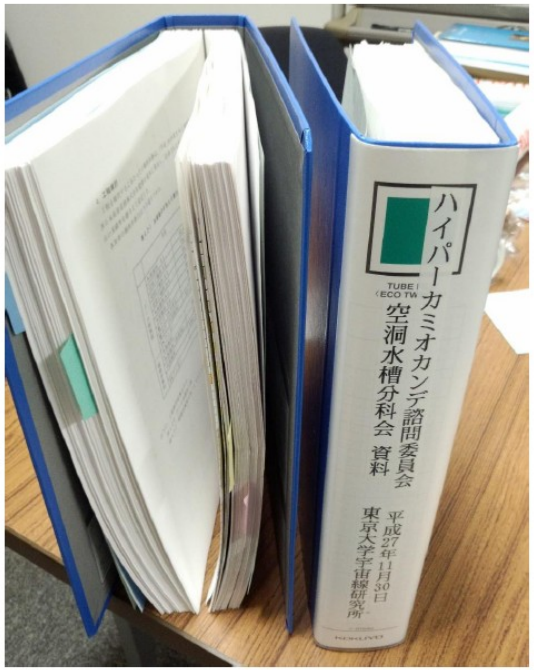

NOT FOR DISTRIBUTION

ONLY FOR INTERNAL USE

Hyper-Kamiokande

DesignReport

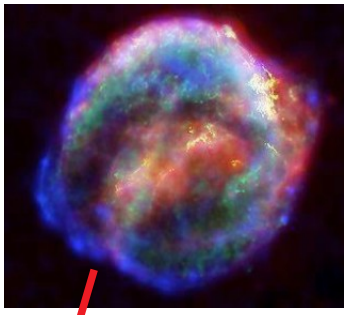
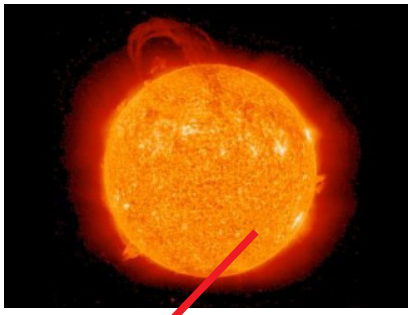
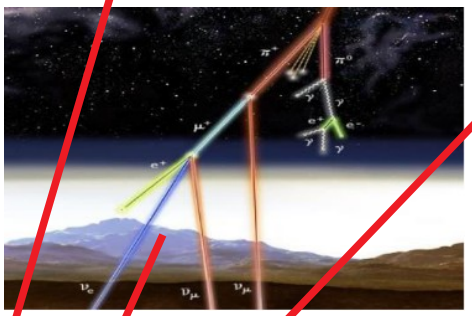
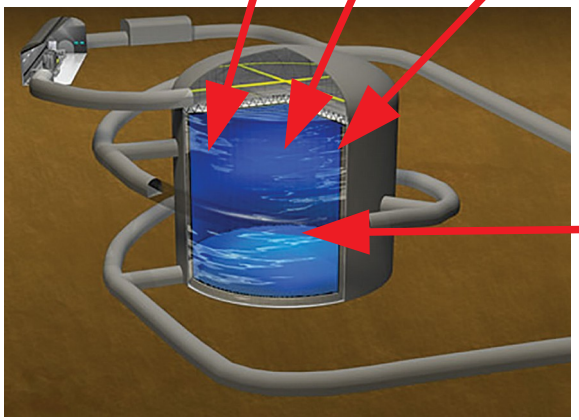
Version2 (Dated: February7, 2016)



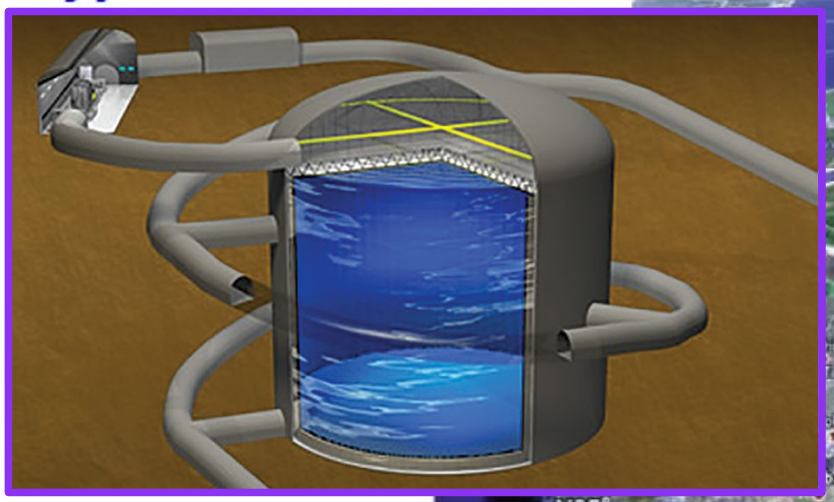
Physics Overview

Broad physics programme

- **Neutrino oscillation**
  - Atmospheric neutrinos (still statistics limited!)
  - Accelerator neutrinos
    → focus on CP violation & mass ordering
  - Solar neutrinos
- **Proton decay**
- **Neutrino astrophysics**
  - Supernova burst
    - O(10,000) events expected @ 10 kpc
  - Supernova relic neutrinos
- **Additional astrophysical topics**
  - Dark matter
    - Indirect WIMP searches
  - Multimessenger astronomy
  - Gamma ray burst searches


Beam Programme

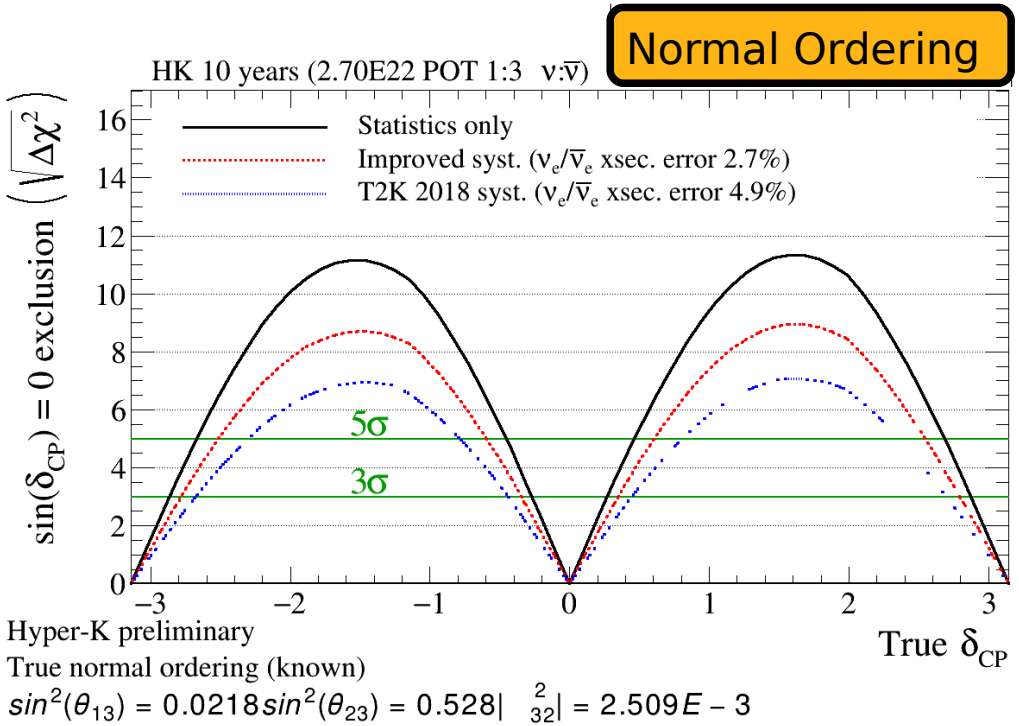


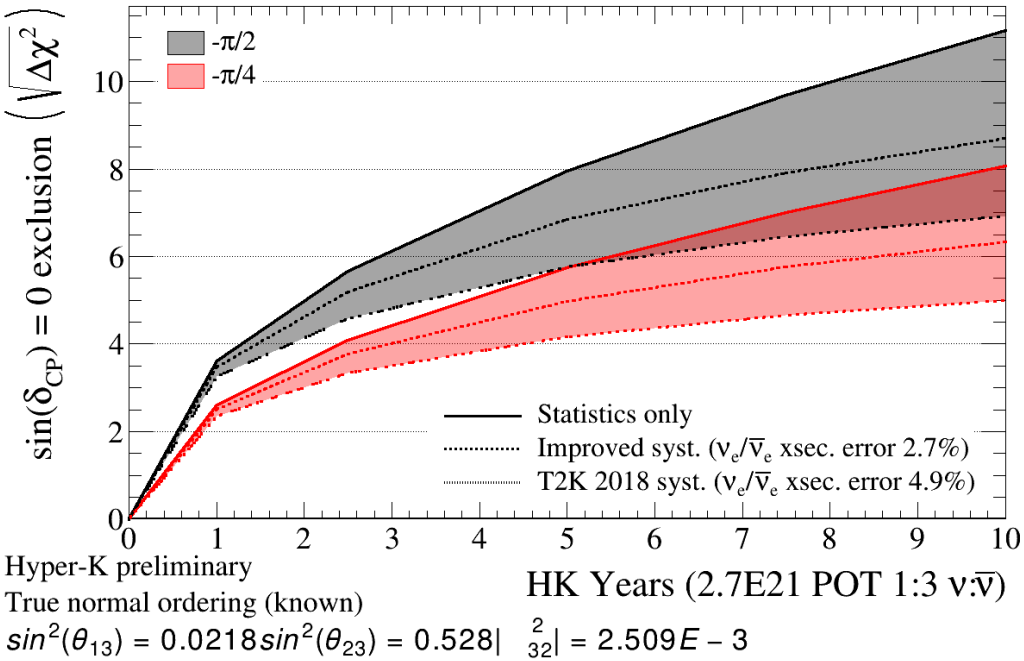
Much larger detector → significantly higher statistics → need better systematics

- Improved near detector (ND280) at Tokai
- New "Intermediate Water Cherenkov Detector"
  - See talk by Nick Prouse later today (17:50)

CP Violation

Sensitivity to exclude $\delta_{CP} = 0$





Also:

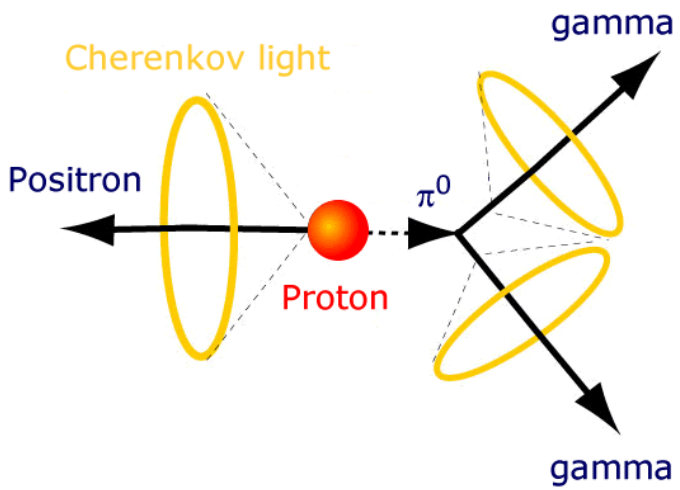
– Neutrino mass ordering may be resolved by combining accelerator and atmospheric neutrinos at Hyper-Kamiokande (multi-baseline)

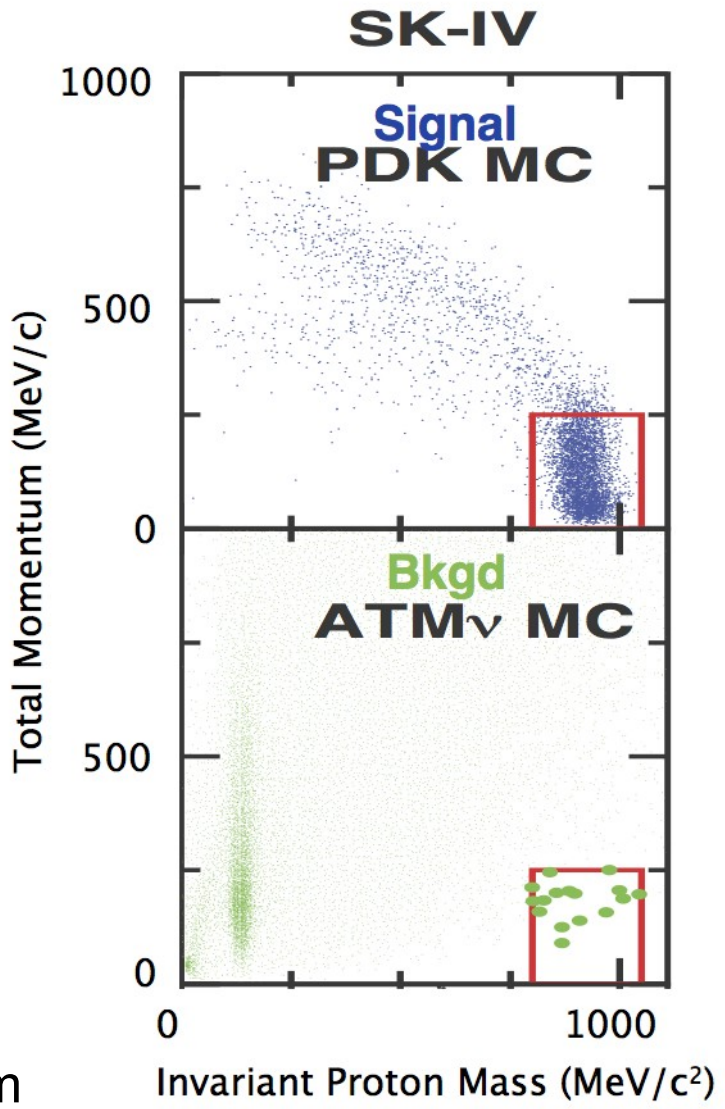
Proton Decay

In a water Cherenkov detector, a typical signal looks like:

- Three rings (all electron-like)
- Total energy close to M_p
- Unbalanced momentum close to 0.

$$p \rightarrow e^+ + \pi^0$$



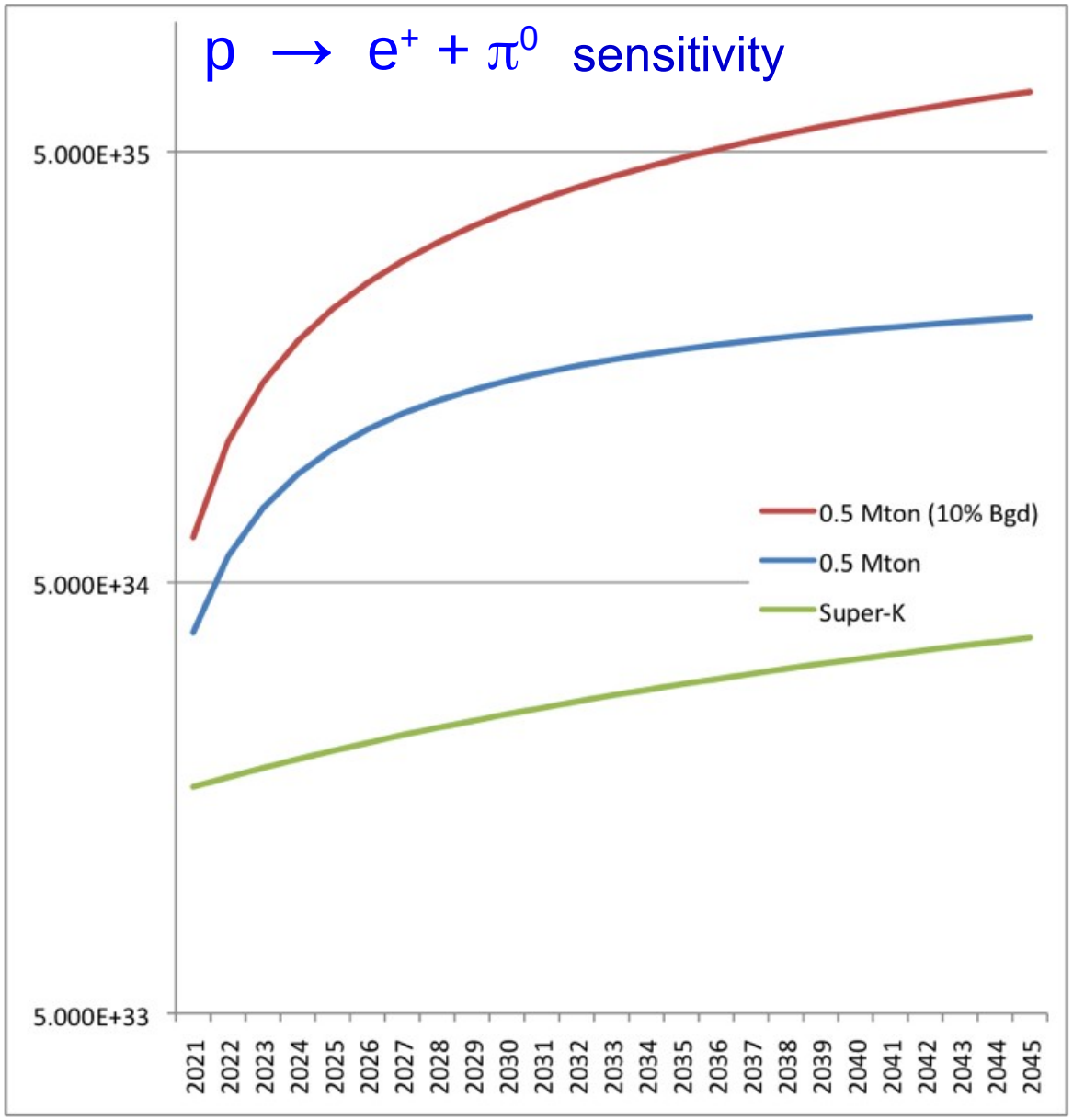


Modern GUTs predict lifetimes of $10^{35\text{-}36}$ years.

→ Current limits from SK at ~10^{34} year level

At this scale, previously negligible backgrounds from atmospheric neutrinos start to limit sensitivity.

Proton Decay



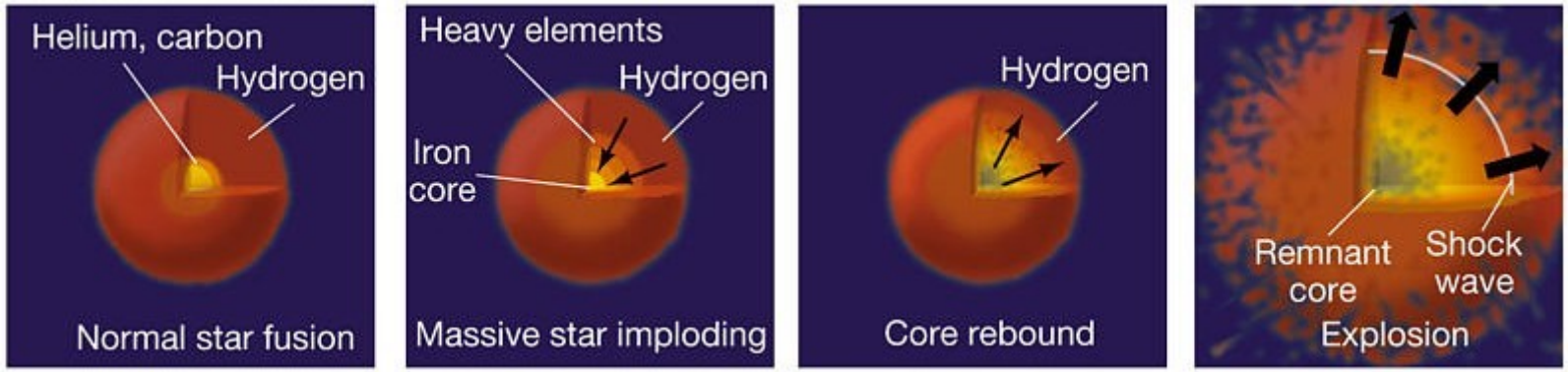
Hyper-Kamiokande (with 10% B.G.)

Hyper-Kamiokande (baseline design)

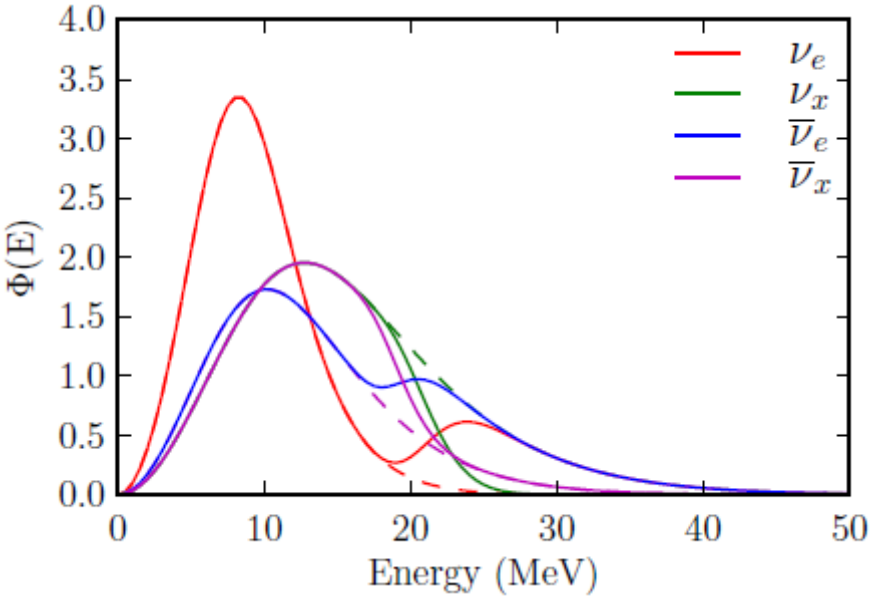
Super-Kamiokande

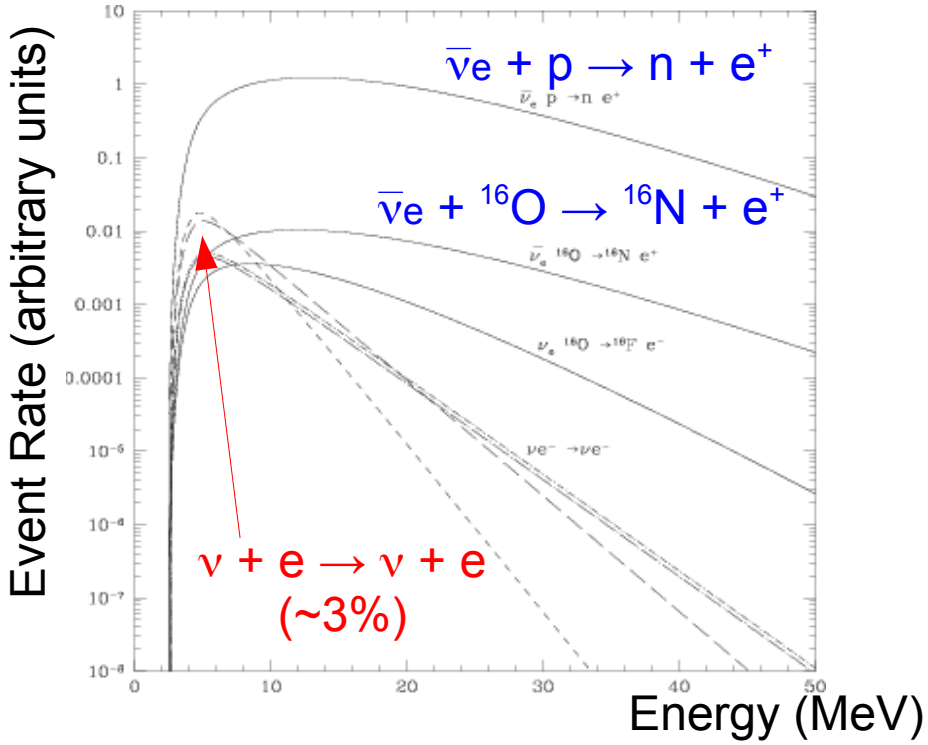
Supernova Neutrinos

Stars with M > 8 M⊙ end as a core-collapse supernova when nuclear fuel exhausted:



All 6 ν species produced; most likely to detect in WC is $\bar{\nu}e$ via inverse beta decay (89%):





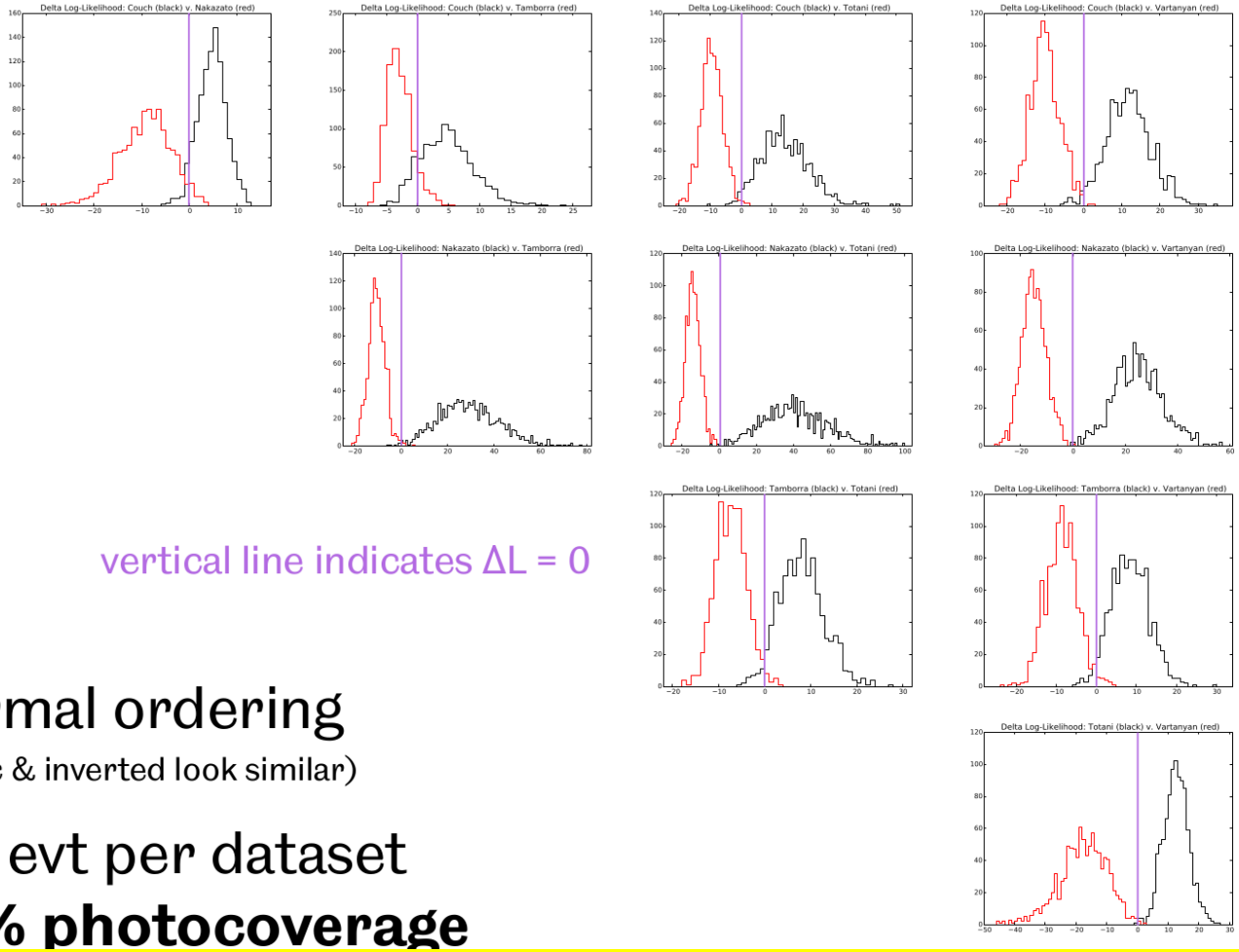
We expect **O(100,000) events** at HK from a SN near the galactic centre (10 kpc distance)!

Supernova Neutrinos

Supernova model discrimination via maximum likelihood analysis:

Nakazato Tamborra Totani Vartanyan

NEW!



Couch

Nakazato

Tamborra

Totani

vertical line indicates ΔL = 0

Normal ordering
(noosc & inverted look similar)

100 evt per dataset
20% photocoverage

Supernova Neutrinos

Using a water Cherenkov detector w/ 20% photocathode coverage and collecting 300 ν events:

Identified as

Normal	Couch	Nakazato	Tamborra	Totani	Vartanyan
Couch	**982**	2	16	0	0
Nakazato	1	**999**	0	0	0
Tamborra	16	0	**980**	2	2
Totani	0	0	0	**1000**	0
Vartanyan	0	0	0	0	**1000**

True model

Identified as

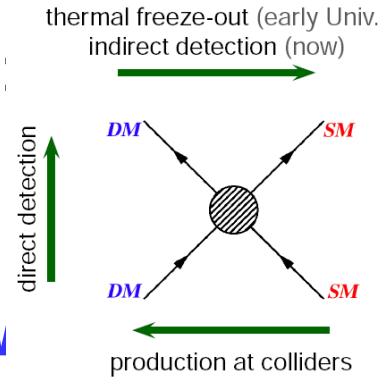
Inverted	Couch	Nakazato	Tamborra	Totani	Vartanyan
Couch	**999**	1	0	0	0
Nakazato	0	**1000**	0	0	0
Tamborra	0	0	**974**	1	25
Totani	0	0	0	**1000**	0
Vartanyan	0	0	8	0	**992**

True model

Published last year in *Astrophysical Journal* (*ApJ* **916**:15, 2021)

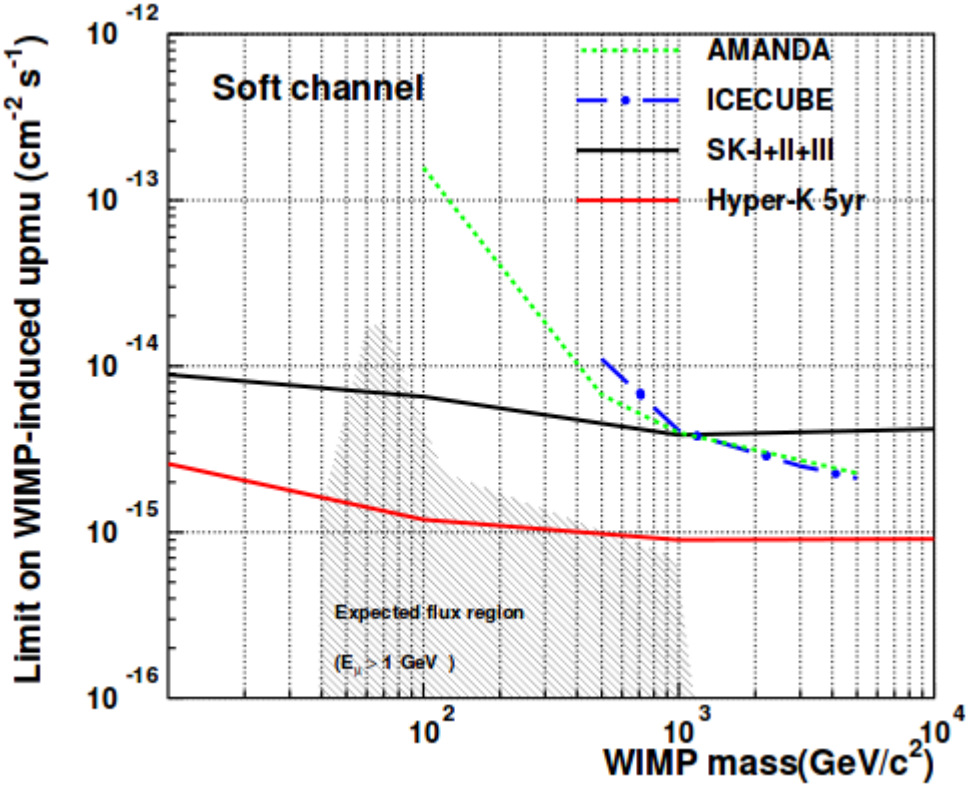
Dark Matter

Potential for dark matter detection via indirect channel

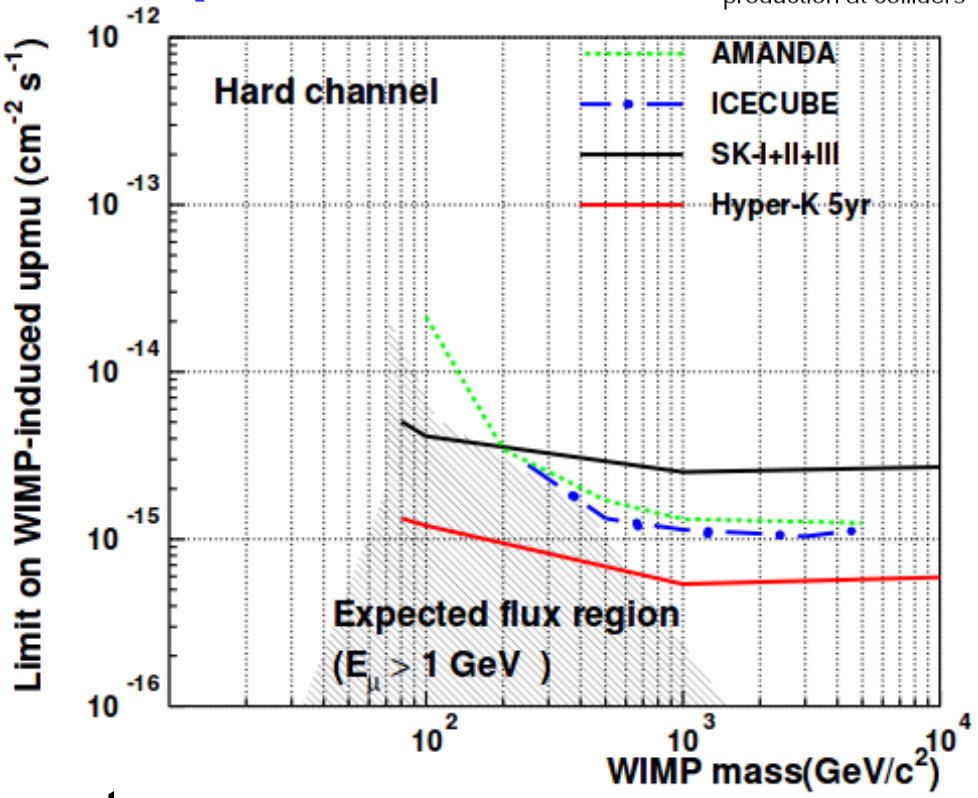


Event Rate Limits

Soft (WIMP → $b\bar{b}$)



Hard (WIMP → W^+W^-)



Figures taken from Hyper-K design report

→ further improvement possible using flavour information

Summary (1)

- **Hyper-Kamiokande: Kamioka's Next Generation**
  - Improved statistical power of 8x Super-Kamiokande
  - New technologies incorporated (*e.g.*, better photosensors, intermediate WC detector)

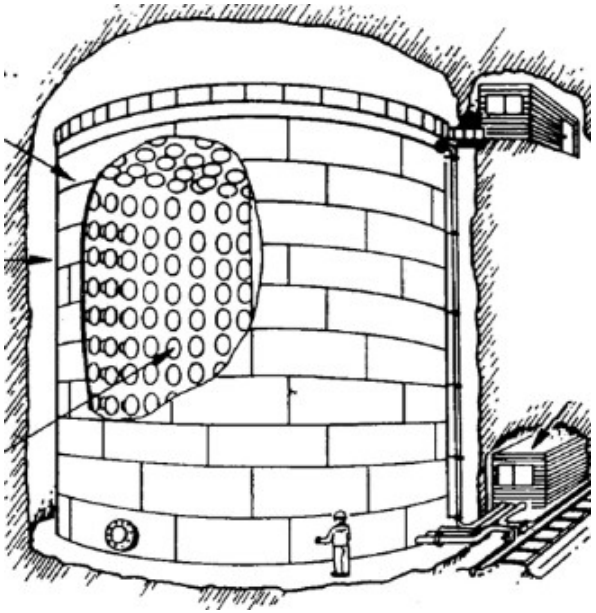
- **Particle physics goals**
  - Neutrino oscillation
    - Accelerator programme (“T2HK”) will have world-leading sensitivity to leptonic CP violation
    - Joint analysis with atmospheric neutrinos gives strong sensitivity to resolving mass ordering
  - Proton decay

- **Astroparticle physics goals**
  - Supernova neutrinos (burst and relic)
  - Also: Indirect searches for dark matter, solar neutrinos, multimessenger astronomy, etc.

- **Status**
  - Construstion phase has begun, with tunnel excavation underway
  - Expect to see first data circa 2027

Summary (2)

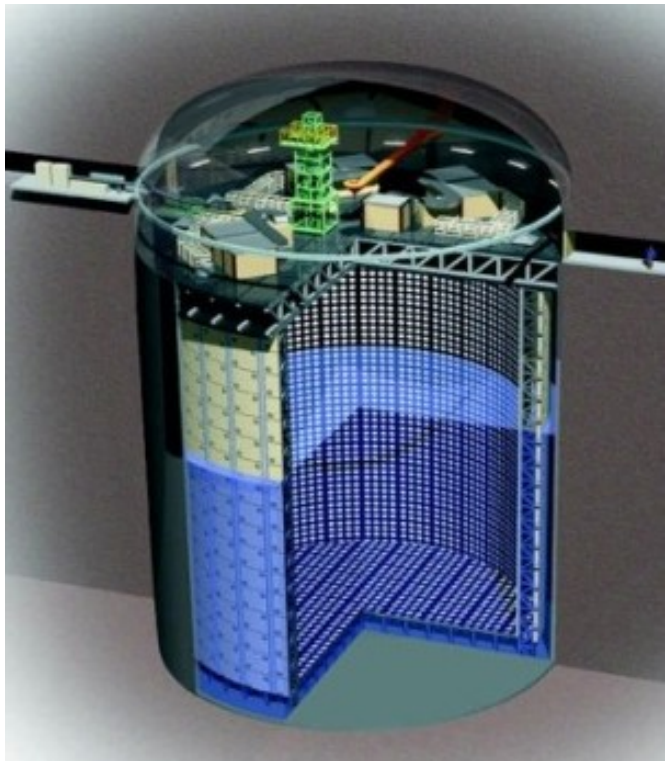
The Trilogy's Conclusion?



Kamiokande
- 1983 – 1996
- 3 ktonnes total
- 680 tonnes fiducial

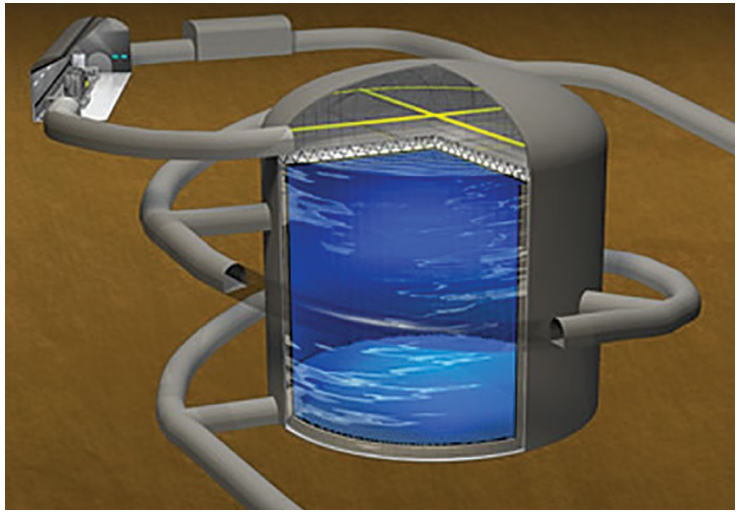
1987: Supernova ν (2002 Nobel)

Super-Kamiokande
- 1996 – ??



1998: ν oscillation (2015 Nobel)

Hyper-Kamiokande
- 2027 – ??
- 260 ktonnes total
- 190 tonnes fiducial – 8x Super-K



203X: Leptonic CPV? Indirect DM? Proton decay??