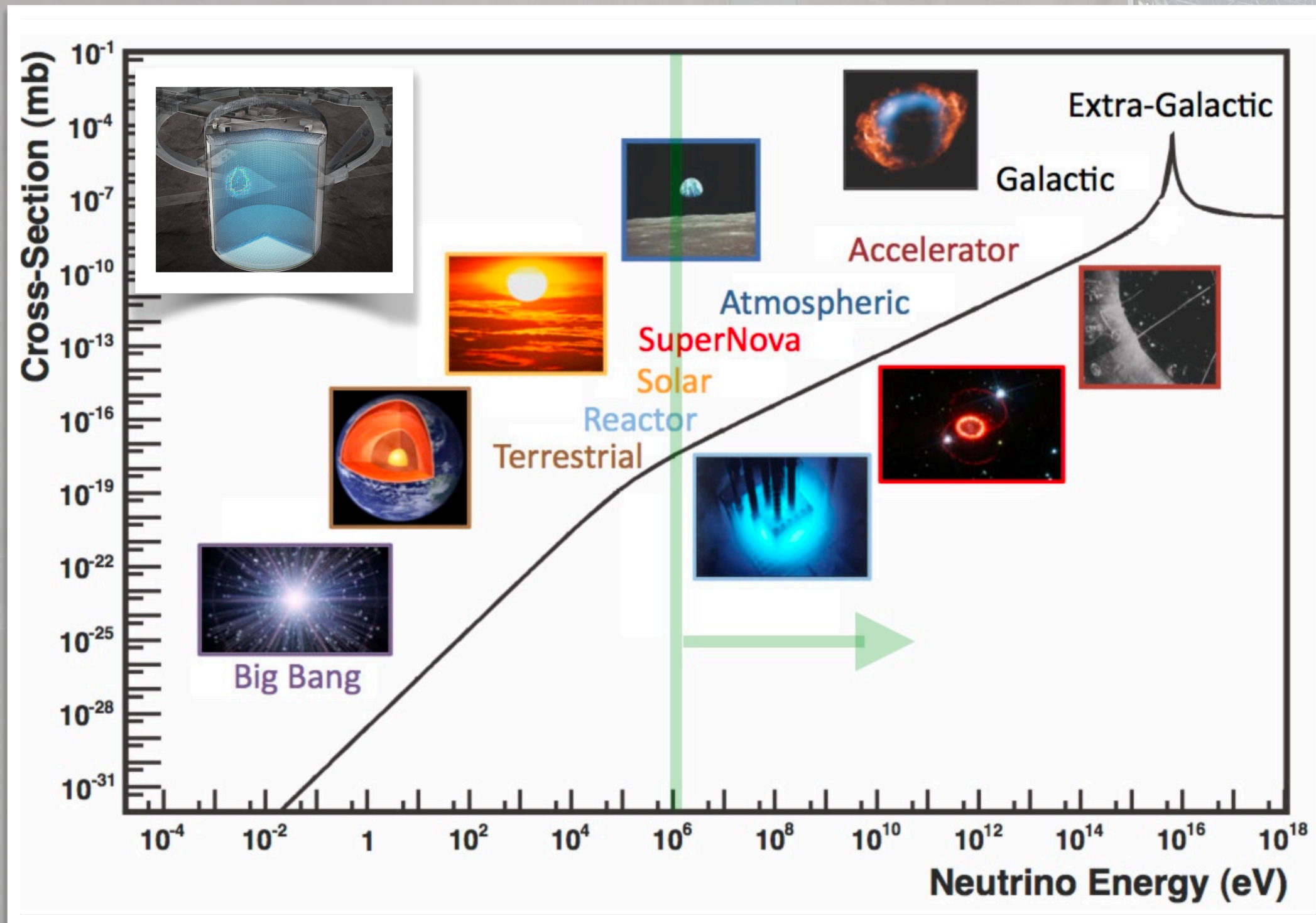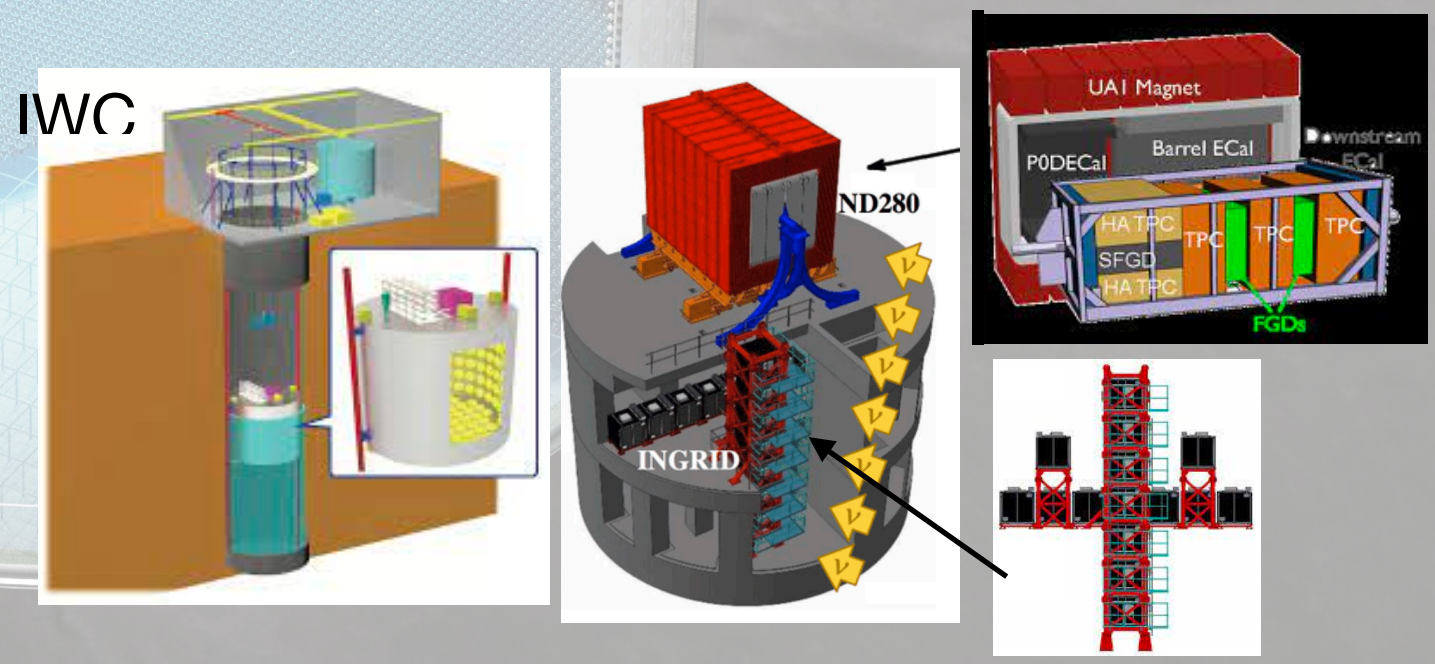# Hyper-K Physics

- Broad physics program:
  - Oscillations of atmospheric, accelerator and solar neutrinos
  - Supernova neutrinos
  - Search for proton decay
  - Dark matter indirect detection

- Standard Hyper-K analysis will be with beam + atmospherics
  - Unknown mass ordering complicates δ_{CP} measurement
  - Hyper-K can use atmospheric data to exclude incorrect MO

Hyper-K has sensitivity to	Beam	Atmospheric	Solar
δ_{CP}	✓	✓	
θ_{13}	✓	✓	
θ_{23}	✓	✓	
$|\Delta m^2_{32}|$	✓	✓	
Mass ordering	✓	✓	
θ_{12}			✓
Δm^2_{21}			✓

- Exotic Physics
- Cross sections
- Flux measurements.

Hyper-K Physics

	$\sin^2\theta_{23}$	Atmospheric neutrino	Atm + Beam
Mass ordering	0.40	2.2 σ	3.8 σ
	0.60	4.9 σ	6.2 σ
θ_{23} octant	0.45	2.2 σ	6.2 σ
	0.55	1.6 σ	3.6 σ

10 years with 1.3MW, normal mass ordering is assumed

Oscillation Physics

- 10y data taking at 1.3 MW.
- With known MO and improved syst., 5σ sensitivity for 62% of true δ_{CP} values.

- In most favorable case (NO, $\delta_{CP} = -\pi/2$), can exclude CP conservation in 3-5 years depending on systematics.
- If unknown mass ordering, combination with atmospheric neutrinos can resolve degeneracies.
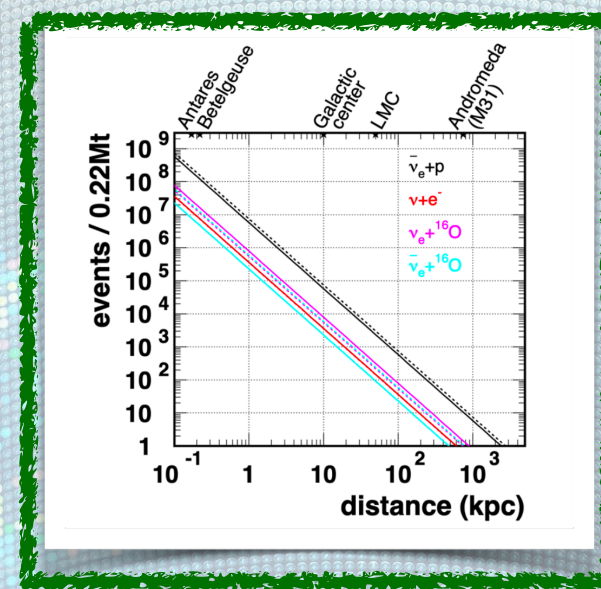
- Precise measurements of Δm^2_{32} (0.35% error) and $\sin^2\theta_{23}$ (2.47% error)
- Can determine octant if true $\sin^2\theta_{23} < 0.45$ or true $\sin^2\theta_{23} > 0.57$
- Mass Ordering can be measured: $3.8 - 6.2\sigma$ depending on $\sin^2\theta_{23} > 0.57$

Supernova bursts

- Exceptional statistics due to size of Hyper-K.
- Excellent complementarity with other experiments.
- >70k neutrinos expected for 10 kpc supernova.

Low Energy neutrinos- Solar neutrinos

- At low energy, Hyper-K will study remaining questions on solar neutrino oscillations
- $> 3\sigma$ sensitivity for the spectrum up-turn in 10 yrs ($E_{th} = 4.5\mathrm{MeV}$).
- $\sim 2\sigma$ day/night asymmetry sensitivity expected for the difference in $\nu_e/\bar{\nu}_e$ osc. in 20 yrs.
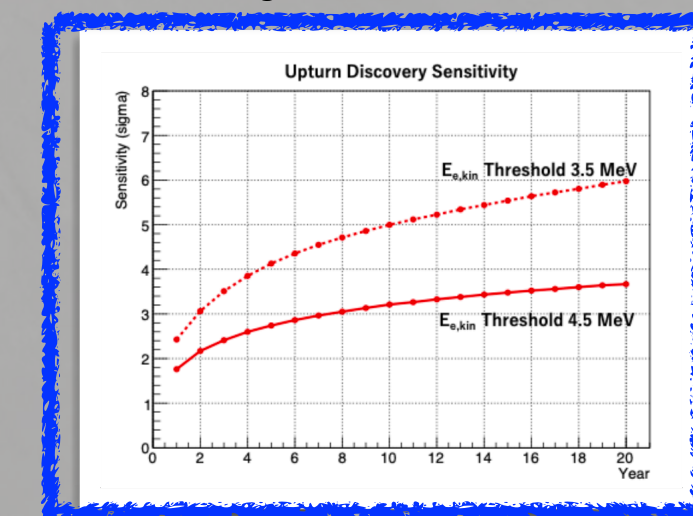
Diffuse Supernova Neutrino Background (DSNB)

- Hyper-K aims for precise flux and spectrum measurement.
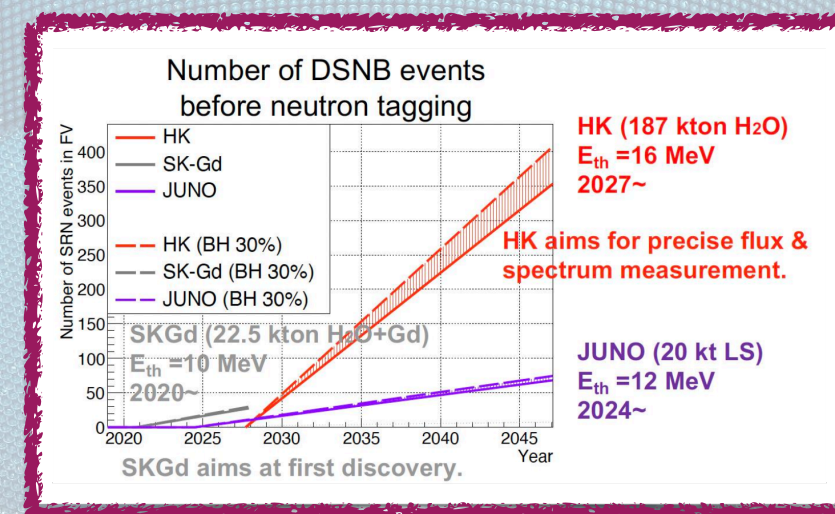
Proton Decay

- World leading sensitivity for proton decay searches: large mass and can use free protons to avoid problems of nuclear effects 3σ discovery potential reaches half-life of 10^{35} years for $p \to e^+\pi^0$ and 3×10^{34} years for $p \to \nu K^+$ after 20 years

Hyper-K in the UK

- Hyper-K has ~ 600 persons from 22 countries and growing!
- Recognised experiment at CERN (RE45)
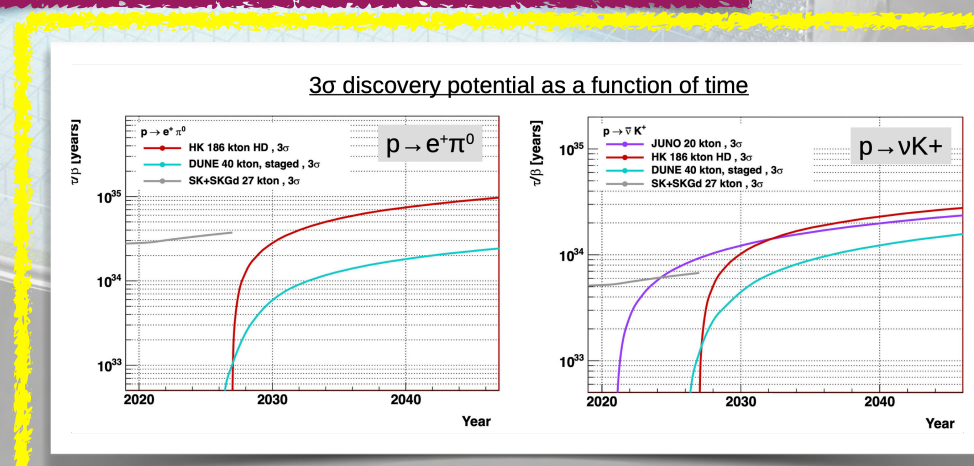- Active member of CERN neutrino platform.
- Electronics assembly and testing at CERN.
- UK
  - *Second largest member of Hyper-K.*
  - *International leadership roles:* International co-spokesperson, six working group conveners, Deputy Technical Coordinator.
  - *Involvement/leadership:*
    - ✓ Beam target.
    - ✓ DAQ for Far and Near detector.
    - ✓ Calibration leadership and responsibility of a few systems.
    - ✓ Outer Detector.
    - ✓ Physics, Simulation and Computing.

Hyper-Kamiokande Members:

Europe	335 members
Armenia	3
Czech	8
France	50
Germany	1
Greece	4
Italy	46
Poland	45
Russia	21
Spain	45
Sweden	5
Switzerland	14
Ukraine	2
UK	91

Asia	164 members
India	9
Korea	19
Japan	136

Oceania	9 members
Australia	9

Americas	67 members
Brazil	3
Canada	43
Mexico	11
USA	10

Africa	11 members
Morocco	11

Hyper-Kamiokande UK Institutions:

University of Glasgow · IMPERIAL · KING'S College LONDON · Lancaster University · UNIVERSITY OF LIVERPOOL

UNIVERSITY OF OXFORD · UKRI · Science and Technology Facilities Council · The University Of Sheffield · WARWICK
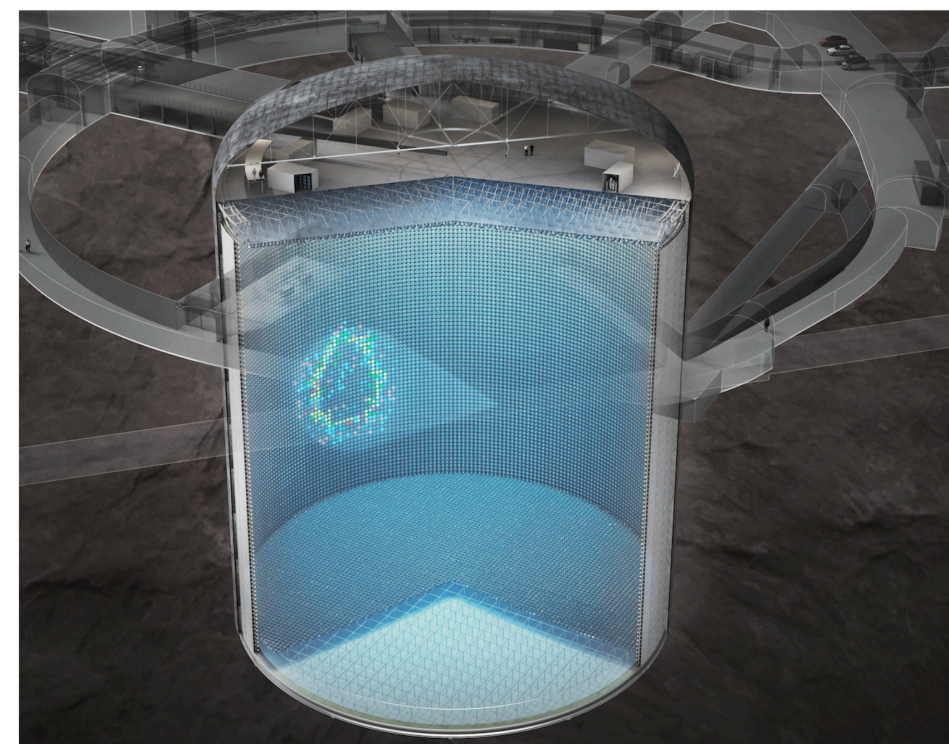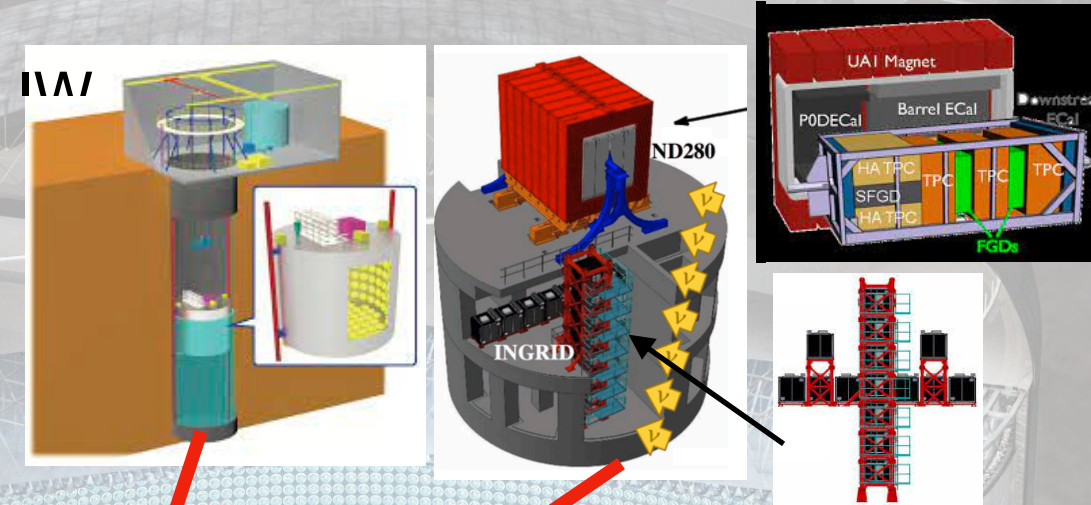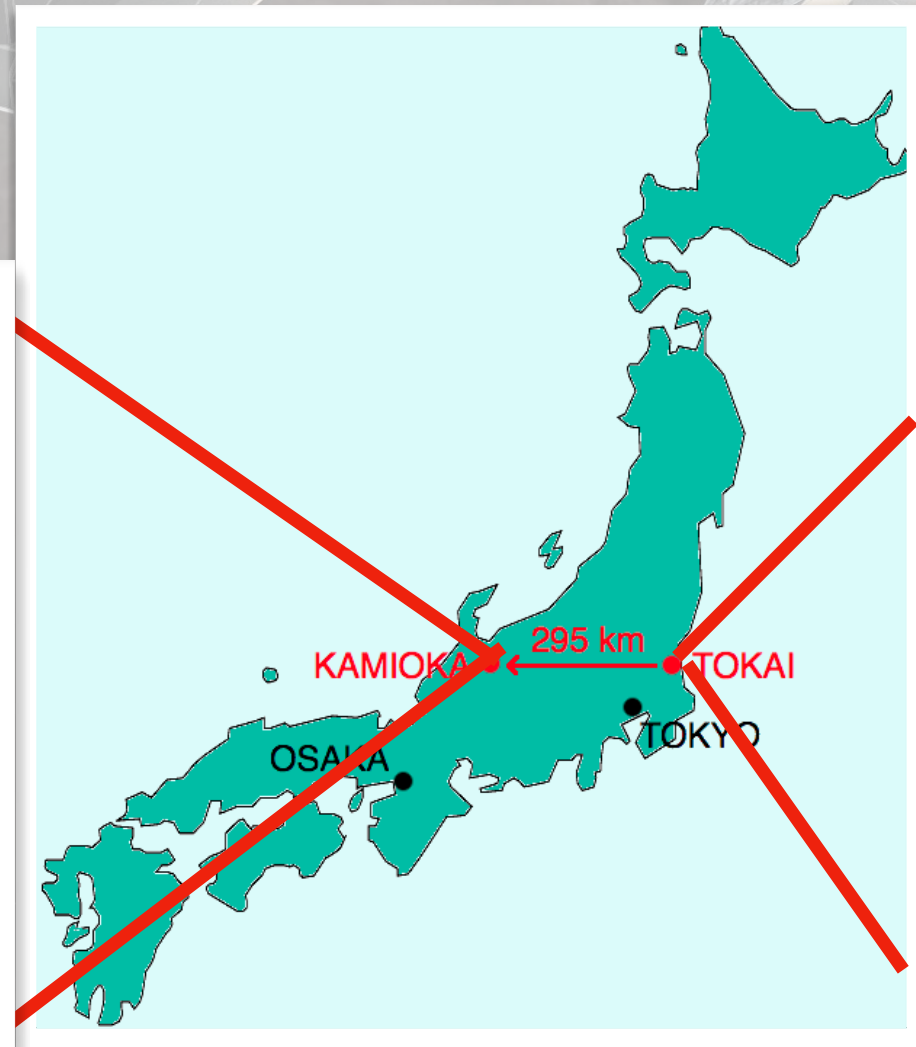
Hyper-K in the UK

Computing/Simulation: 🇬🇧

- Leading development of:
  - Simulation software for WC detectors.
  - Oscillation analysis frameworks.
  - Distributed computing model.

Physics: 🇬🇧

- Leading contributions to oscillations physics, atmospherics, supernova, proton decays, near detectors.

Near Detectors 🇬🇧

- DAQ and light injection system (IWCD).
- Support for operations and analysis (ND280).
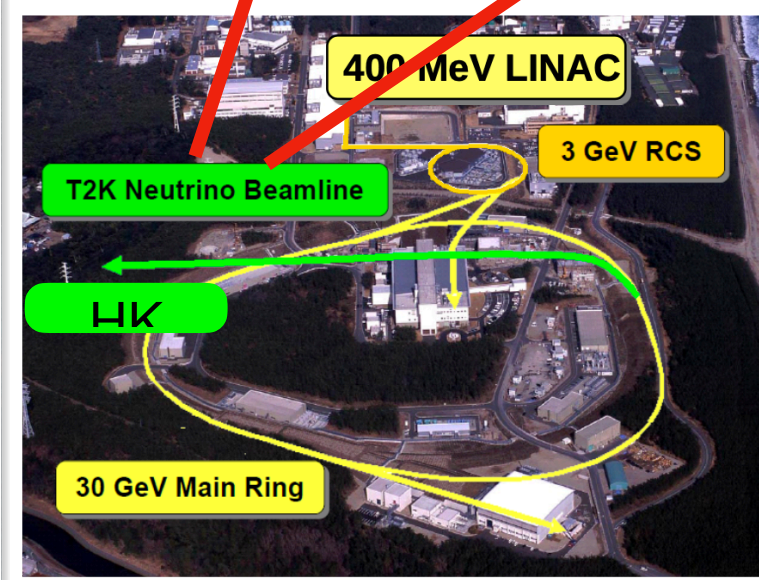
Beamline 🇬🇧

- Beam target and beam windows.
- Beam target update.
- Simulation.

Far detector DAQ: 🇬🇧

- Software-based DAQ, trigger and monitoring systems.
- Simple trigger for E > 10 MeV events + sophisticated low energy triggers.

Far detector Calibration: 🇬🇧

- Optical calibration systems to make position/time dependent measurements of
  - water absorption/scattering
  - PMT timing
  - PMT gain.

Far detector Outer Detector: 🇬🇧

- Design of photosensing system.
- Selection and validation of PMTs, Tyke, WLS plates.
- OD calibration.
- Design and validation of electronics.
- Installation and commissioning.

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University of Glasgow · IMPERIAL · KING'S College LONDON · Lancaster University · UNIVERSITY OF LIVERPOOL · UNIVERSITY OF OXFORD · UKRI Science and Technology Facilities Council · The University Of Sheffield · WARWICK

Hyper-K

400 MeV LINAC · 3 GeV RCS · T2K Neutrino Beamline · HK · 30 GeV Main Ring

295 km · KAMIOKA ← TOKAI · OSAKA · TOKYO

ND280 · UA1 Magnet · PODECal · Barrel ECal · INGRID

Hyper-K Project Inputs

- Estimate of financial costs (provide separate numbers for R+D phase, construction phase and operations phase)
  - Construction: supported by Infrastructure Grant.
  - Exploitation: requested support in Consolidated Grant.
    - Support for UK-built items for 3 detectors and for physics exploitation. Larger support needed than for T2K. Crucial support needed to analyse first data.
  - Common funds will start at the beginning of data taking in 2027.
  - Upgrade
    - Under development studies for limited refurbishment of the ND280 ECal and improved beam target.
- Does your project plan dedicated submission(s) for the ESPPU (if so, give details):
  - One Hyper-K submission is being planned.
- Comparison of physics goals with the current state of the art in the area.
  - The matter antimatter discrepancy is a major question in particle physics.
  - Astrophysics will provide high statistics for supernova and potential to observe DSNB for the first time.
  - Solar neutrino addressing day night asymmetry.
  - Physics beyond the standard model
- List the project's main advantages compared to competitor projects.
  - Physics:
    - Hyper-K will start with the highest beam, largest far detector and enlarged near detector suite to address CP violation and constraint the PMTS oscillation matrix parameters.
    - Multipurpose experiment: oscillation physics, astrophysics, rare decays, new physics with largest statistics.
    - Use of atmospheric neutrinos in oscillation fit to resolve degeneracies. No need to know MO.
  - Technical:
    - The underlying technology, Water Cherenkov, is well known.
    - The neutrino beam is used by T2K, being upgraded during the T2K era.

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Hyper-K Project Inputs

- Preferred location for the project:
  - The experiment is located at J-PARC for beam and near detectors, Kamioka observatory for the far detector.
- Project timeline (if possible provide separate by the R&D, construction and exploitation periods)
  - Construction up to 2027 and thereafter exploitation.
  - After about 5-10 years, the upgrade of ND280 is being planned.

- Next 5 years:
  - *Construction* will complete in 2027.
  - UK members will be on site for *installation, commissioning and operation* of key systems.
  - UK will *maintain its systems* during data-taking operations.
  - UK will *maintain* leading roles in *software, physics and computing* to ensure readiness for "first physics".
- Next 5-10(20) years:
  - *Exploit* first results.
  - Improved systematic uncertainties.
    - ➡ **Near detector upgrade.**
  - Studies for *future improvements* to the detectors its beamline and detectors.

- Main risks/obstacles for realisation of physics goals (e.g. development of new technologies, construction of a new facility)
  - Hyper-K is a very low-risk experiment given that Super-K has been successfully working for more than 30 years. Main risk is probably the systematics, which could limit CP sensitivity.

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