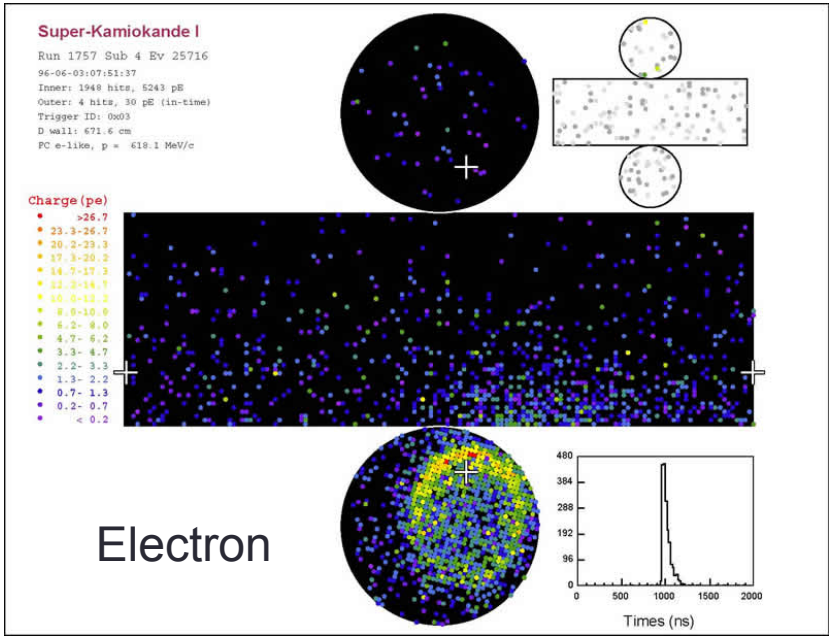
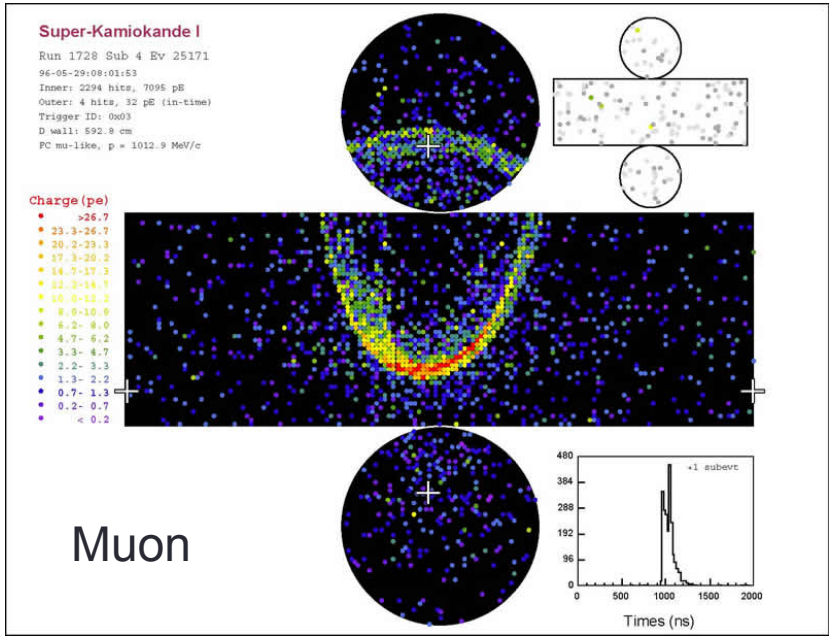
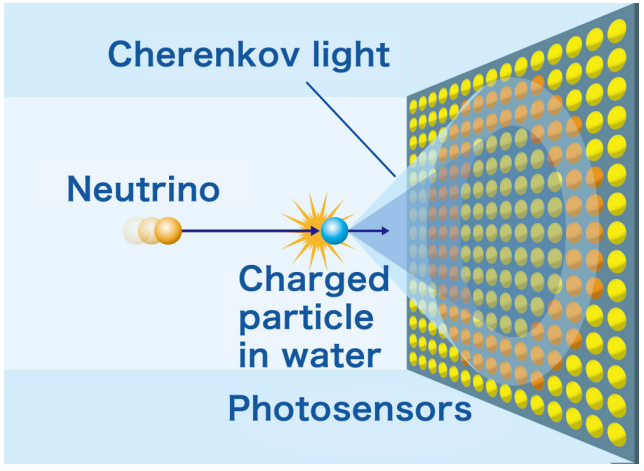
HYPER-KAMIOKANDE

Masaki Ishitsuka (Tokyo Institute of Technology)
on behalf of **the Hyper-Kamiokande proto collaboration**
The XIIIth International Conference on Heavy Quarks and Leptons
May 27, 2016 @ Center for Neutrino Physics, Virginia Tech

Water Čherenkov Detector



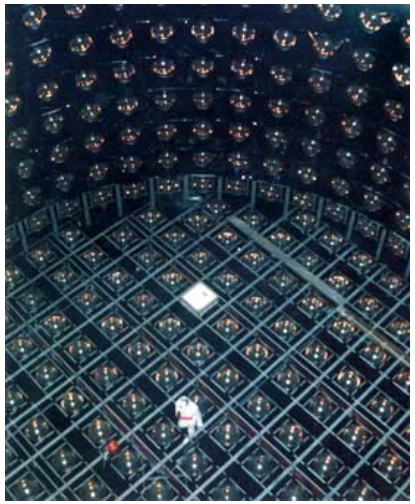




- Cherenkov ring
  - Particle identification (> 99% efficiency)
  - Momentum reconstruction (energy and direction)
- Large mass ⇒ rare process (p decay, ν physics)
- Well established technology → next slide

New physics revealed by WČ detectors

Kamiokande (1983-1996)

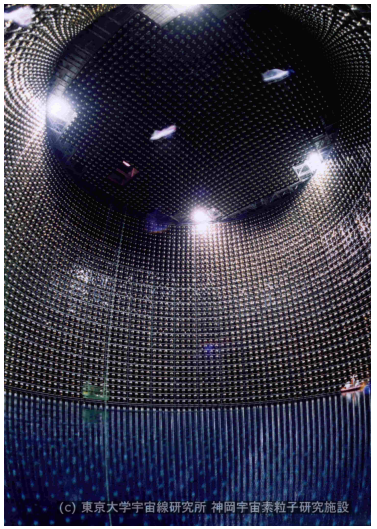


3 kton water
1,000 PMTs

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

⇒ **Birth of Neutrino Astrophysics**

Super-Kamiokande (1996-)



55 kton water
11,000 PMTs

- 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

x3 J-PARC beam power

X

39m Φ
x 40m H

SK

74m Φ x 60m H x 2

Hyper-K
~2026

Hyper-K
2nd detector

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

X

Improved detector performance

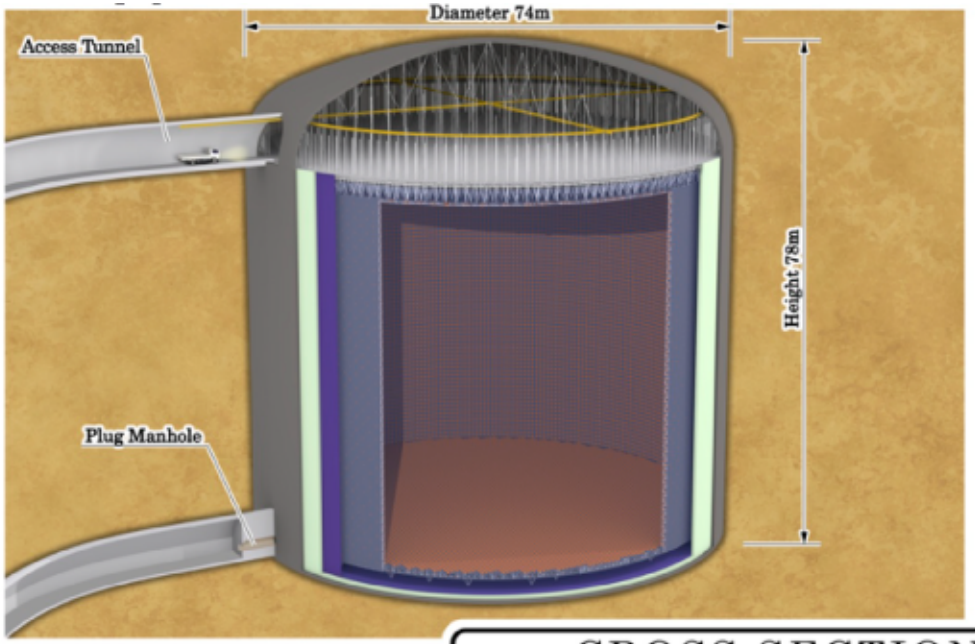
- CP violation
- Mass hierarchy
- θ_{23} octant
- Neutrino astrophysics
- Supernova
- Proton decay
- …?!

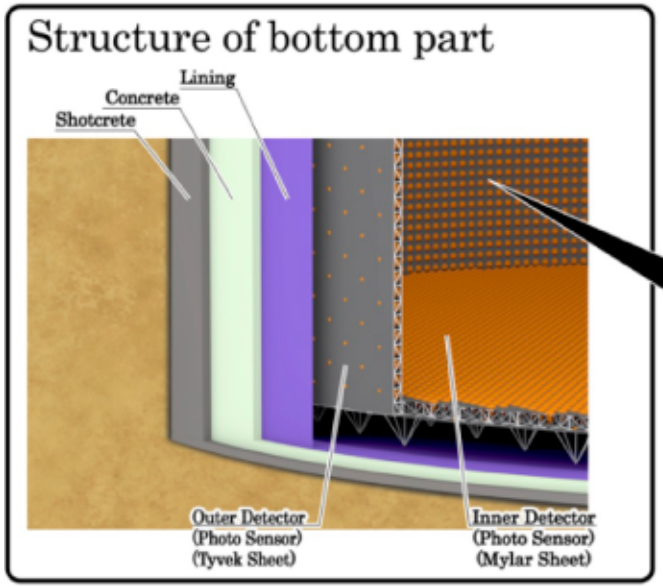
New photosensor

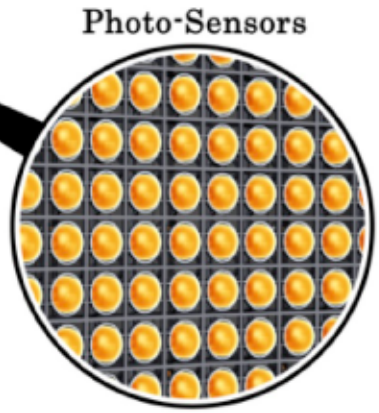
Hyper-Kamiokande Detector Design

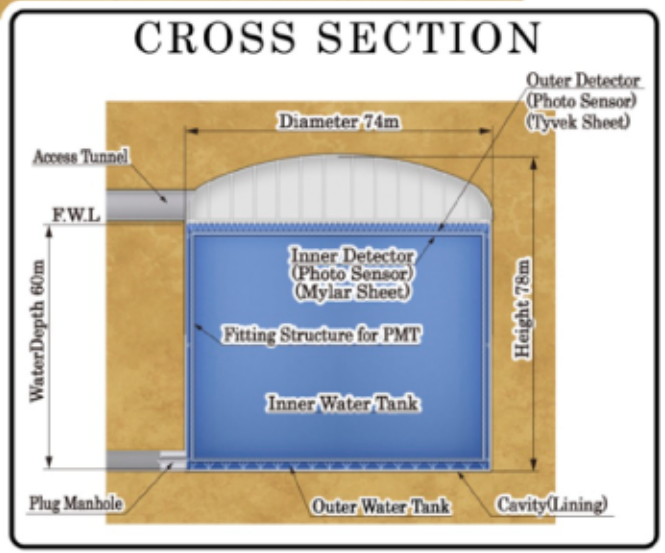
Two high performance water Cherenkov detectors

- 74m Φ × 60m H
  ⇒ 180kton fiducial mass
- 40,000 × 20-inch new PMTs (next slide)
  ⇒ 40% photocoverage

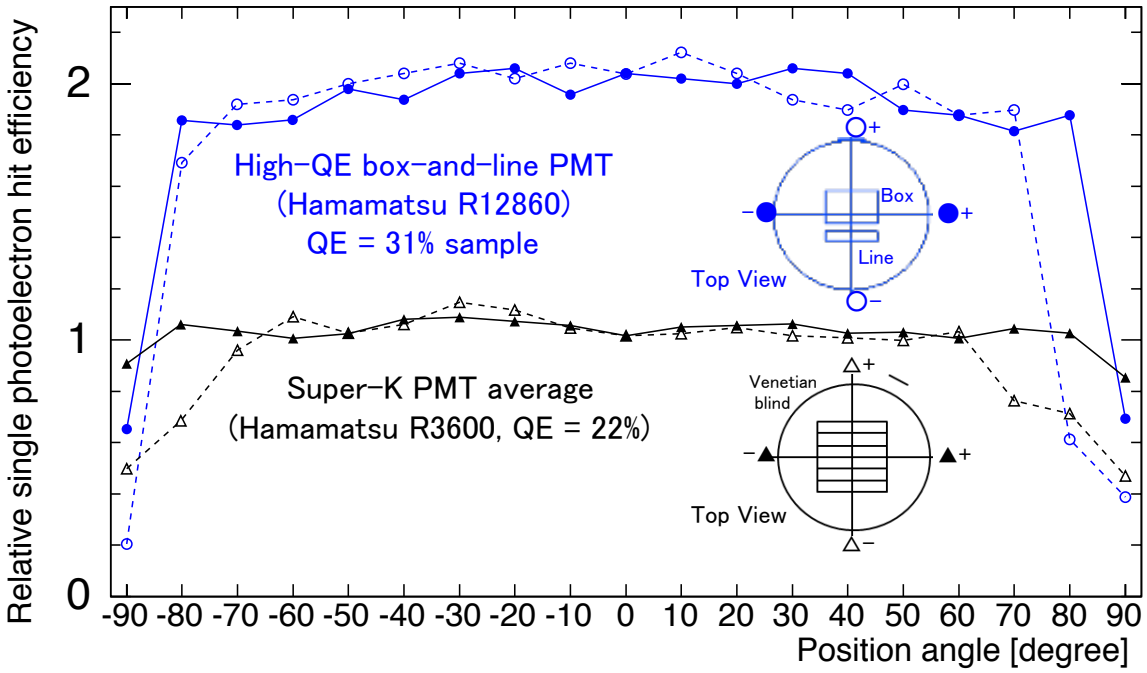


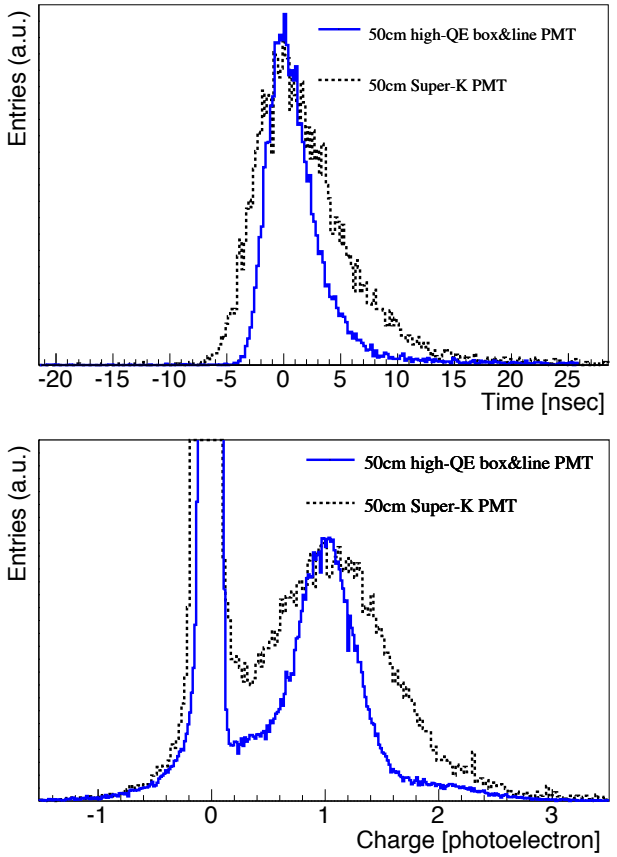






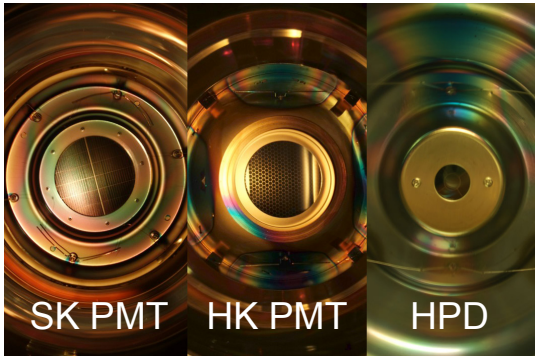
New Photosensor





Hyper-K PMT developed with Hamamatsu

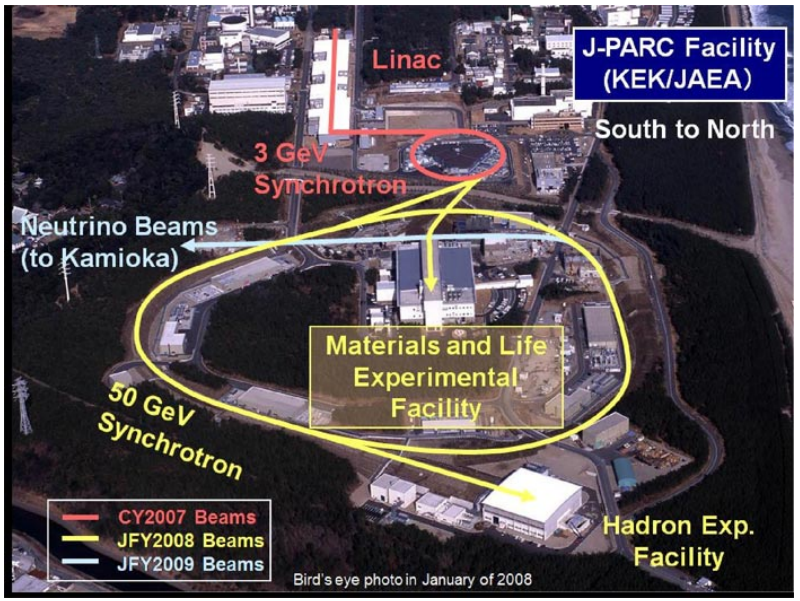
- Box & Line dynode structure (SK: Venetian Blind)
- **×2 photodetection efficiency**
- **×2 better timing response**
- **×2 water pressure resistance (>100m equivalent)**

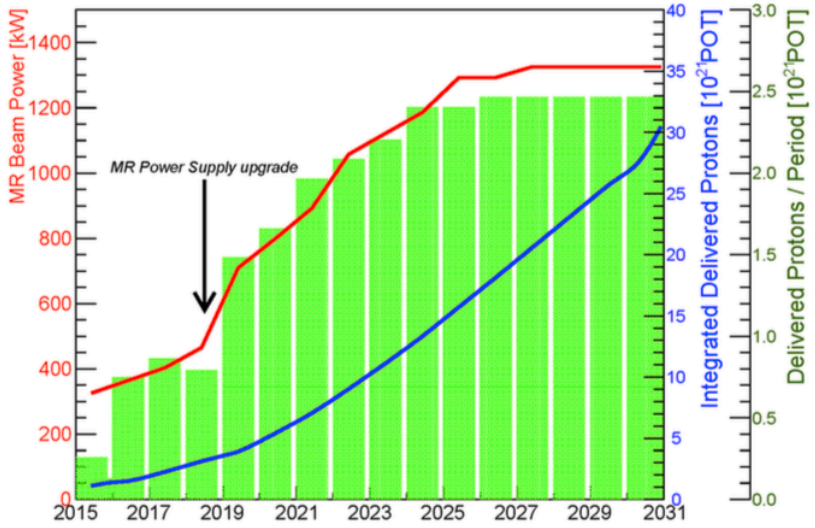


⇒ Significant impact to detector design and physics performance

Upgrade of J-PARC neutrino beam

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





- J-PARC upgrade plan
  - Upgrade of Main Ring approved
    - ×2 rate with new power supply system
    - T2K: ~900kW ⇒ ~1.3MW by 2026

×3 beam power for Hyper-K

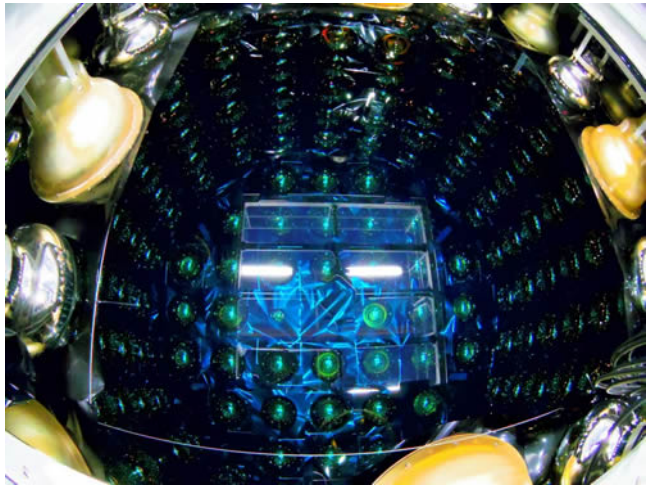
Hyper-Kamiokande Proto-collaboration

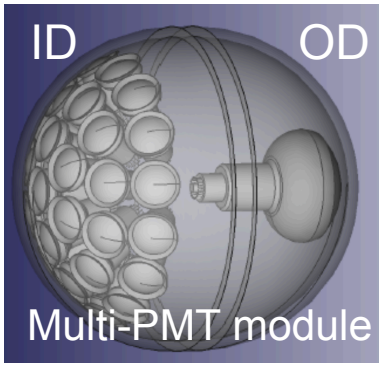
- Proto-collaboration formed in January 2015 with ~250 physicists
  - Defined governance structure and international task/cost sharing
- ICRR and KEK-IPNS signed MoU for promotion of Hyper-Kamiokande

Worldwide R&D

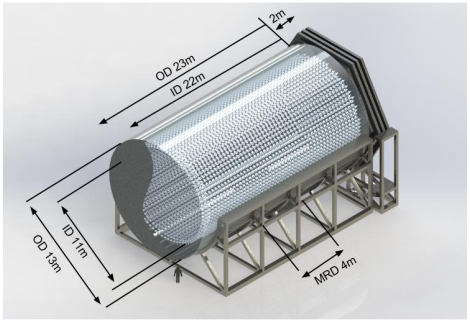
- Alternative options for photo-sensors
  - 50cm High-QE Hybrid Photodetector (HPD)
  - Multi-PMT module
  - Texas 11” PMT for OV

200ton water Cherenkov test detector at Kamioka (EGADS)





TITUS

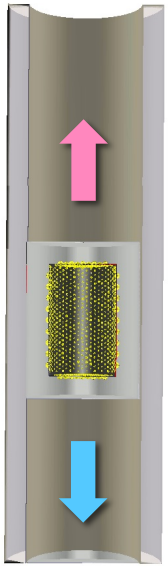


WČ + magnetized μ range detector

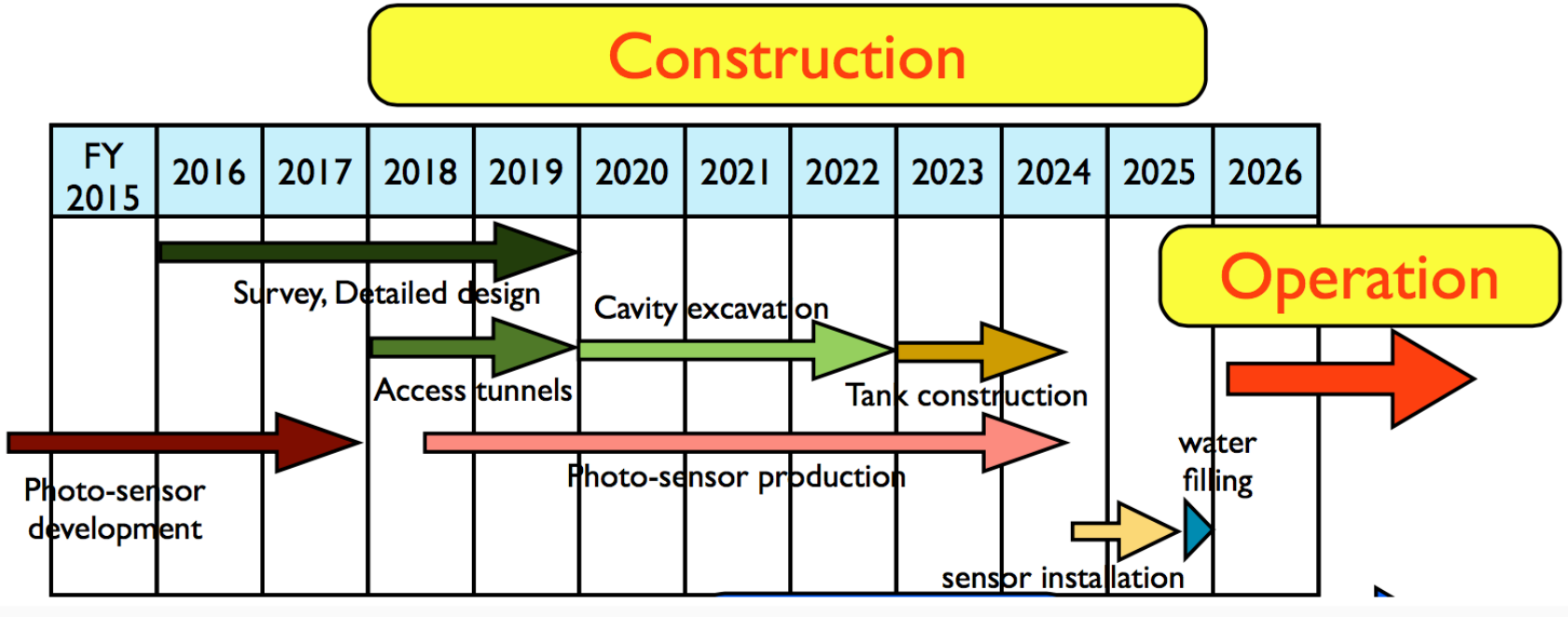
- Near Detectors
  - Upgrade plans for 280m detectors
  - Water Cherenkov detectors at 1-2 km proposed
    - Neutrino flux close to Hyper-K
      ⇒ suppression of systematic uncertainties

NuPRISM

Measures spectrum at 1°~ 4° off-axis



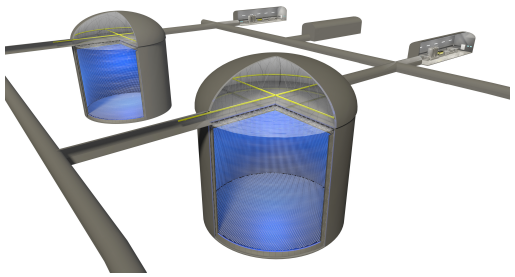
Hyper-Kamiokande proposed timeline



- Target to start operation with 1st detector from 2026
- Sensitivity evaluated assuming staged construction strategy with the same 2nd detector starts 6 years later

Hyper-K Physics Capabilities

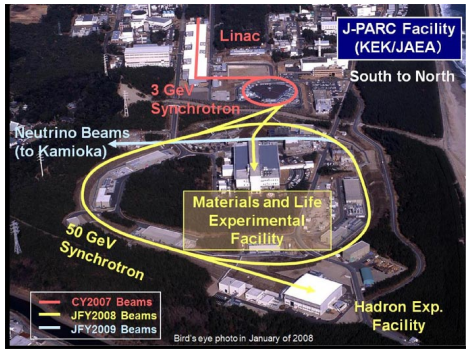
CP violation in neutrino sector



$\nu_e \xleftarrow{\text{Neutrino mode}} \nu_\mu$

$\bar{\nu}_e \xleftarrow[295\text{km}]{\text{Antineutrino mode}} \bar{\nu}_\mu$

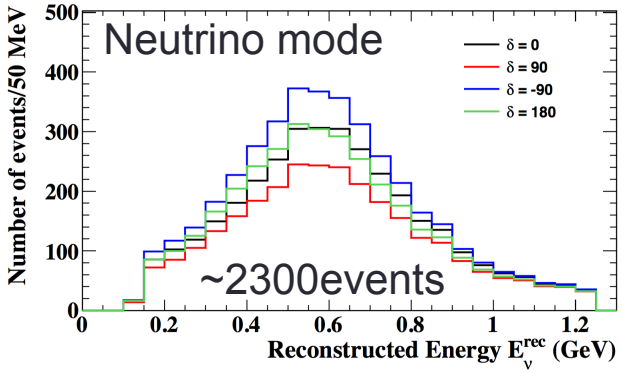
$P(\nu_\mu \to \nu_e) \neq P(\bar{\nu}_\mu \to \bar{\nu}_e)$?

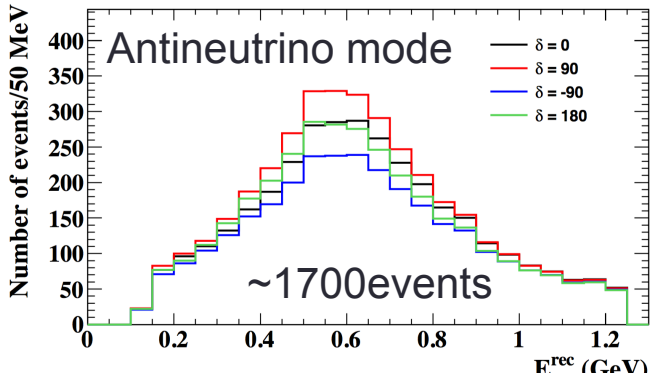


J-PARC neutrino beam

Appearance signal at Hyper-K

- $1.3\text{MW}\times10\times10^7\text{s}$ (10years running)



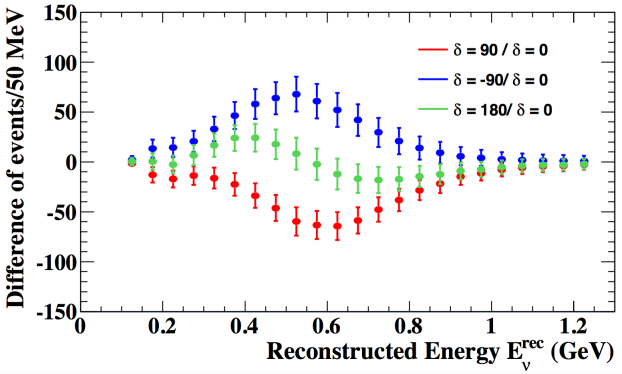


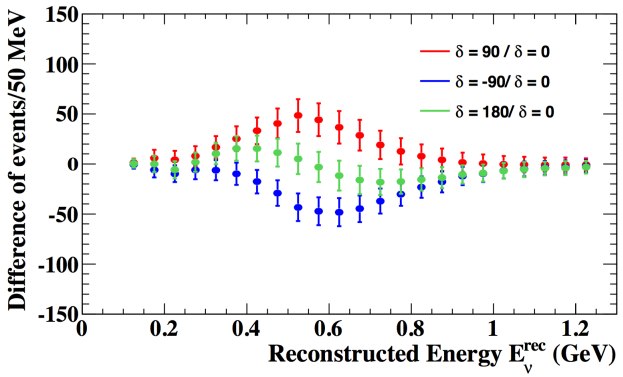
Diff. from $\delta_{CP} = 0$

$\delta_{CP} = 90°$

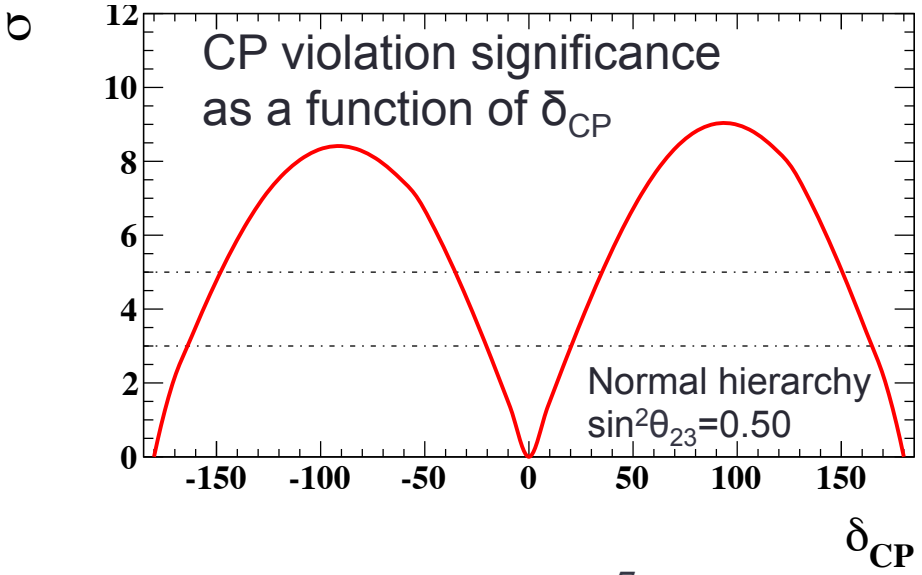
$\delta_{CP} = -90°$

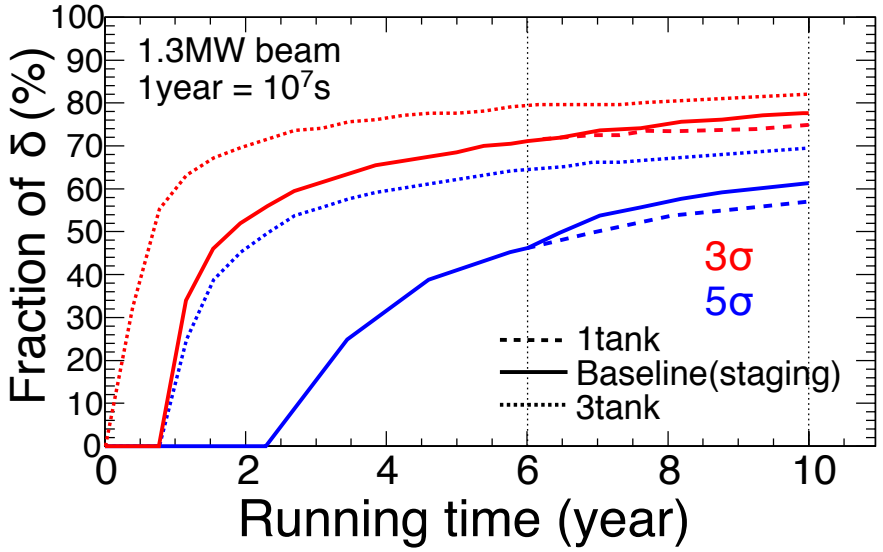
$\delta_{CP} = 180°$





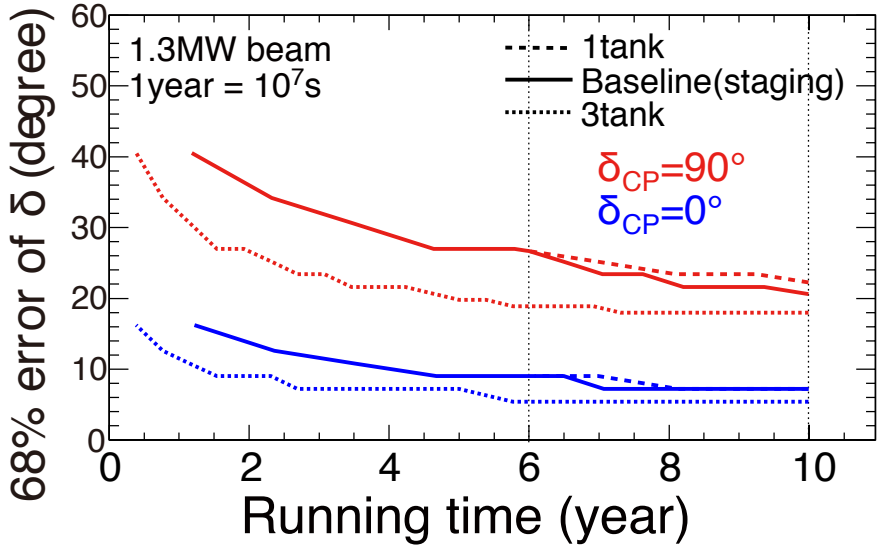
Projected sensitivity to δ_{CP}



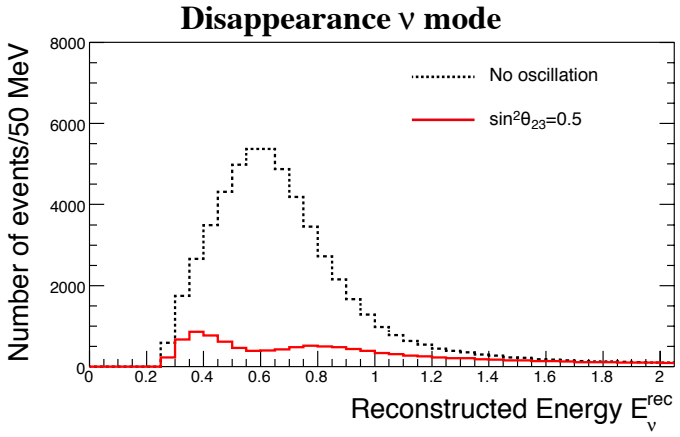


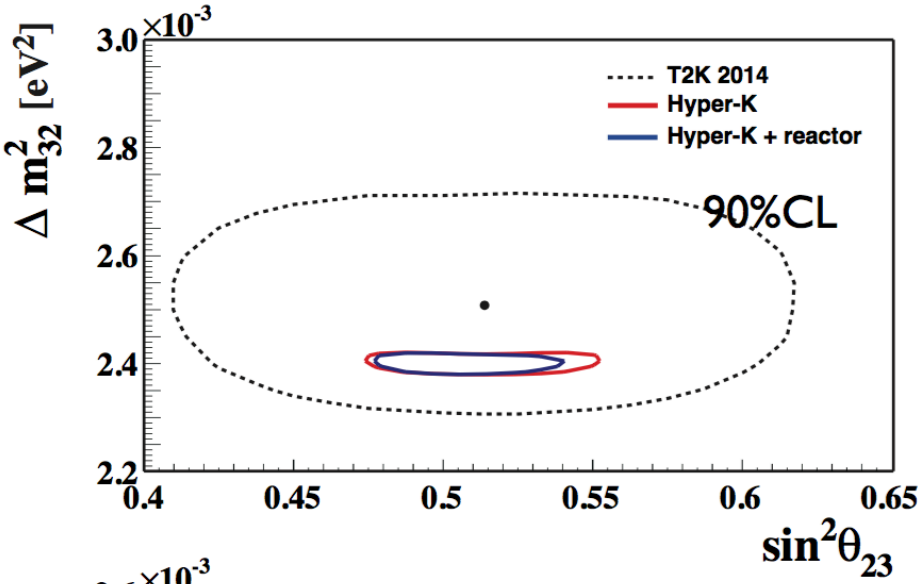
With 1.3MW×10×10^7s (10yr)

- CP violation observation
  - > 3σ for 78% of δ_{CP}
  - > 5σ for 62% of δ_{CP}
- Measurement of δ_{CP}
  - 21° for δ_{CP} = 90°
  - 7° for δ_{CP} = 0°



Precise measurements of Δm^2_{32} and θ_{23}



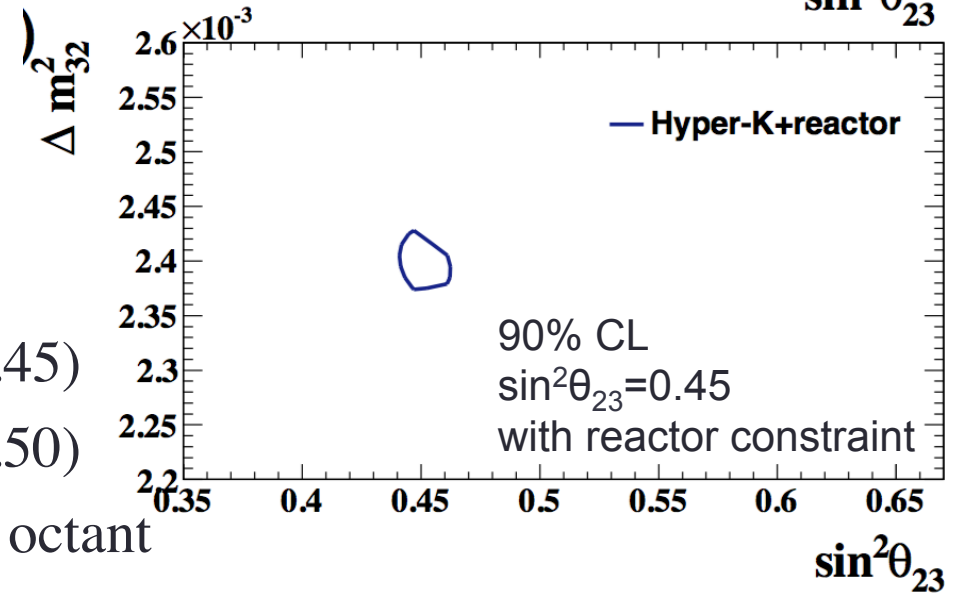


- Precision of $\mathbf{\Delta m^2_{32}}$
  - $\delta(\Delta m^2_{32}) \sim 1.4\times10^{-5}eV^2$
    (ref. $\Delta m^2_{21} = (7.5\pm0.2)\times10^{-5}eV^2$)

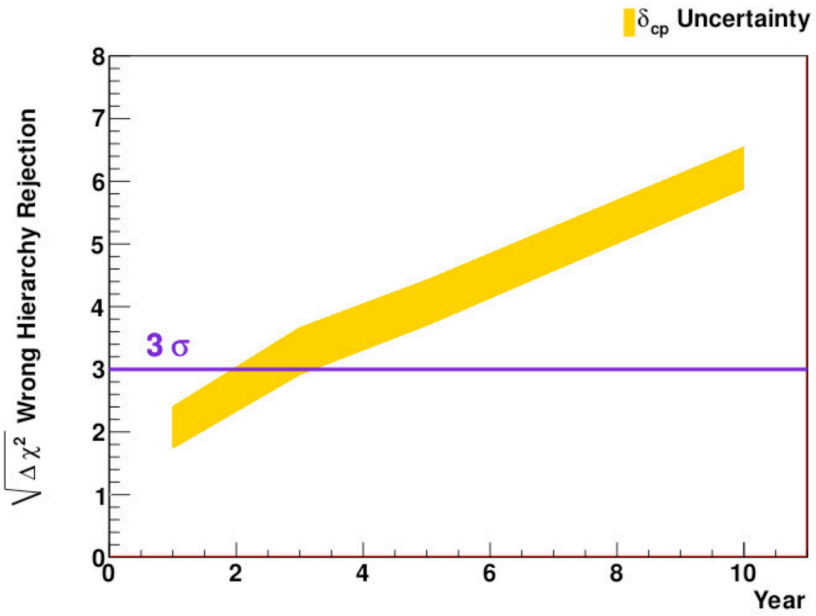
  ⇒ Sensitivity to mass hierarchy in combination with reactor

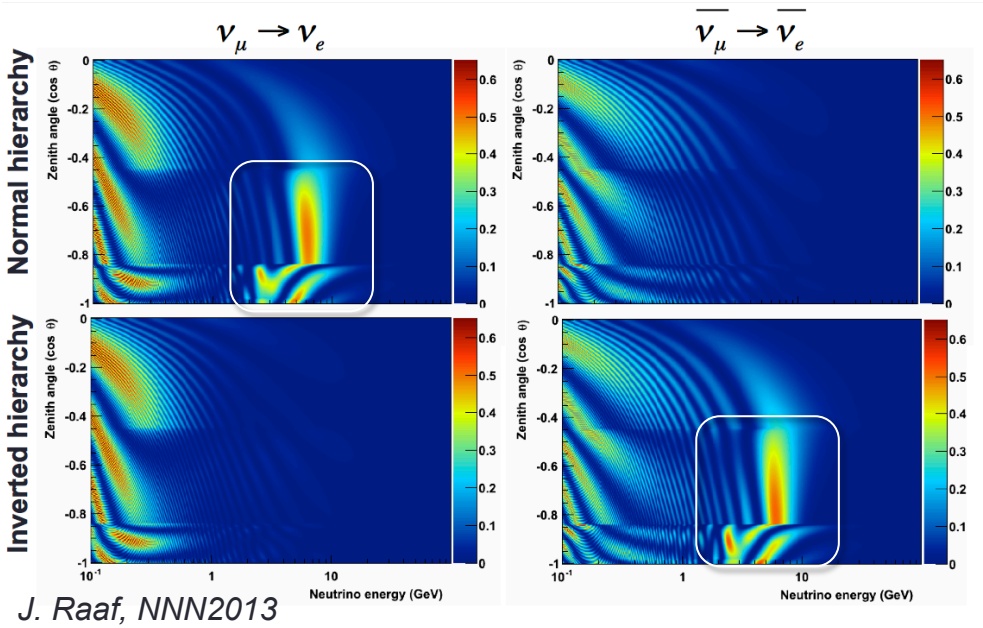
- Precision of $\mathbf{\theta_{23}}$
  - $\delta(\sin^2\theta_{23}) \sim 0.006$ (for $\sin^2\theta_{23}=0.45$)
  - $\delta(\sin^2\theta_{23}) \sim 0.015$ (for $\sin^2\theta_{23}=0.50$)

  ⇒ Good potential to determine θ_{23} octant



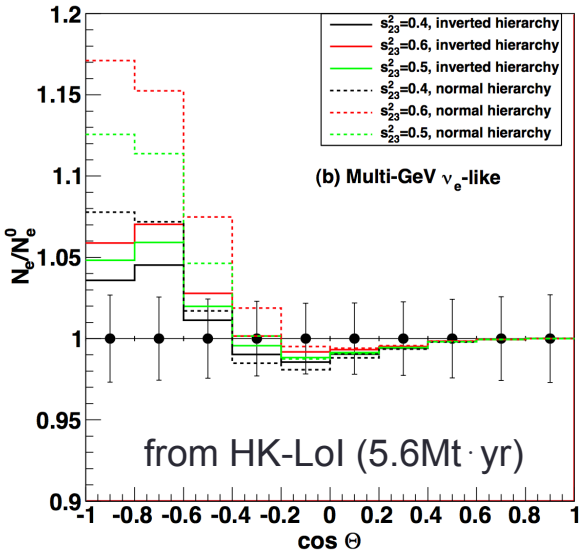
Atmospheric neutrino





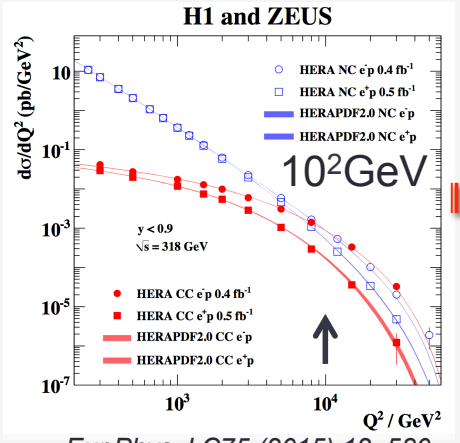
J. Raaf, NNN2013

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



Proton decay search

EW unification



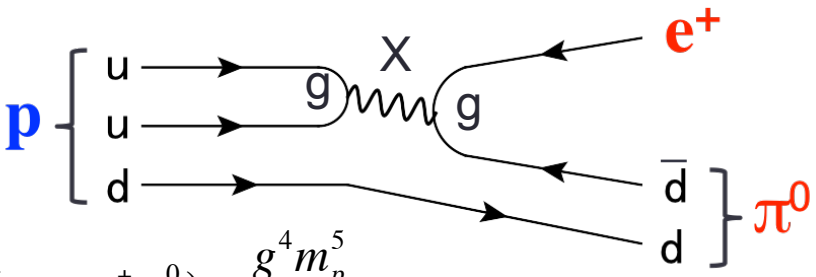
10^2GeV

GUT?

> 10^{15}GeV
How to access?

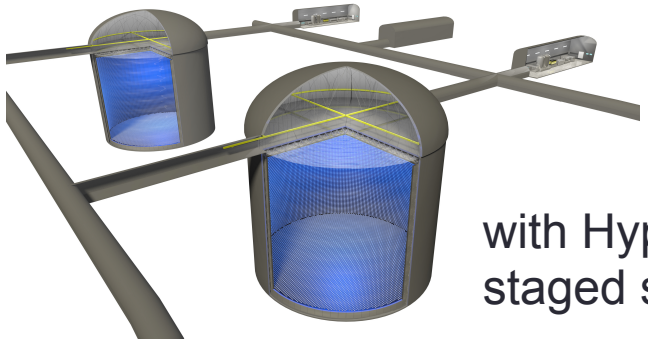
Eur.Phys.J.C75 (2015) 12, 580

- Probe GUT scale by virtual particle exchange ⟹ **proton decay**

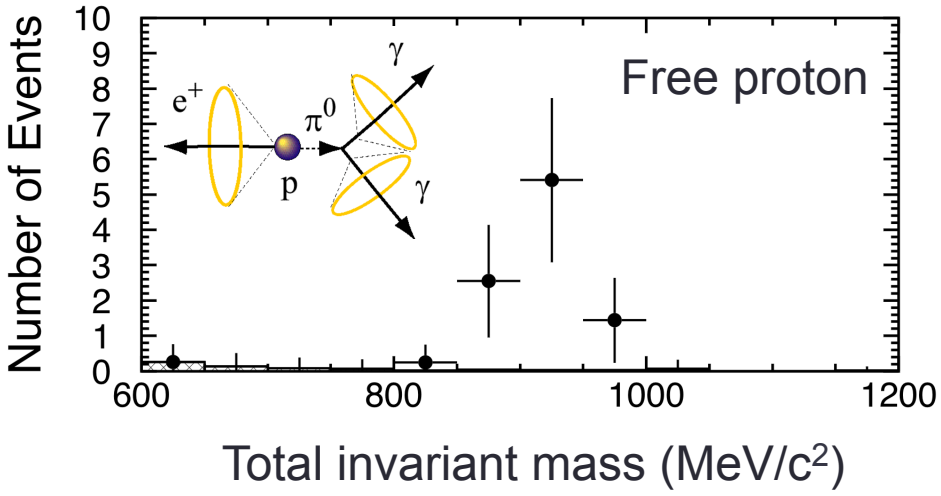


$$\Gamma(p \to e^+\pi^0) \approx \frac{g^4 m_p^5}{M_X^4}$$

New physics BSM

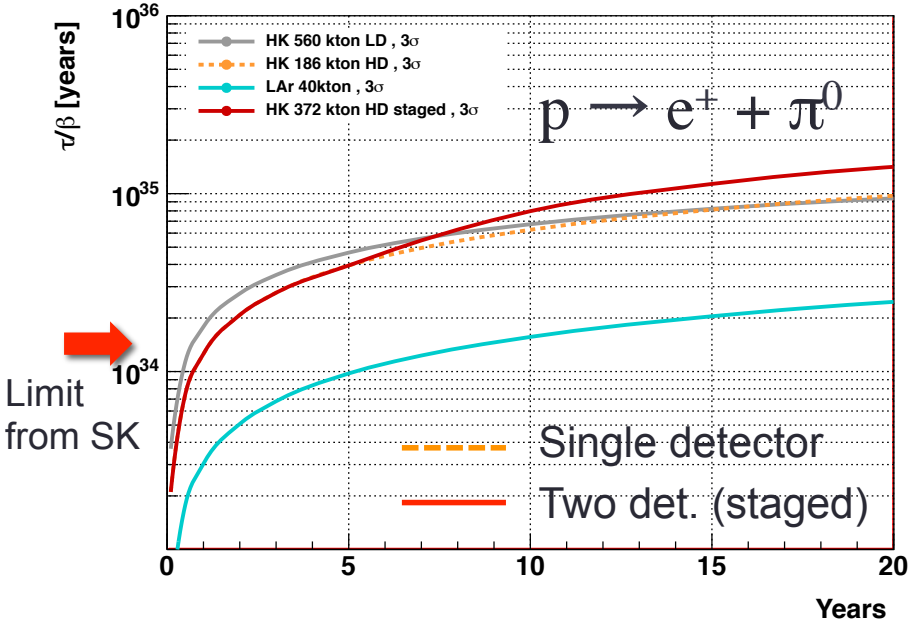


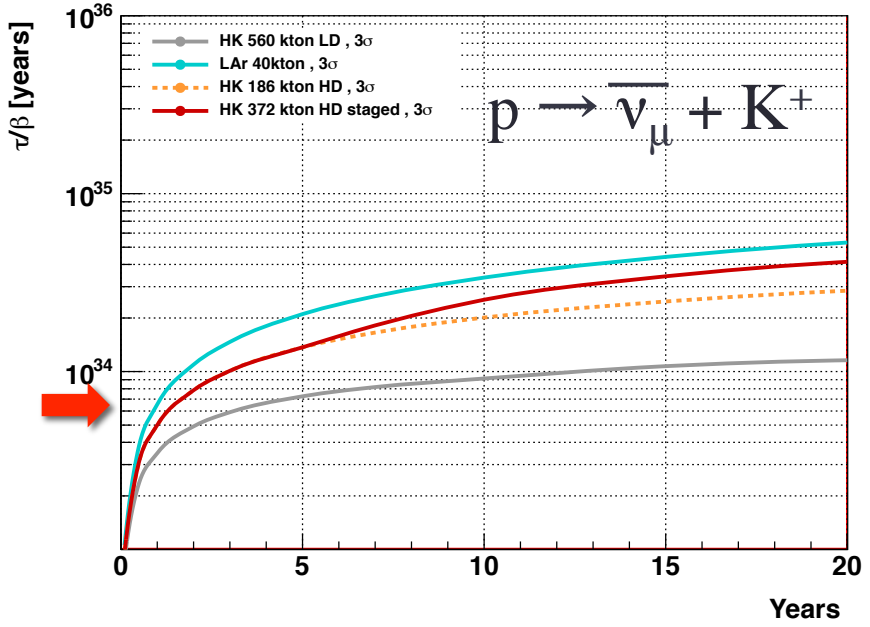
with Hyper-K
staged strategy



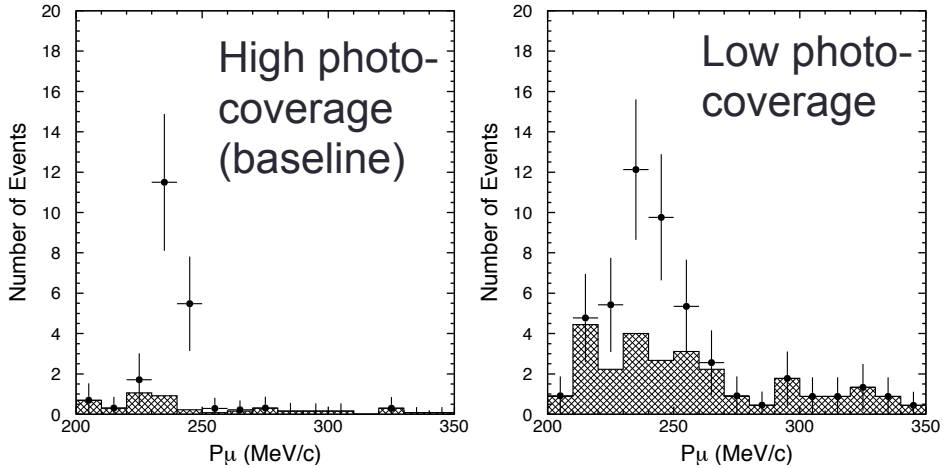
- **BG free** observation with high photo-coverage + HQE PMT
- **9σ discovery** in 10 years for $\tau_p = 1.4\times10^{34}$yr (SK limit)

Proton decay search: 3σ discovery potential



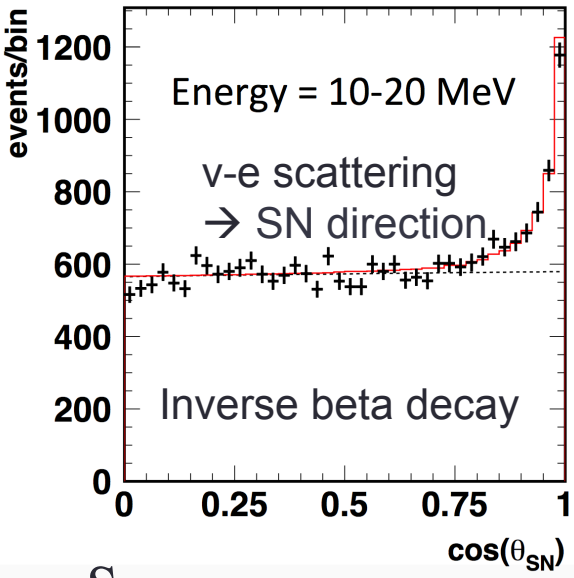


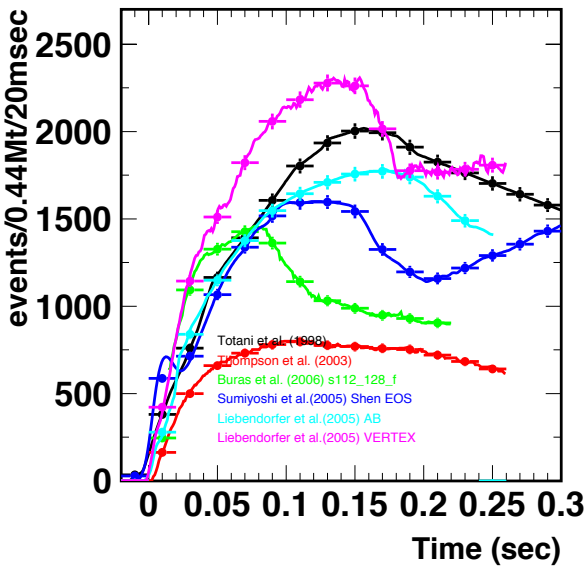
- Good discovery potential for $\tau_p > 10^{34} \sim 10^{35}$ years (test of SUSY SO(10) etc.)
- Further improvement under study

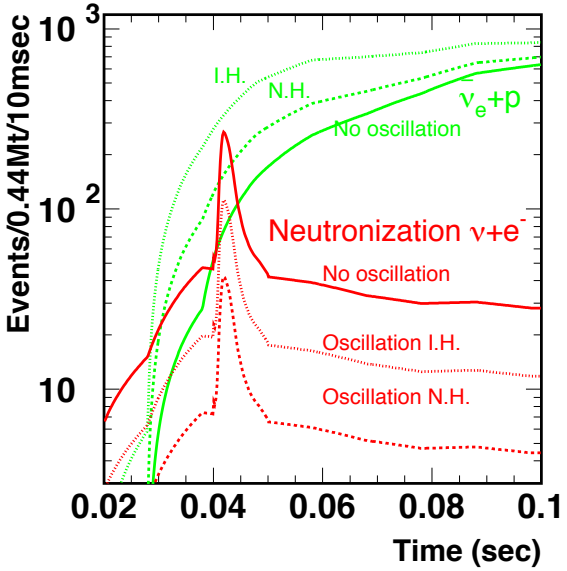


Muon momentum (p→νK search)

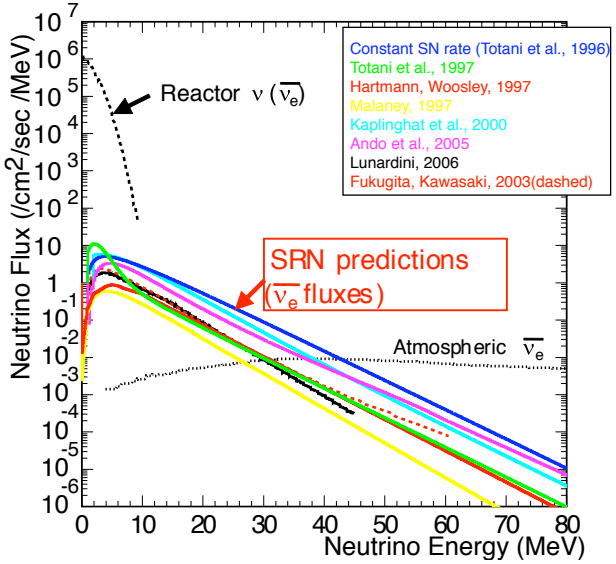
Hyper-Kamiokande neutrino telescope







- 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