# Hyper-Kamiokande

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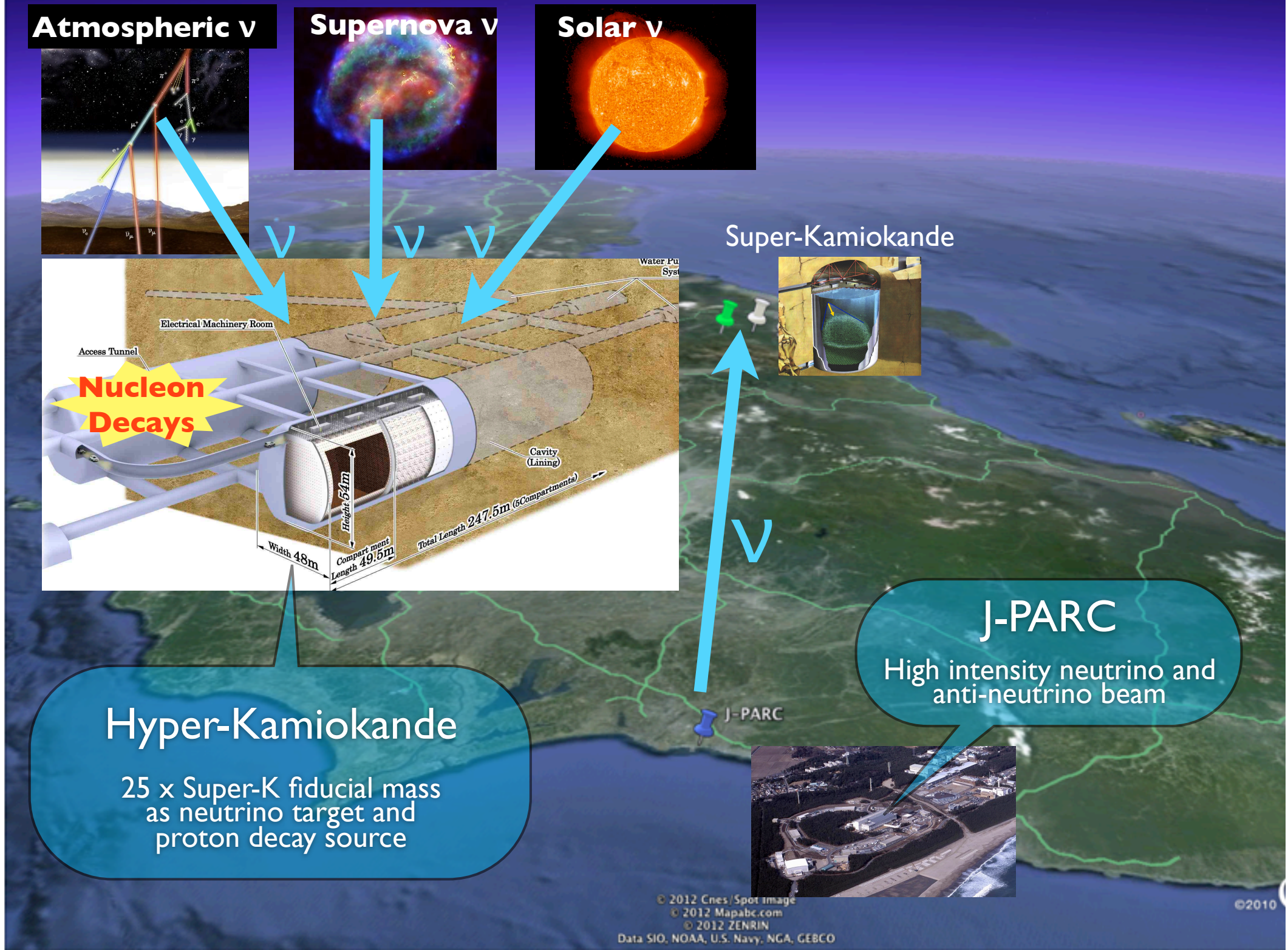
*Neutrino Telescope 2015*
*March 5, 2015*

# Overview of the Hyper-K


Atmospheric ν
Supernova ν
Solar ν
ν
ν
ν
Super-Kamiokande
Electrical Machinery Room
Access Tunnel
Nucleon Decays
Cavity (Lining)
Height 54m
Width 48m
Compartment Length 49.5m
Total Length 247.5m (5Compartments)
ν
J-PARC
Hyper-Kamiokande
25 x Super-K fiducial mass as neutrino target and proton decay source
J-PARC
High intensity neutrino and anti-neutrino beam
© 2012 Cnes/Spot Image
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Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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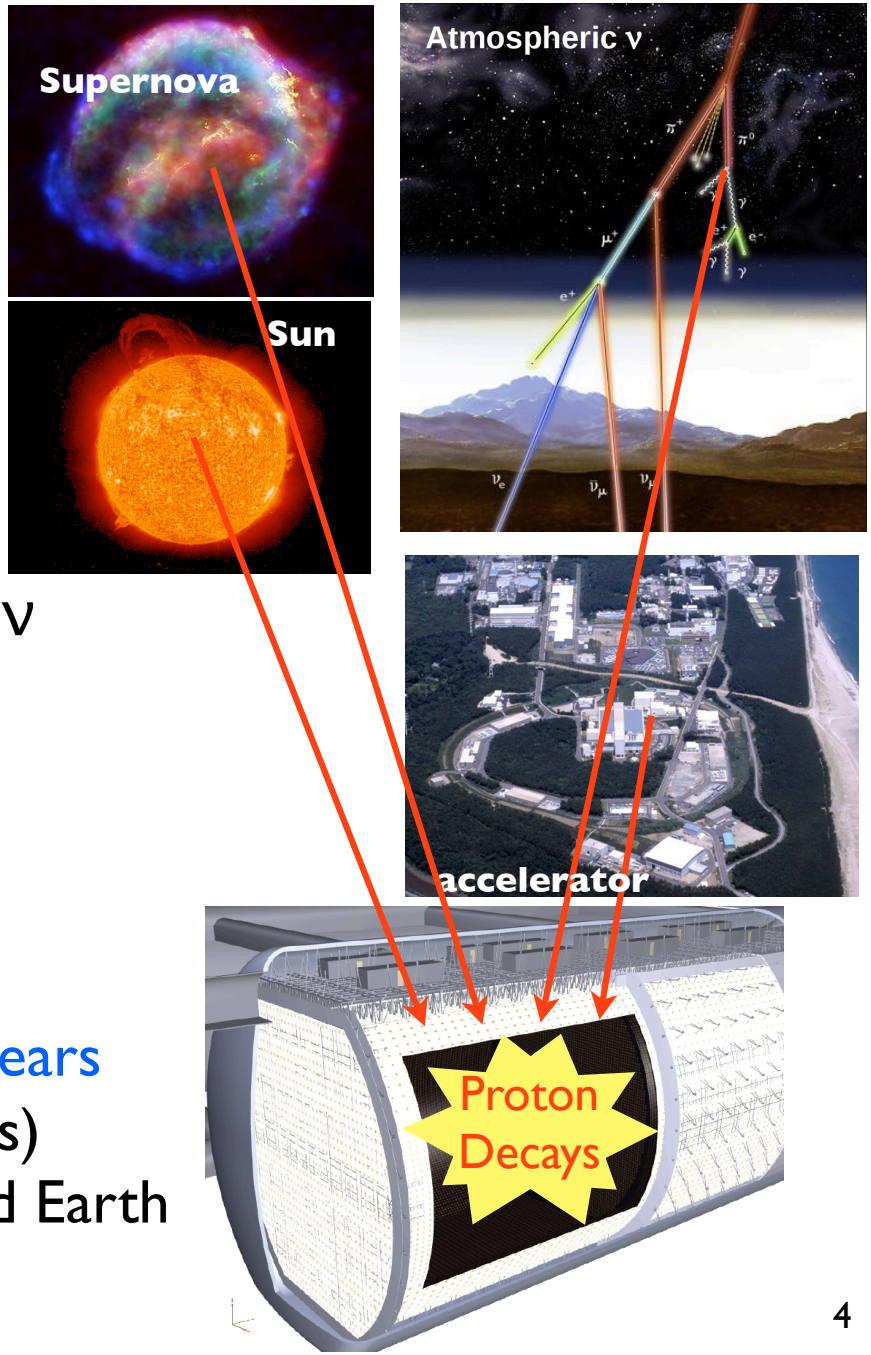
# Multi-purpose detector, Hyper-K

Letter of Intent, Hyper-K WG, arXiv:1109.3262 [hep-ex]

LBL study, Hyper-K WG, arXiv:1502.05199 and submitted to PTEP

- Proton decay 3σ discovery potential
  - $5\times10^{34}$ years for $p\rightarrow e^+\pi^0$
  - $1\times10^{34}$ years for $p\rightarrow \nu K^+$
- Comprehensive study on ν oscillations
  - CPV (76% of δ space at 3σ), <20° precision
  - MH determination for all δ by J-PARC/Atm ν
  - $\theta_{23}$ octant: $\sin^2\theta_{23}<0.47$ or $\sin^2\theta_{23}>0.53$
  - <1% precision of $\Delta m^2_{32}$
  - test of exotic scenarios by J-PARC/Atm ν
- Astrophysical neutrino observatory
  - Supernova up to 2Mpc distance, ~1SN /10 years
  - Supernova relic ν signal (~200ν events/10yrs)
  - Dark matter neutrinos from Sun, Galaxy, and Earth
  - Solar neutrino ~200ν events/day



# Hyper-K proto-collaboration w/ cooperation of KEK-IPNS and UTokyo-ICRR

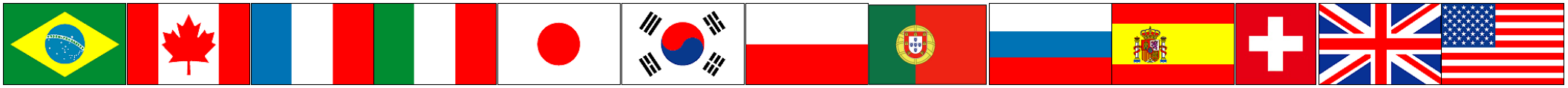
**Inaugural Symposium on 1/31, 2015**

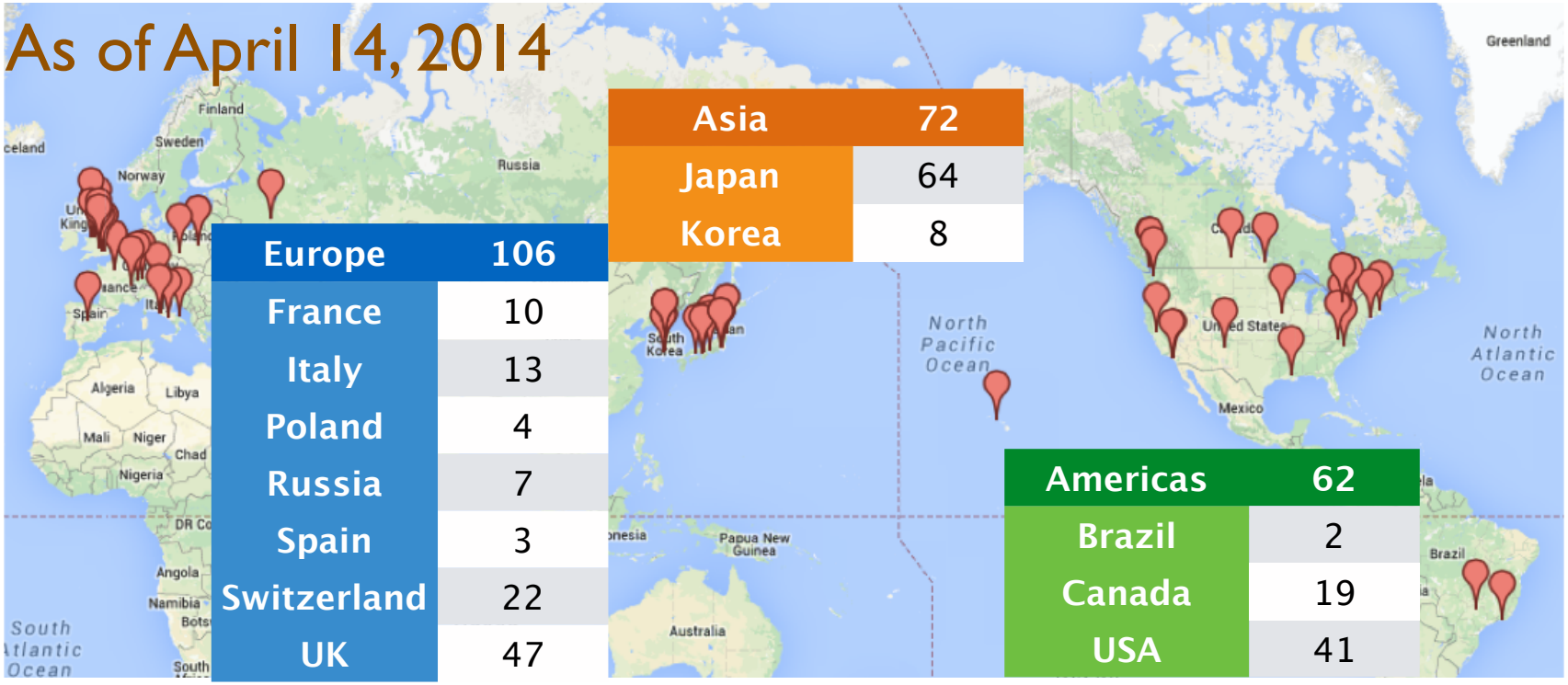

**Hyper-K Proto-Collaboration has been formed**

**MoU signing by KEK/ICRR**

- **KEK-IPNS** and **Tokyo-ICRR** signed the **MOU** of the cooperation in promoting the Hyper-Kamiokande.

# Hyper-Kamiokande International Group






- 240 people and growing!
- Hyper-K Governance Structure has been defined
  - Steering Committee, International Board Representatives, and Convener Board
- R&D fund and travel budget already secured in some countries, and more in securing processes.

# What's next?: Design Report

- **Design Report** to be prepared in 2015
  - Optimum design, Construction cost/period, Beam&Near detectors, International responsibility

- **International review** under **KEK-IPNS/ICRR** to promote the project

- Start **budget request** in 2015~2016

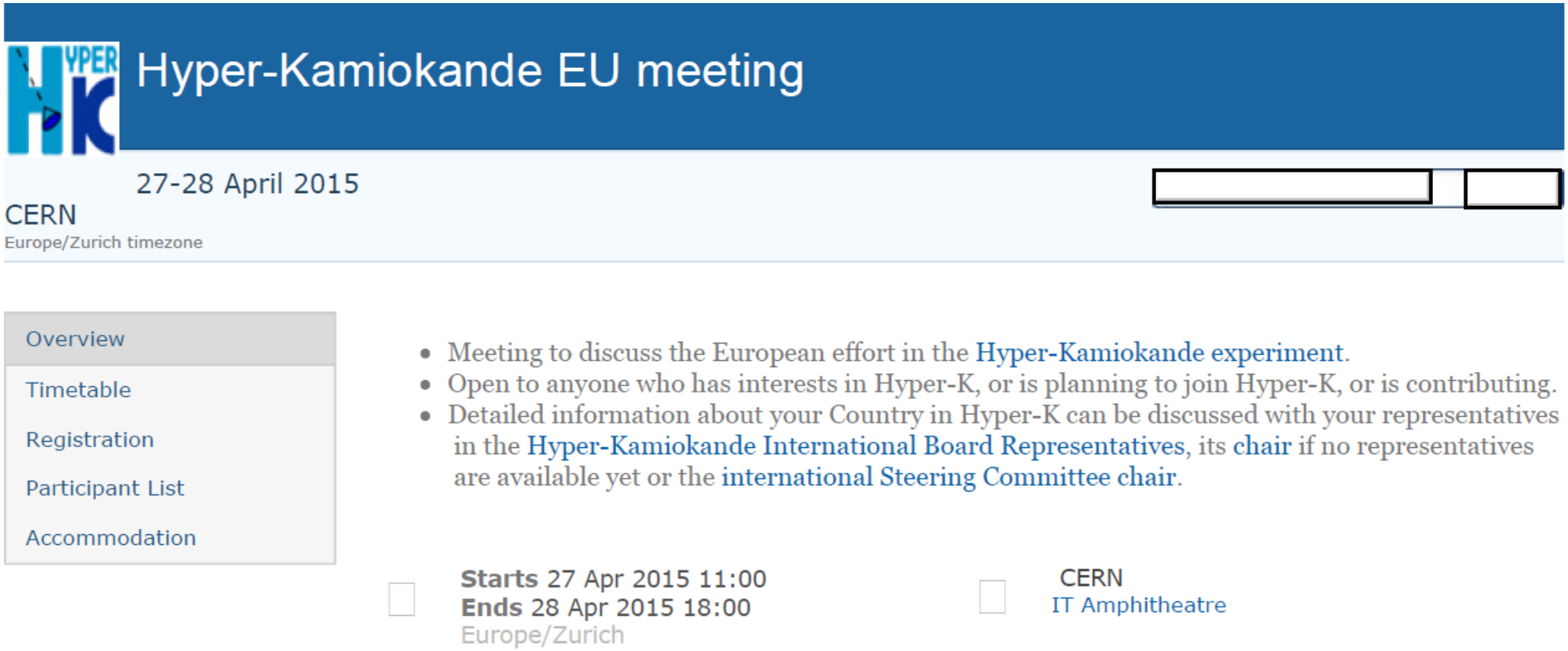
- **Start construction** in 2018
  → start operation in ~2025

It is critical period to promote the project

Still open for new collaborators

# Hyper-Kamiokande EU meeting@CERN 27-28 April 2015

- Meeting to discuss the European effort in Hyper-K
- Open to anyone who has interest in Hyper-K, or is planning to join Hyper-K, or is contributing
- http://indico.cern.ch/e/ThirdEUHyperK



Hyper-Kamiokande EU meeting

27-28 April 2015

CERN

Europe/Zurich timezone

Overview

Timetable

Registration

Participant List

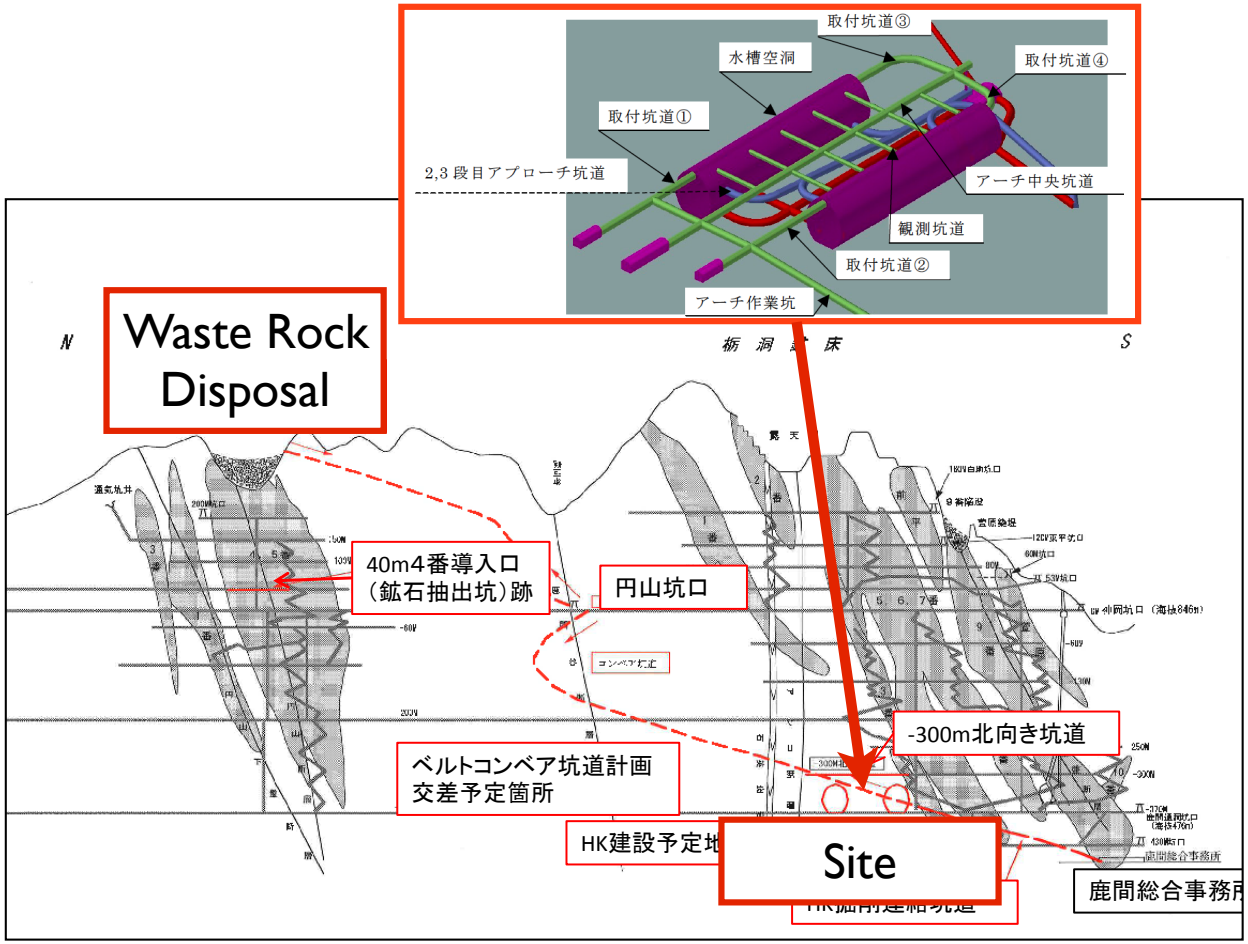
Accommodation

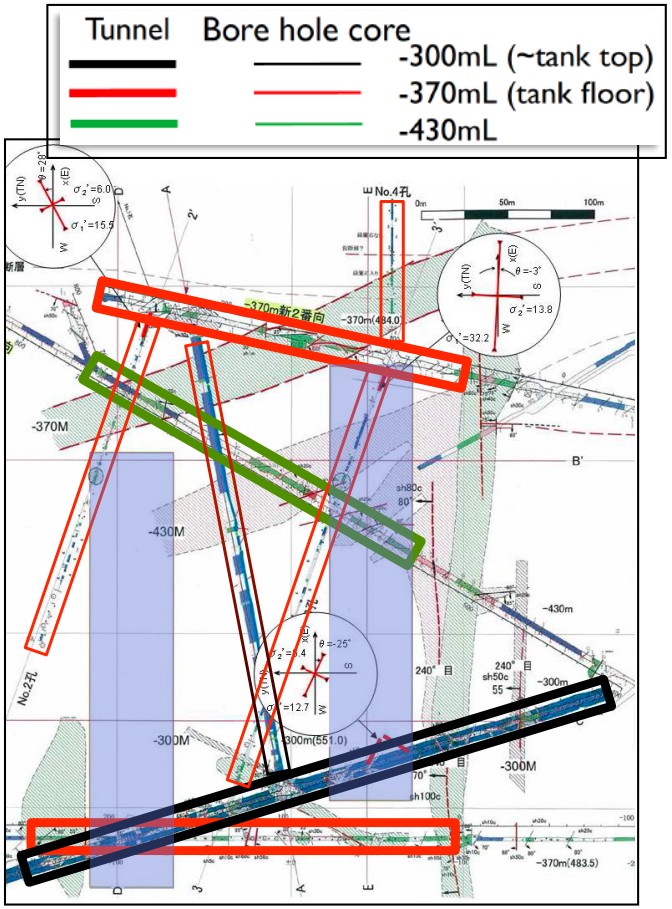
- Meeting to discuss the European effort in the Hyper-Kamiokande experiment.
- Open to anyone who has interests in Hyper-K, or is planning to join Hyper-K, or is contributing.
- Detailed information about your Country in Hyper-K can be discussed with your representatives in the Hyper-Kamiokande International Board Representatives, its chair if no representatives are available yet or the international Steering Committee chair.

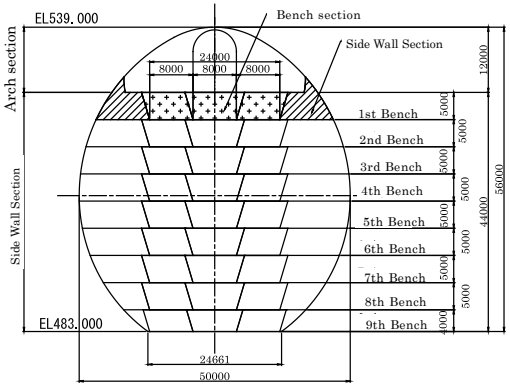
**Starts** 27 Apr 2015 11:00
**Ends** 28 Apr 2015 18:00
Europe/Zurich

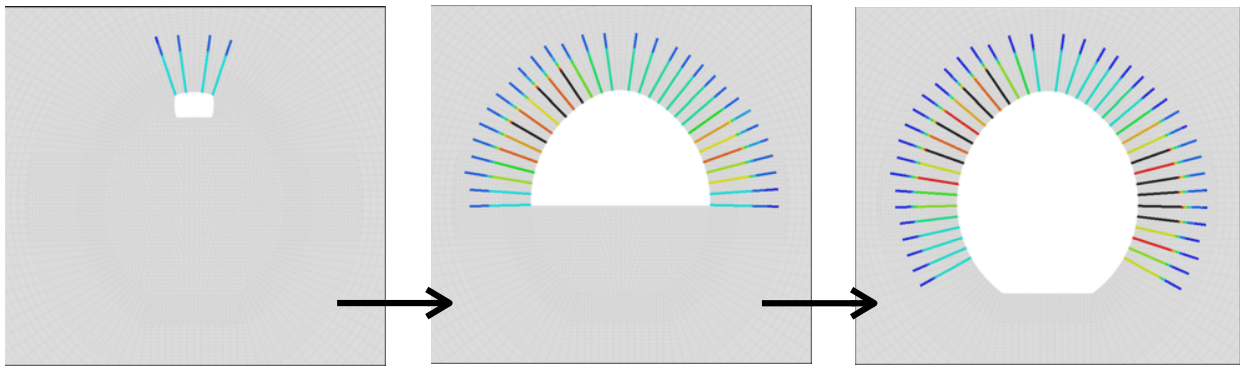
CERN
IT Amphitheatre

# Design and ongoing studies



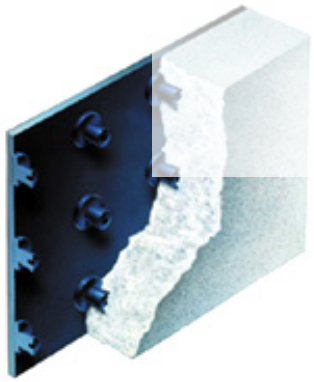



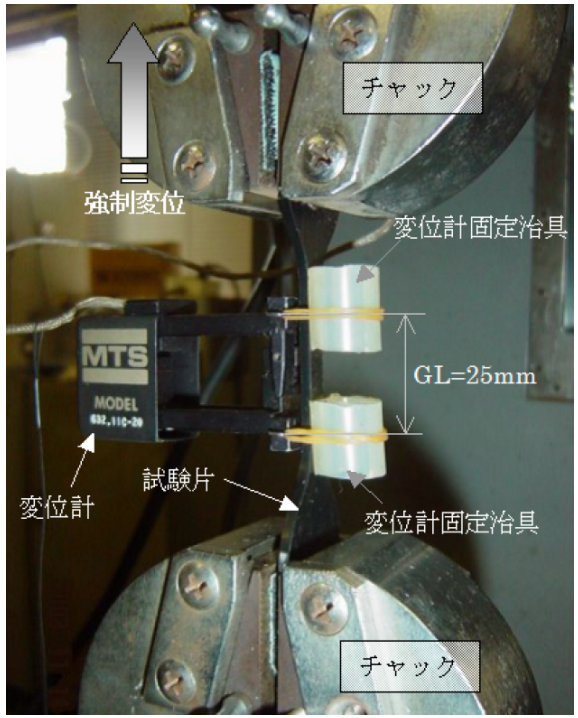



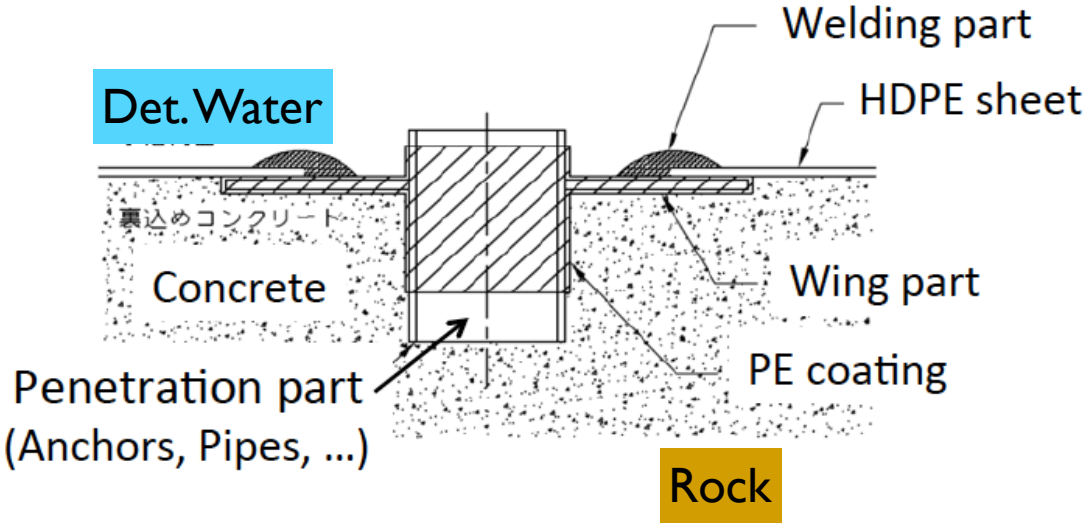
- Conceptual design of caverns, supports have been made.
- Estimation of excavation period/cost → Optimization

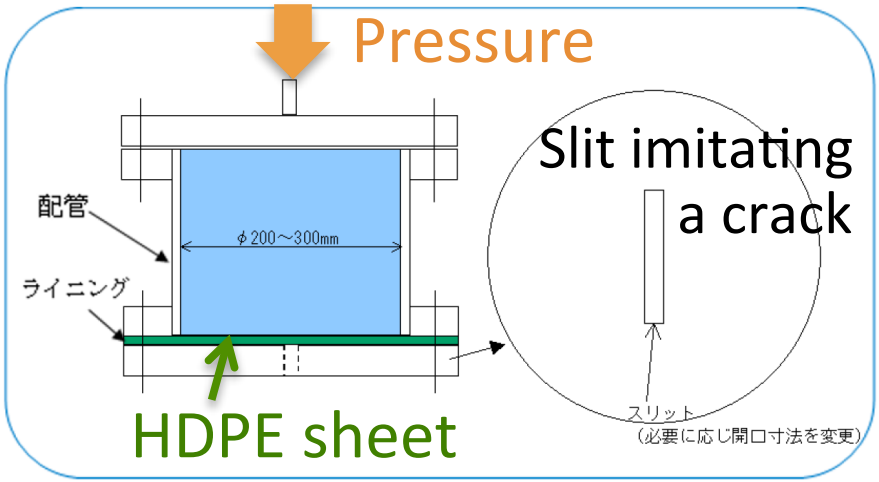
# Tank liner material

## 5mm High Density Polyethylene





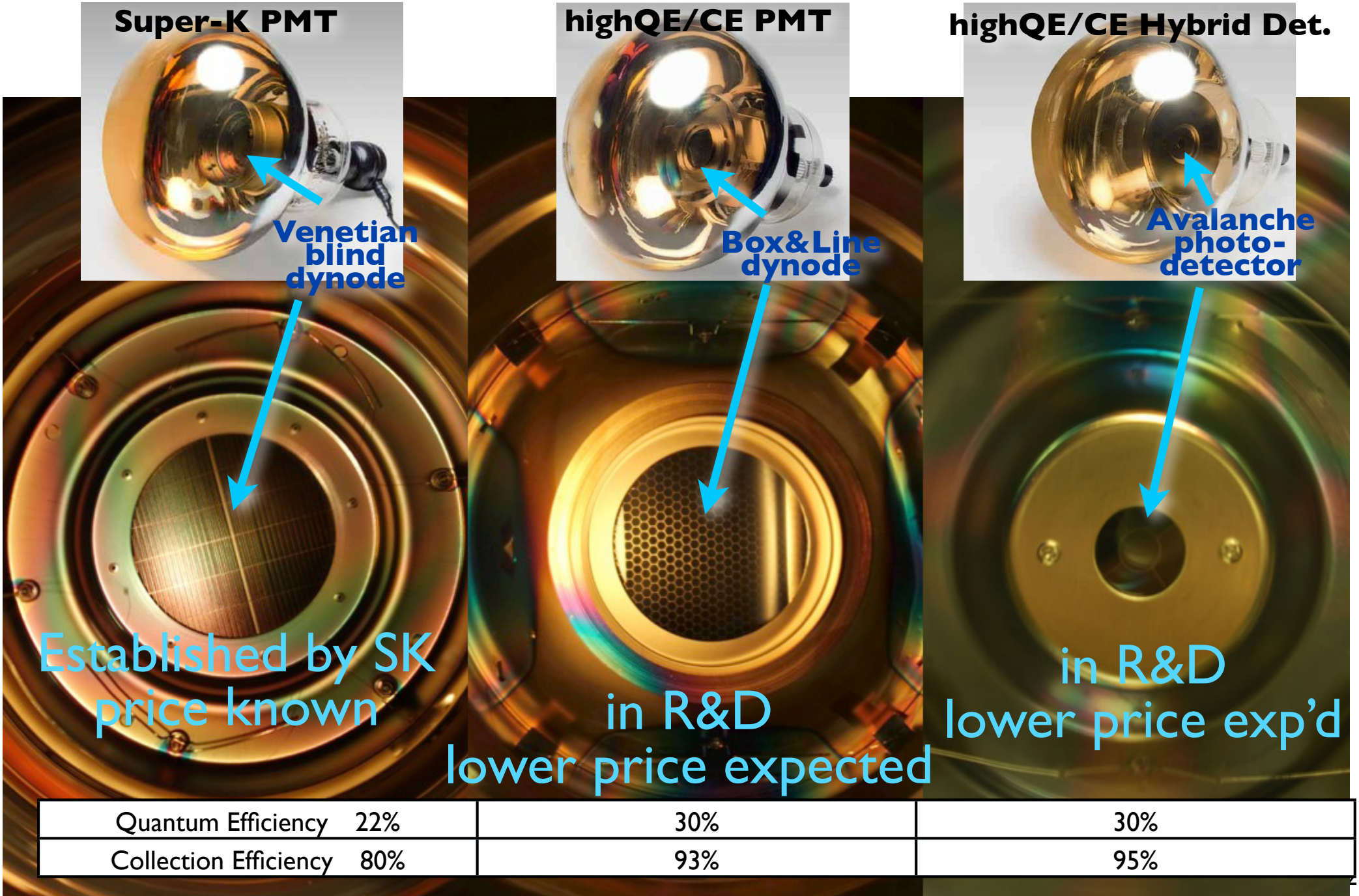




- Soak test
  - pure water, 1% $Gd_2(SO4)_3$ loaded
- Tensile creep test
- pressure test
- leak test at the penetrating part

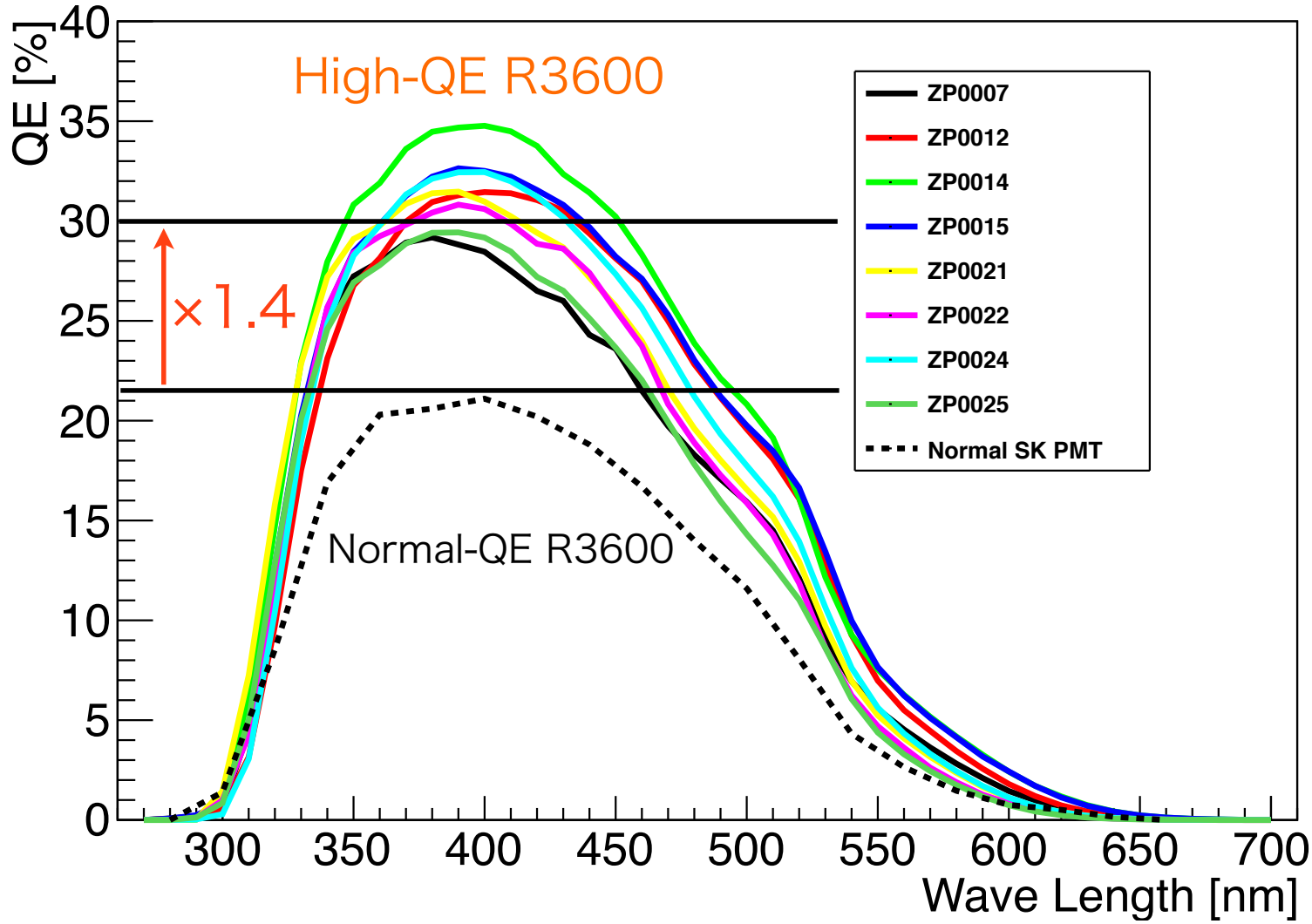
Satisfactory results for Hyper-K

# Photo-sensor candidates




| | | | |
|---|---|---|---|
| Quantum Efficiency | 22% | 30% | 30% |
| Collection Efficiency | 80% | 93% | 95% |

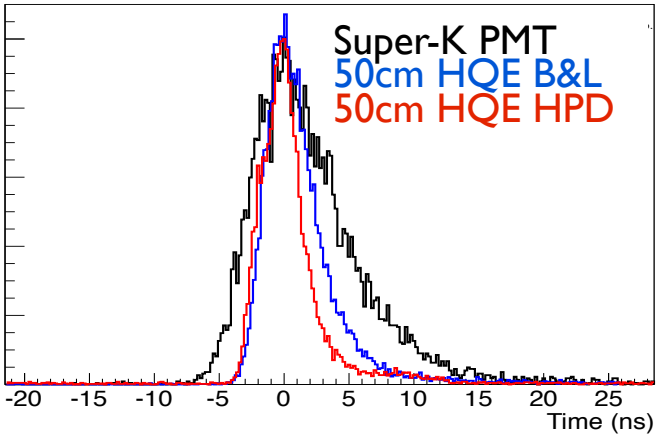
# Higher QE achieved



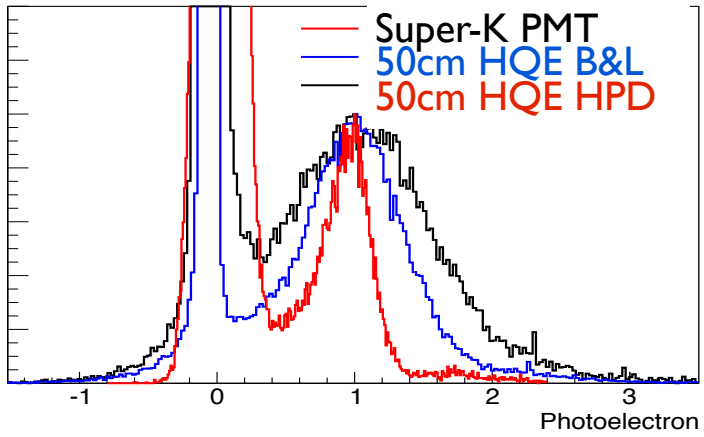

High Quantum Efficiency (QE) of ~30% has been achieved !
for 50cm B&L PMT and HPD

# Photo-sensor performance

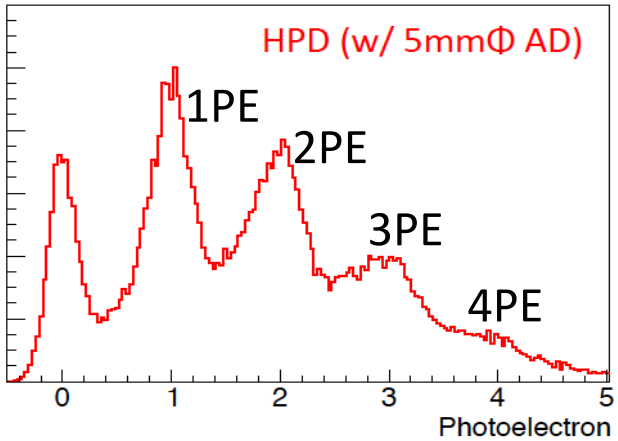
T distribution @1p.e.



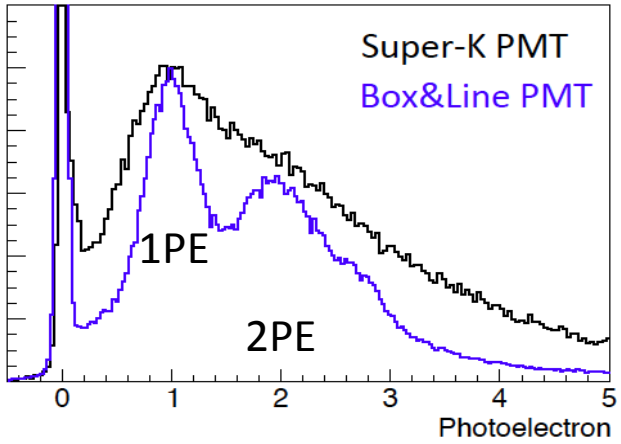

1p.e. Q distribution




multi-p.e. Q dist.




| | SK PMT | B&L PMT | HPD |
|---|---|---|---|
| 1p.e. Δt (ns) | 2.1 | 1.1 | 1.4 |
| 1p.e. ΔQ/Q (%) | 53 | 35 | 16 |
| Peak/Valley ratio | 2.2 | 4.3 | 3.9 |



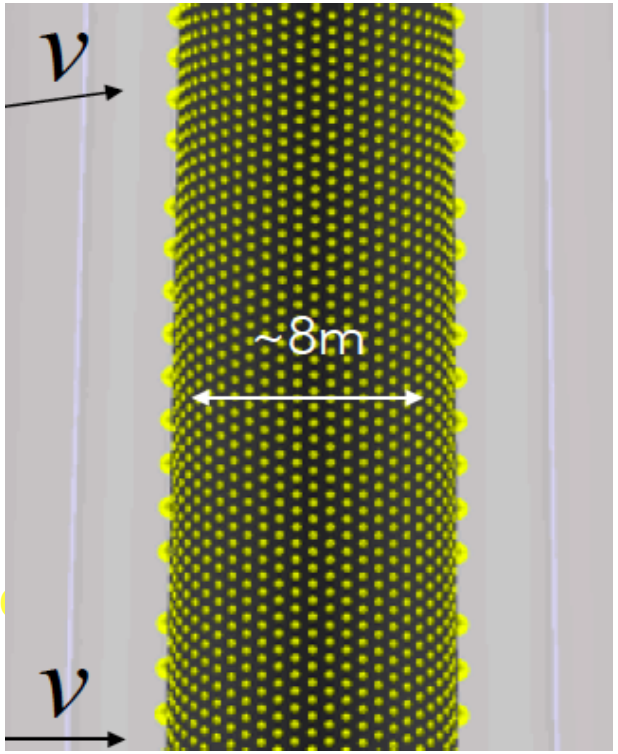

- Achieved better T&Q resolution
- Further tests are planned (test in water, long-term stability etc.)
- to be concluded by 2016

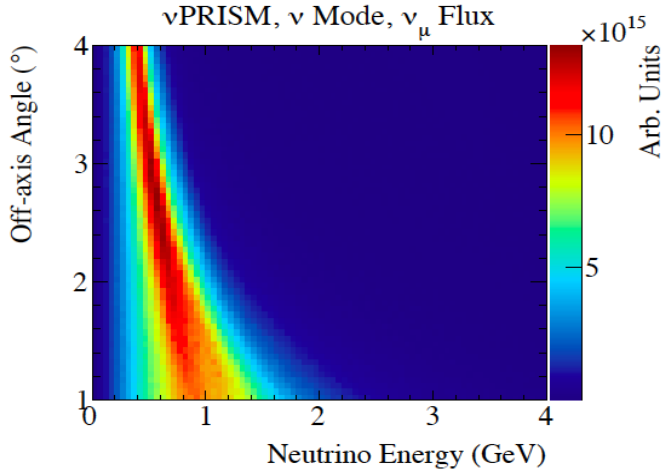
# Near Detectors for J-PARC beam

## Conceptual design

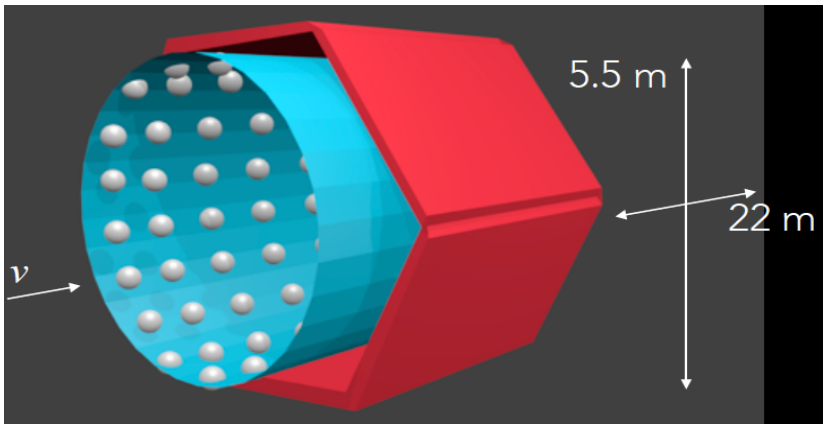
- Oscillation study
  - Water target (same w/ the far detector, minimize nuclear uncertainty)
  - NC$\pi^0$ BG measurement
  - beam $\nu$e BG
- Other physics
  - $\nu\mu$, $\nu$e interaction studies
  - Sterile $\nu$ searches

### νPRISM
### 50m tall WČ

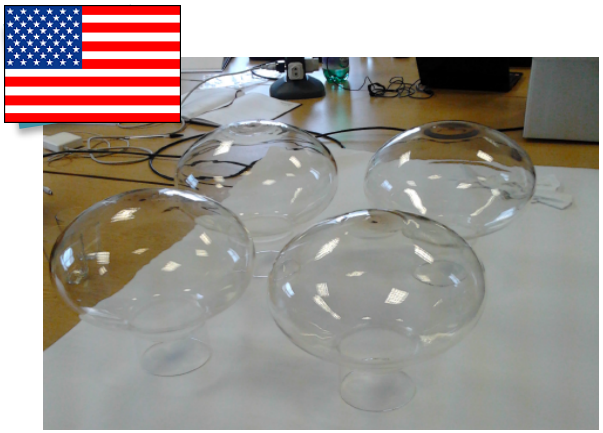


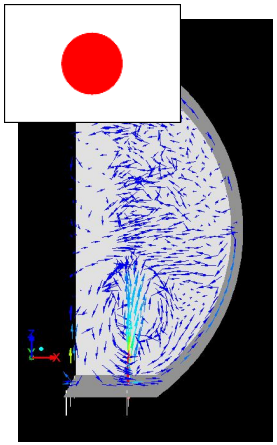




### TITUS
### WČ+MRD

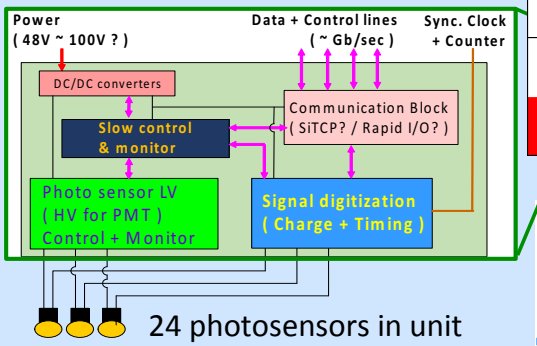


# Worldwide R&D





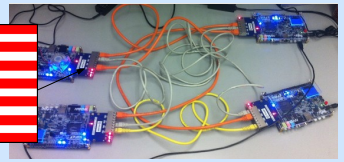

## Elec. + HV modules in water

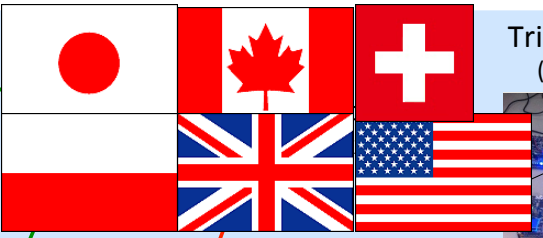


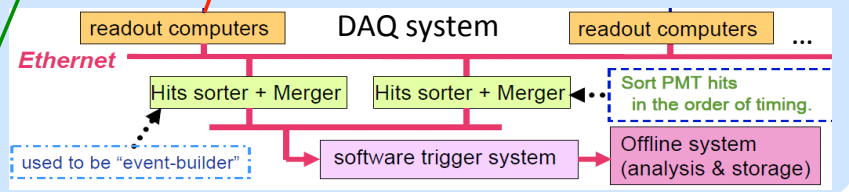

24 photosensors in unit

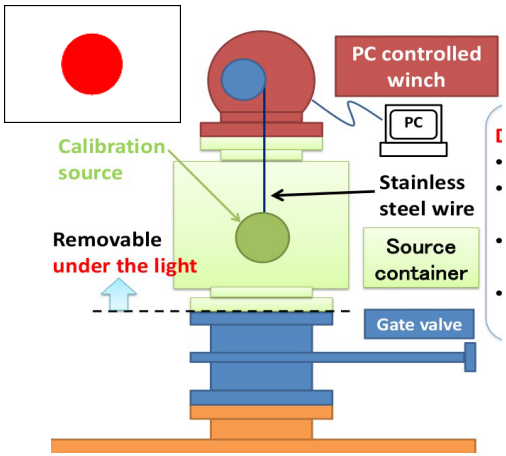
## Trial for communication

(RapidIO in FPGA boards)

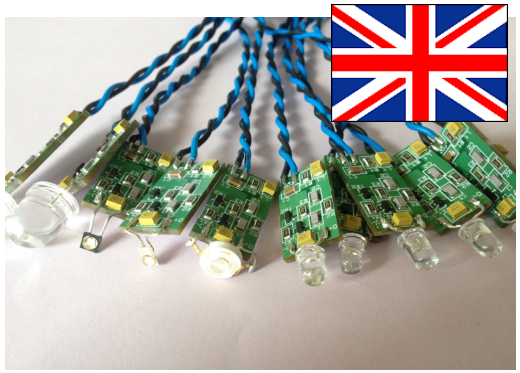




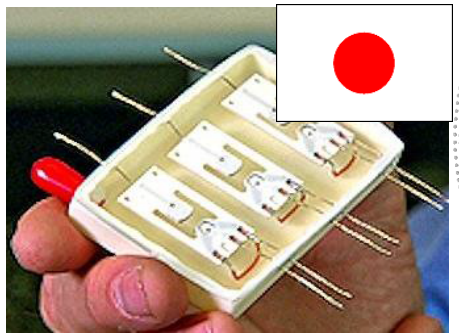


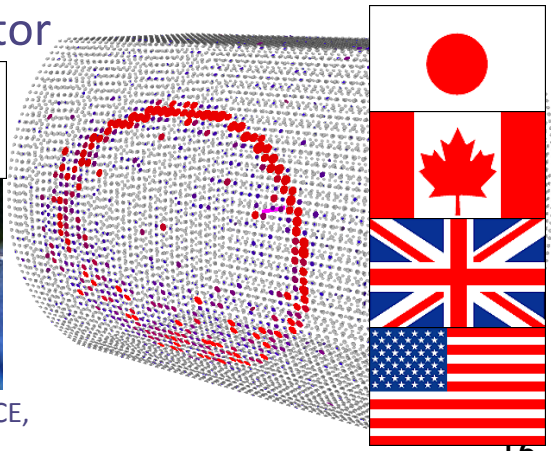




## LED



## Compact neutron generator





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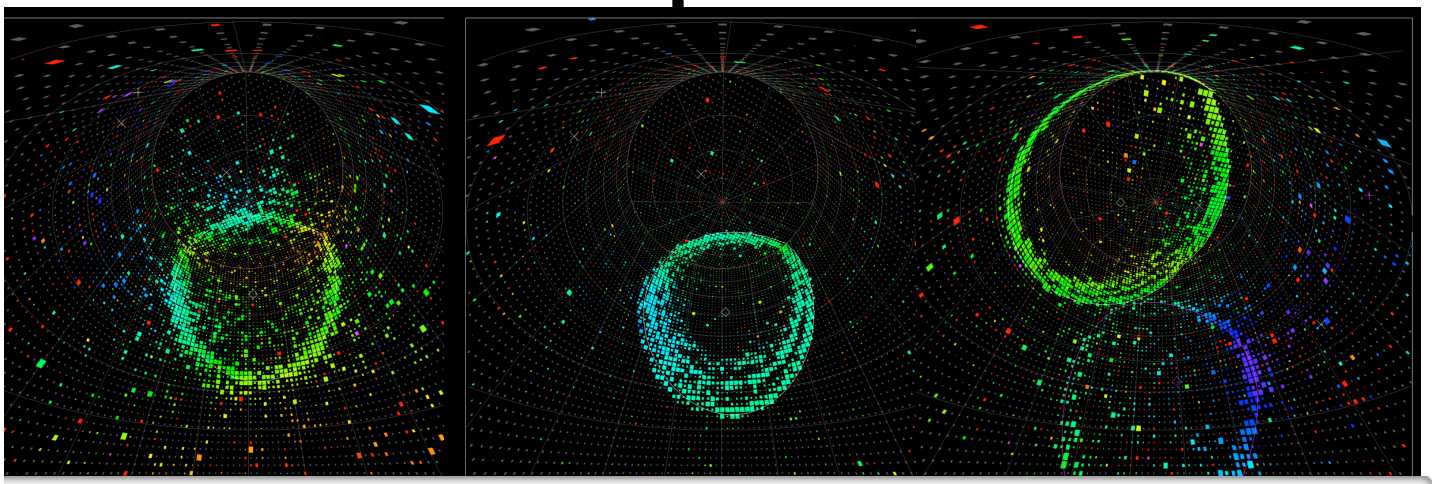
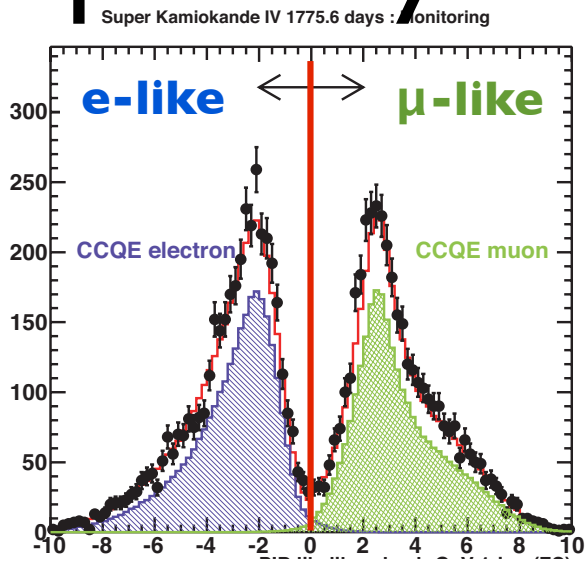
# Hyper-K
# Physics Potentials

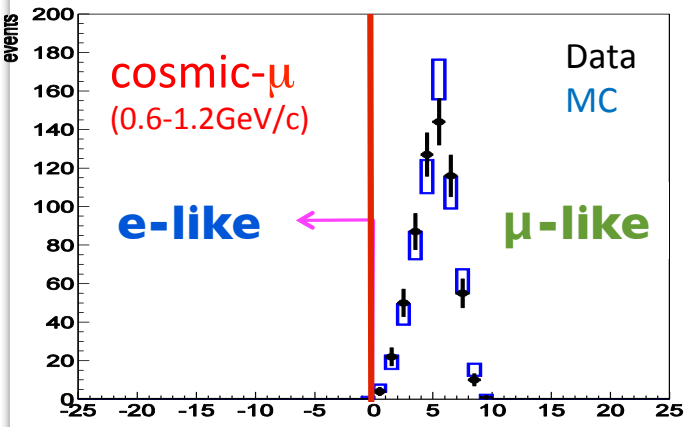
# Detector performance for p-decays






PID likelihood (atmν)

- High mass (1Mton scale, 20×Super-K)
- Good ring-imaging capability at ~1GeV
  - atmospheric ν, proton decays, accelerator ν
- Excellent particle ID (e or μ) capability > 99%
- Energy resolution for e and μ ~3%
- opportunity to improve more
- for proton decay search via $p \rightarrow e^{+}\pi^{0}$
  - good ~5% invariant proton mass resolution
  - high 40% signal efficiency
  - 99.998% atmospheric ν BG rejection

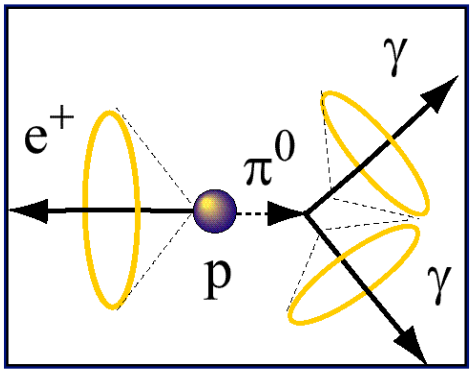



PID likelihood (CRμ)

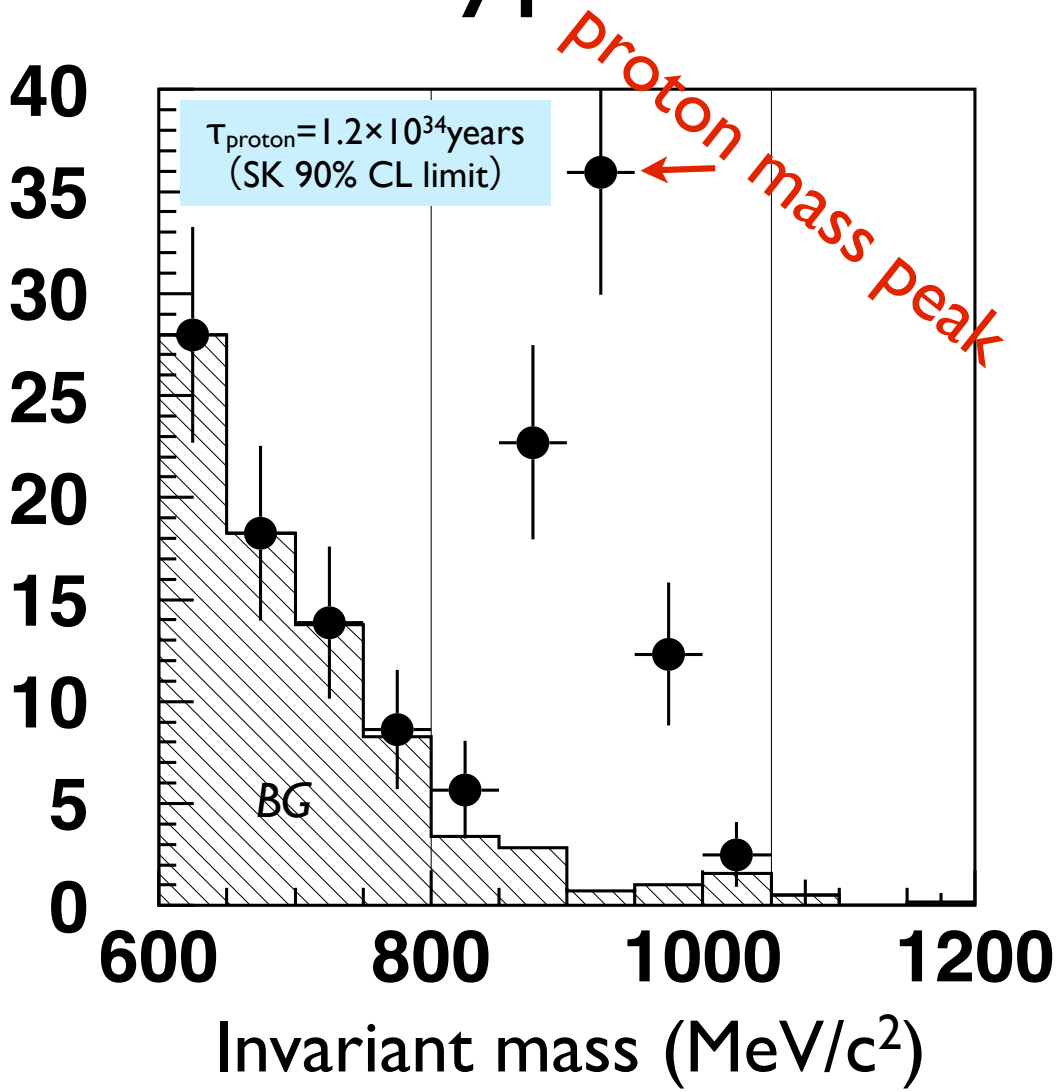
mis-PID:
Data: 0.00±0.16(stat.)%
MC : 0.10±0.10(stat.)%

# Discovery potential in Hyper-K

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



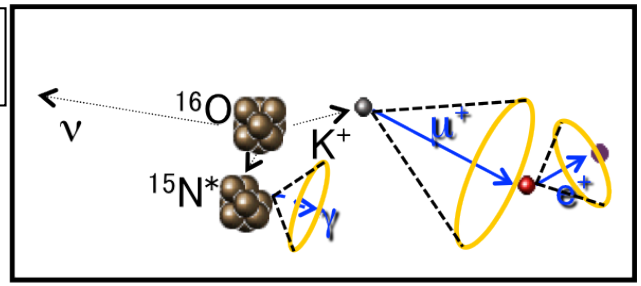

- Discovery reach (3σ)
  - $\tau(p \rightarrow e^+\pi^0) \sim 5\times10^{34}$years （HK 10yrs）
- Limit (90%CL)
  - $\tau(p \rightarrow e^+\pi^0) > 1\times10^{35}$years （HK 10yrs）



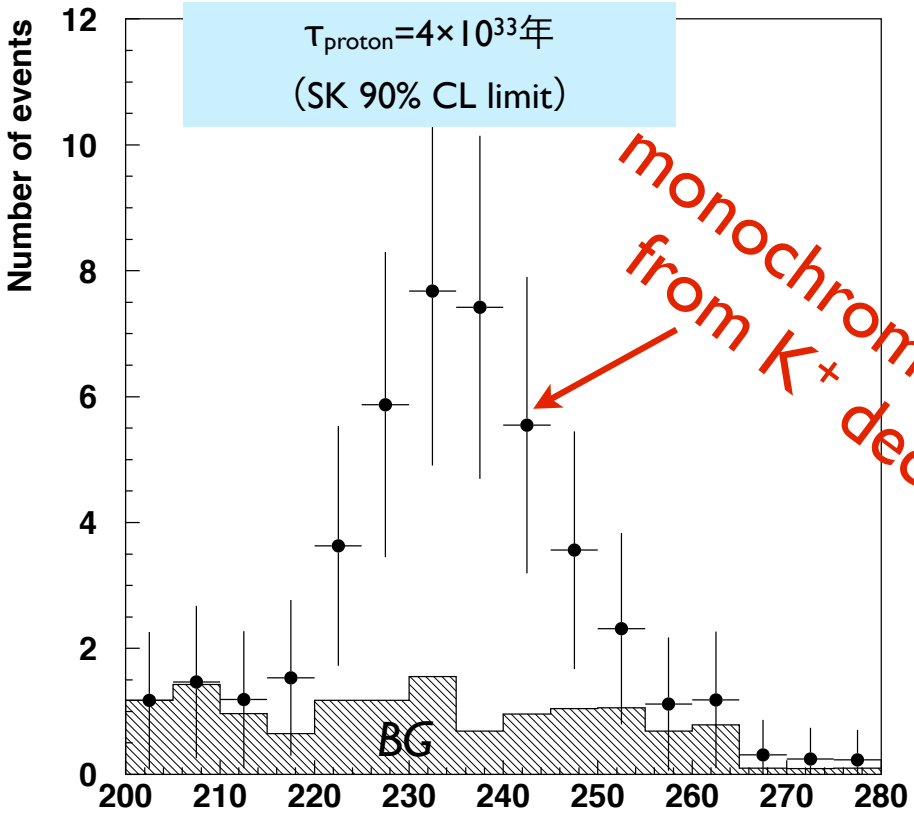

Only realistic proposal to reach the lifetime of $10^{35}$ years for $p \rightarrow e^+\pi^0$

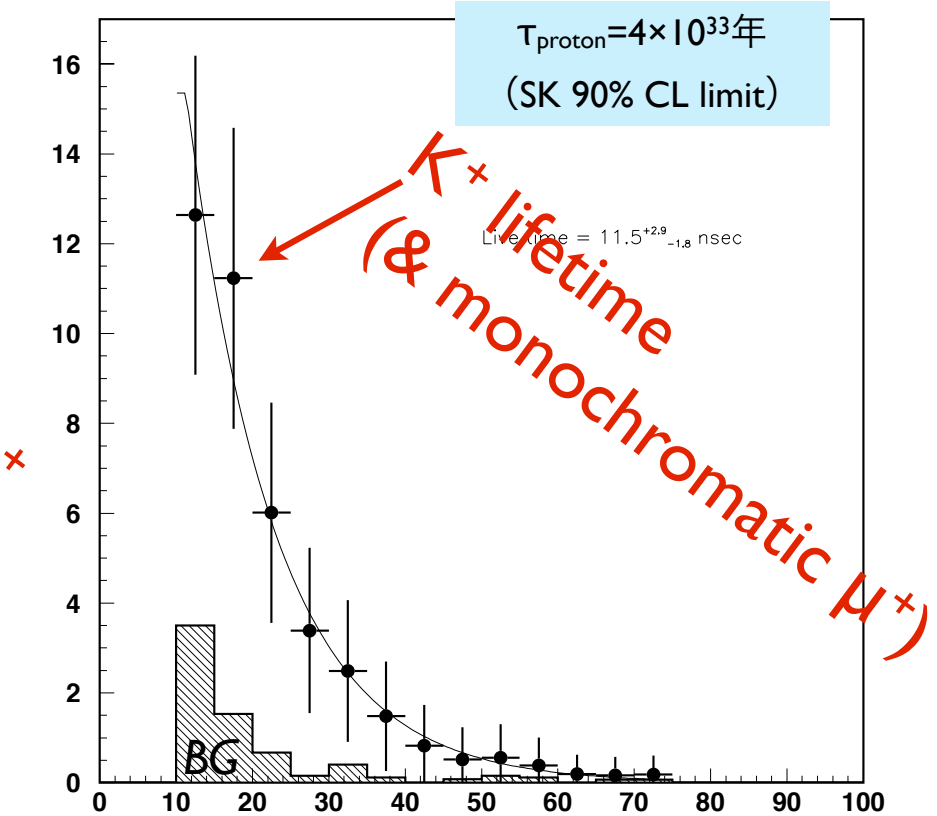
# Discovery potential (2)

$p \rightarrow \nu K^+$



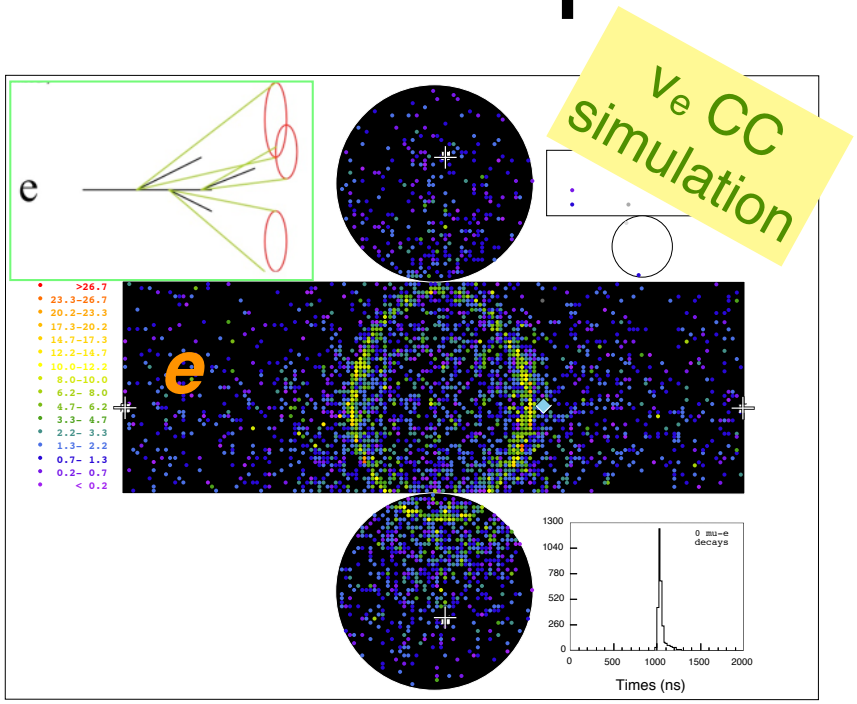

- Discovery reach (3σ)
  - $\tau(p \rightarrow \nu K^+) \sim 1 \times 10^{34}$years （HK 10yrs）
- Limit (90%CL)
  - $\tau(p \rightarrow \nu K^+) > 3 \times 10^{34}$years （HK 10yrs）

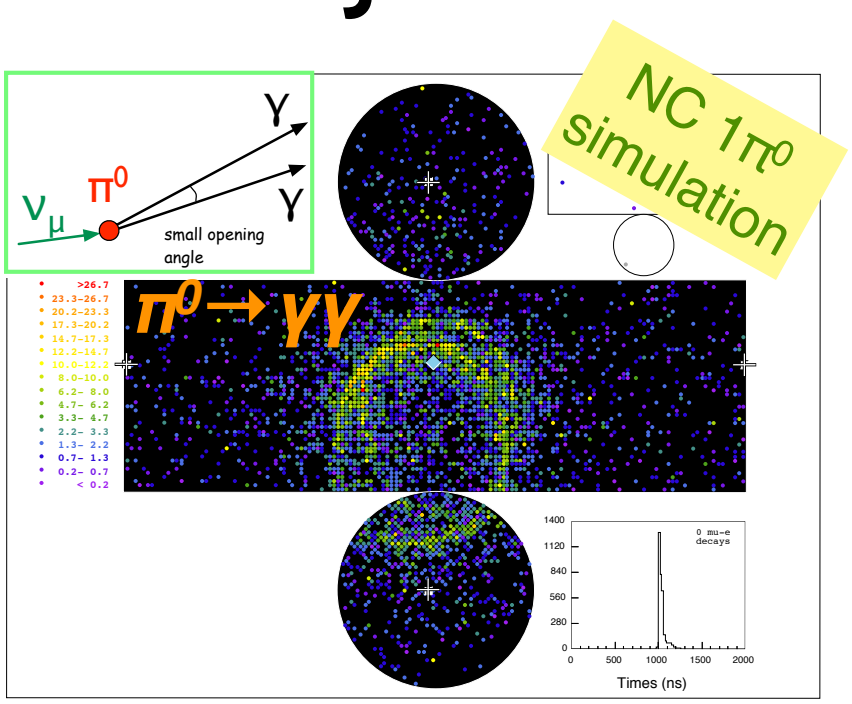



Experimental test on Supersymmetry

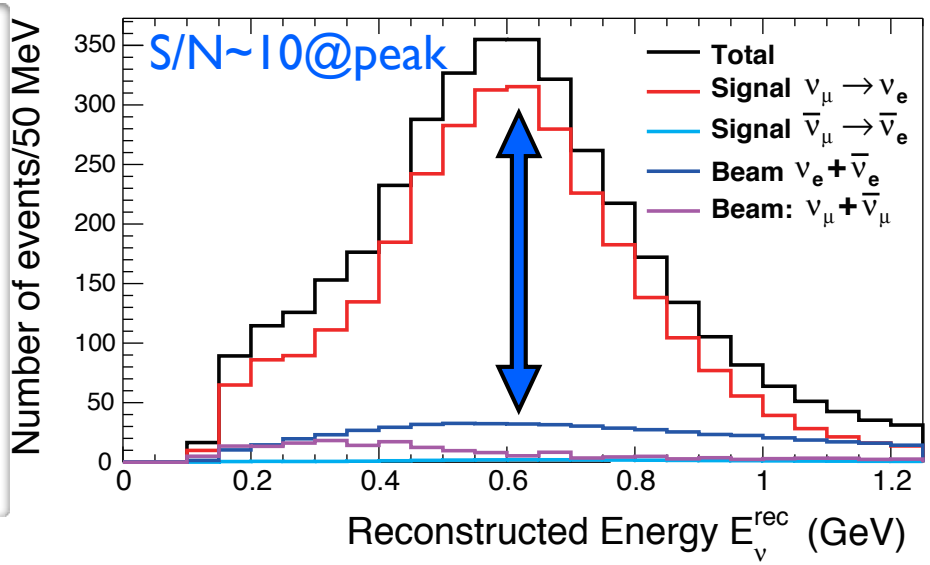
# Detector performance for J-PARCν




**Appearance ν mode**

- For νe appearance in J-PARC $\nu_\mu$ beam
  - high 60% νe signal efficiency
  - >99.9% $\nu_\mu$CC rejection, 99% NC $\pi^0$ rejection
  - opportunity to improve more



# $\delta_{CP}$ dependence of observables

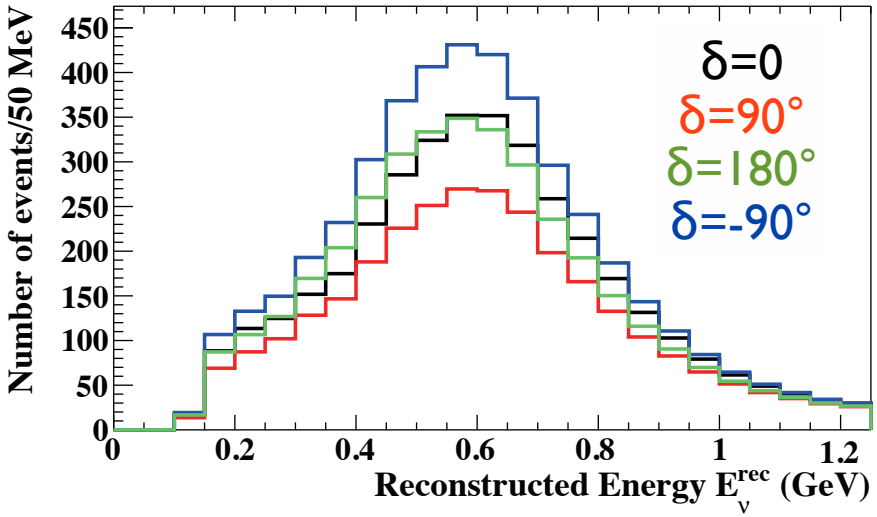
7.5MW×$10^7$s ($1.56\times10^{22}$ POT)

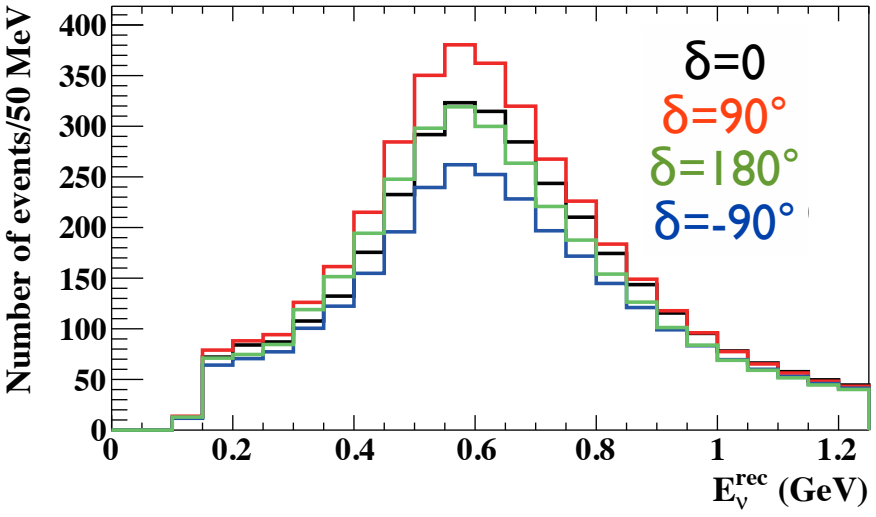
**Neutrino mode: Appearance**

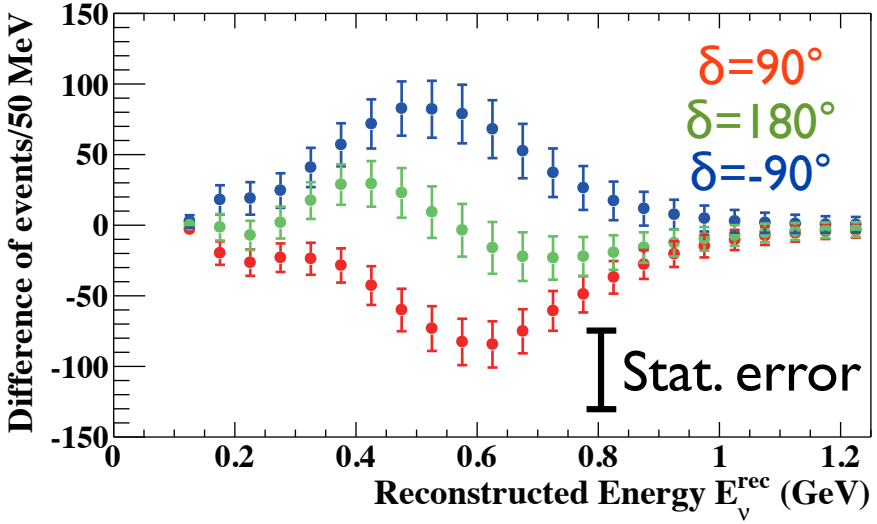
**Antineutrino mode: Appearance**

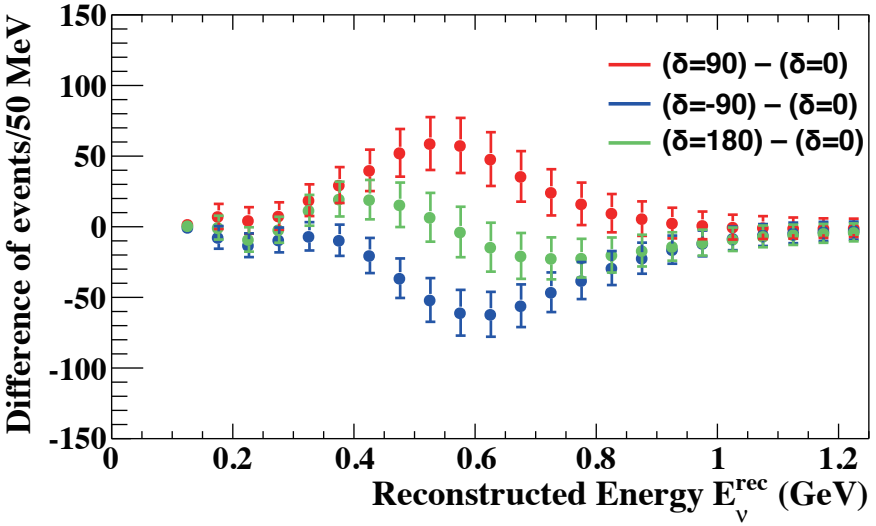
ve candidates

Difference from δ=0




Sensitive to all values of δ with numbers + shape

# Assumed systematic uncertainties

Realistic estimation based on SK/T2K

- Beam flux + near detector constraint
  - Conservatively assumed to be the same
- Cross section uncertainties not constrained by ND
  - Nuclear difference removed assuming water measurements
- Far detector
  - Reduced by increased statistics of atmospheric ν control sample

Uncertainty on the expected number of events at Hyper-K (%)

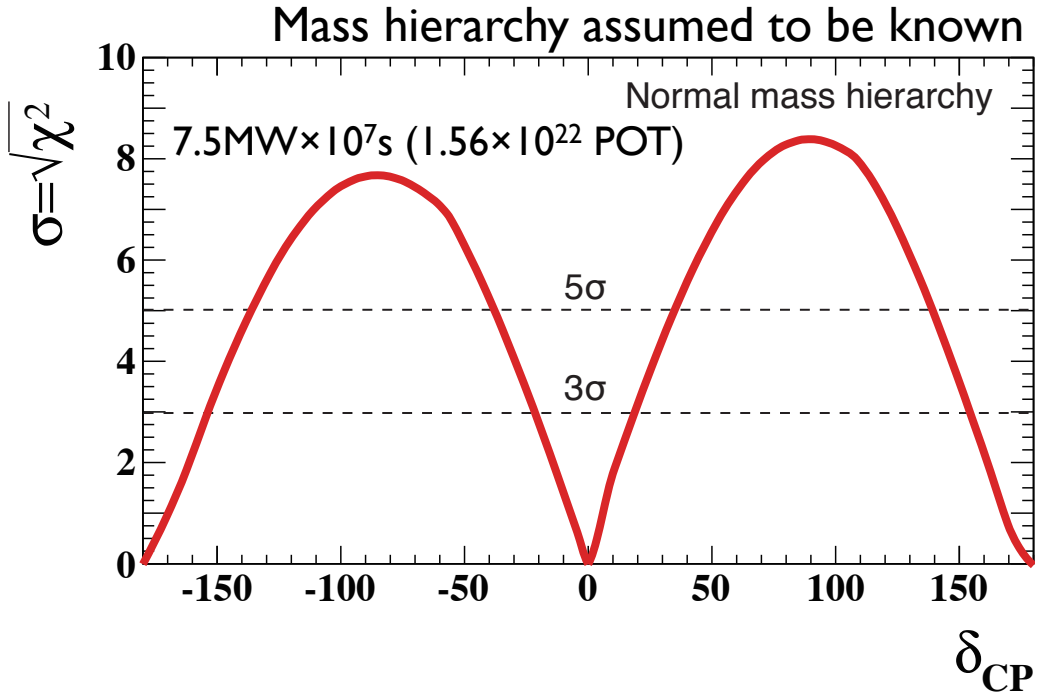
| | ν mode | | anti-ν mode | | (T2K 2014) | |
|---|---|---|---|---|---|---|
| | νe | νμ | $\bar{\nu}$e | $\bar{\nu}$μ | νe | νμ |
| Flux&ND | 3.0 | 2.8 | 5.6 | 4.2 | 3.1 | 2.7 |
| XSEC model | 1.2 | 1.5 | 2.0 | 1.4 | 4.7 | 5.0 |
| Far Det. +FSI | 0.7 | 1.0 | 1.7 | 1.1 | 3.7 | 5.0 |
| Total | 3.3 | 3.3 | 6.2 | 4.5 | 6.8 | 7.6 |

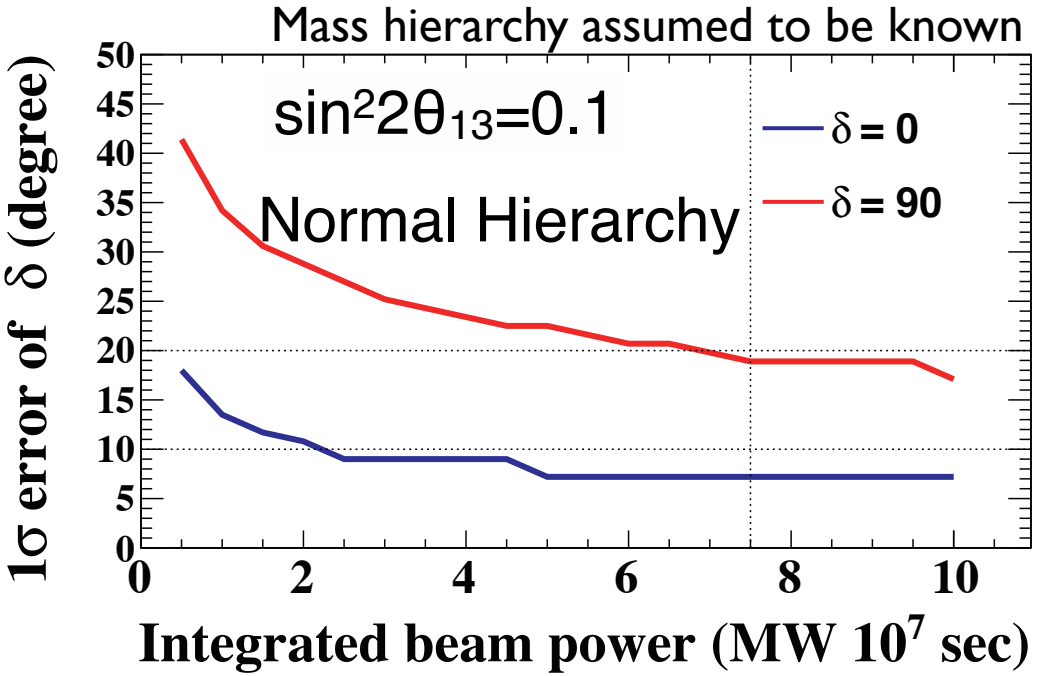
- Further reduction by new near detectors under study

# Sensitivity to CP violation

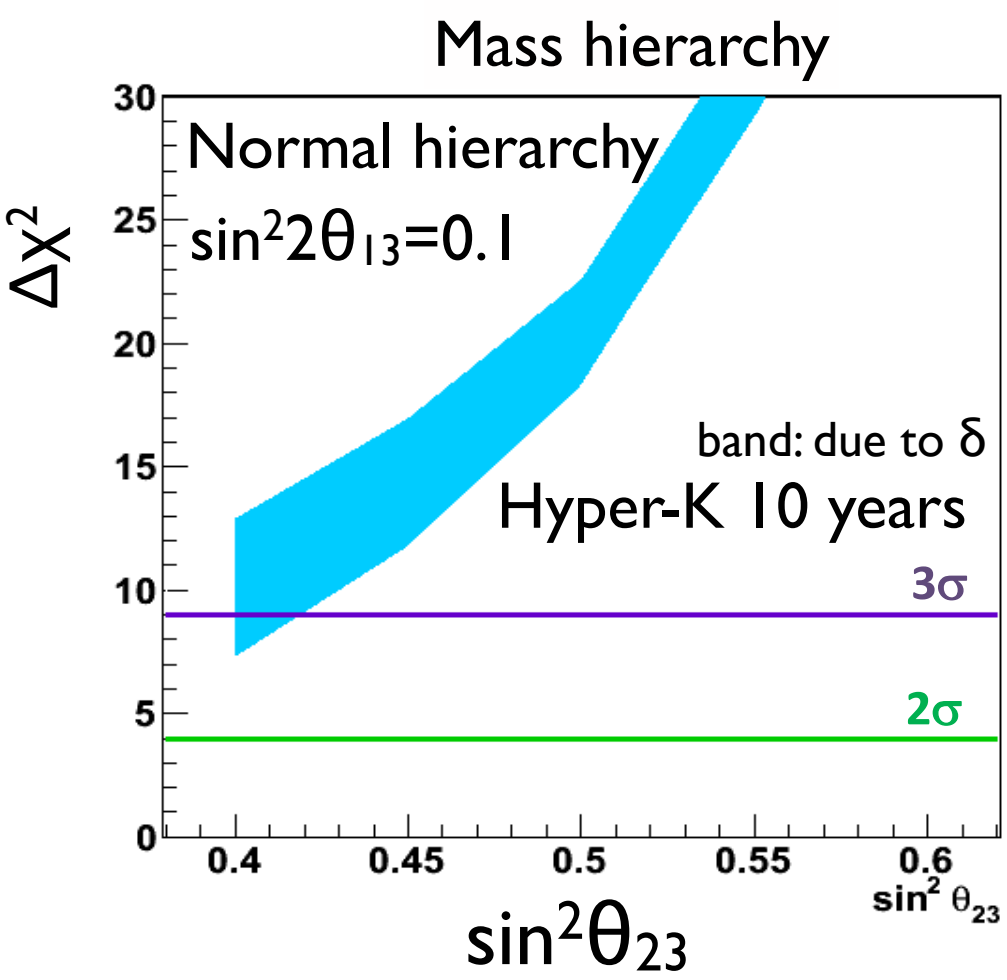
arXiv:1502.05199 and submitted to PTEP

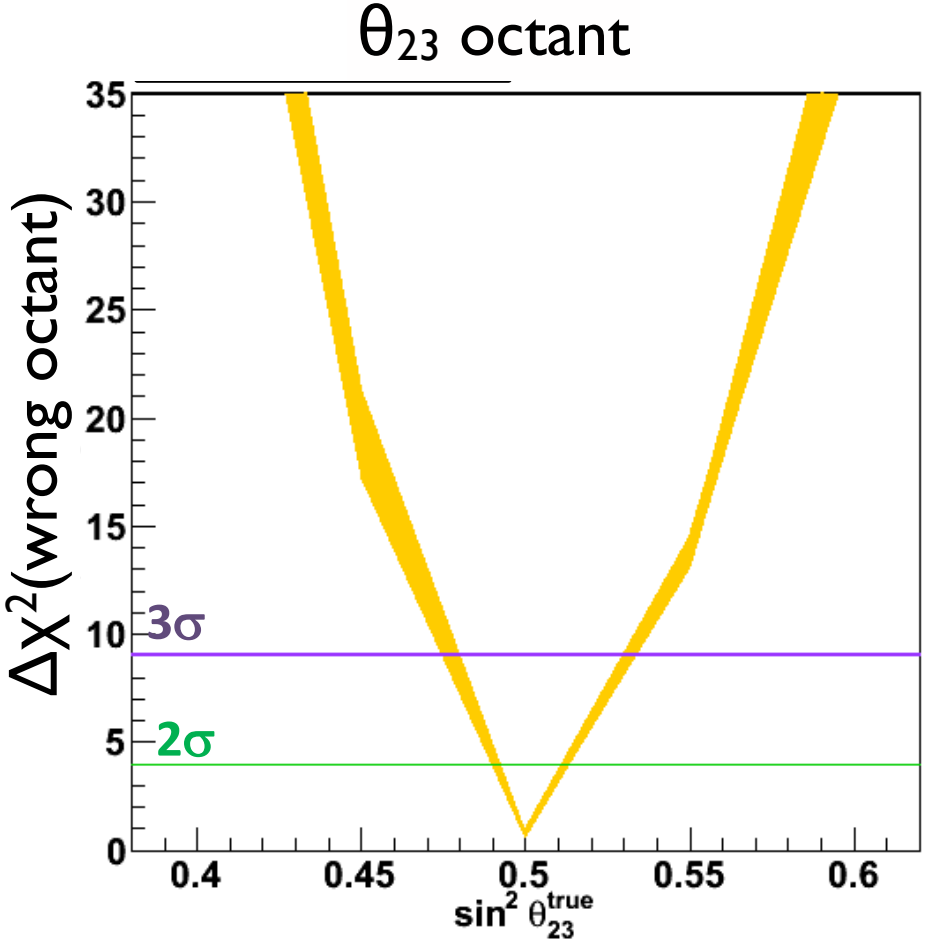
- Exclusion of sinδ=0
  - >3σ for 76% of δ
  - >5σ for 58% of δ
- 8°-19° precision depending on the true value of δ



# Atmospheric ν

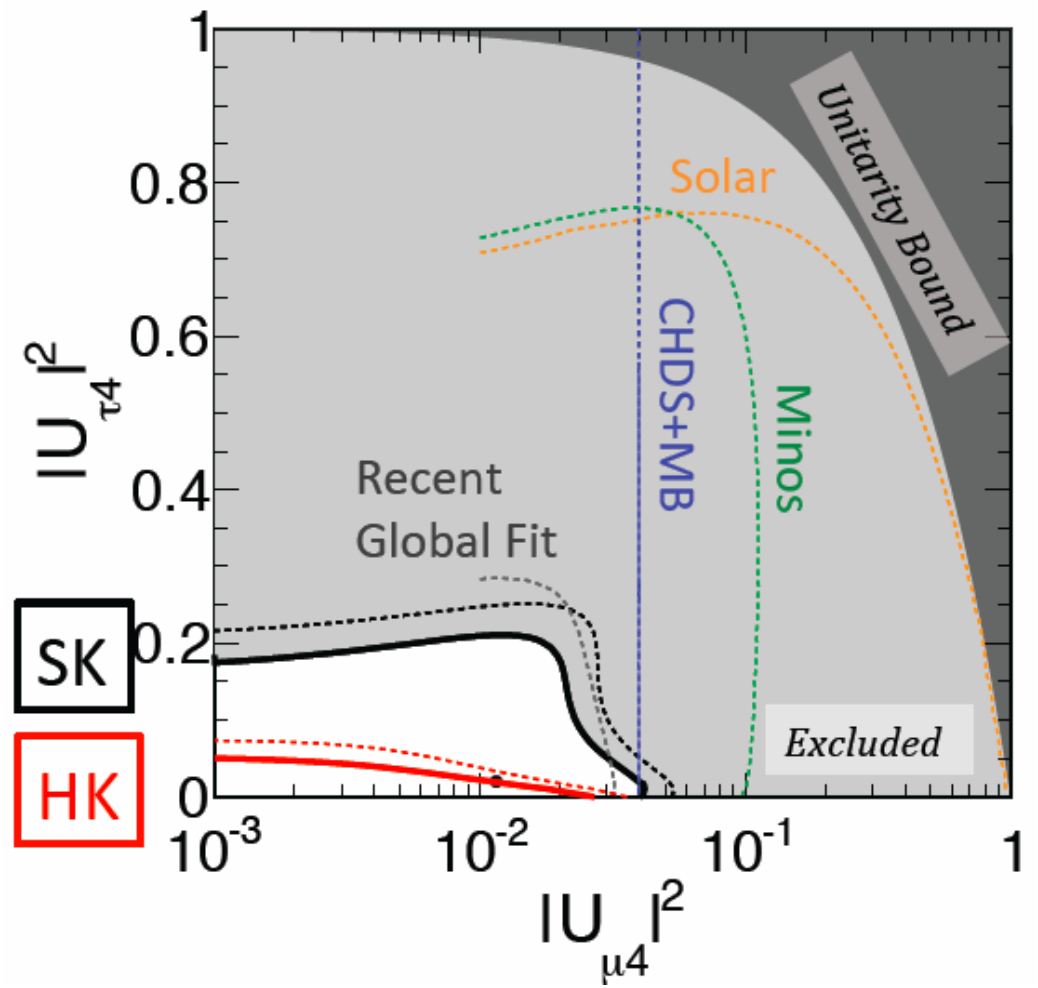


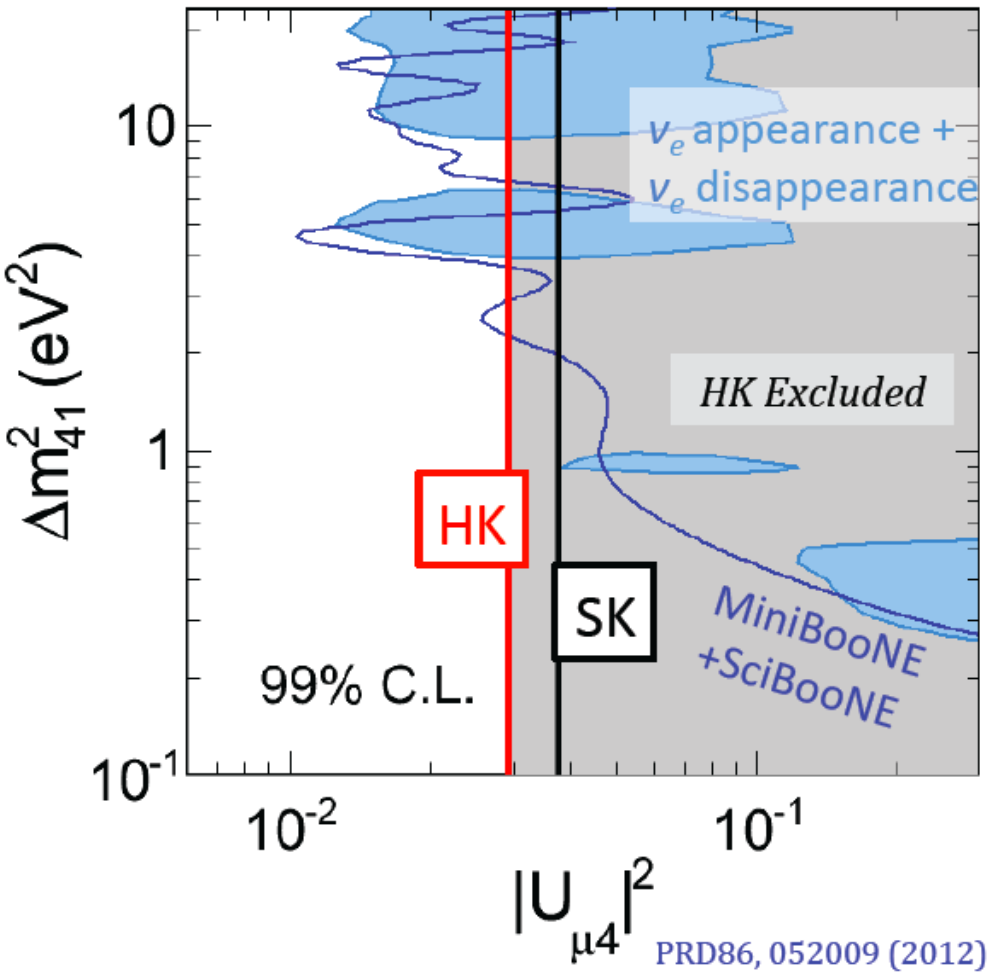




Complementary measurements to accelerator ν
Combined analysis of acc + atm ν will enhance capability

# Test of Sterile ν by atmospheric ν

Look for **extra overall muon deficit** or **shape distortion**



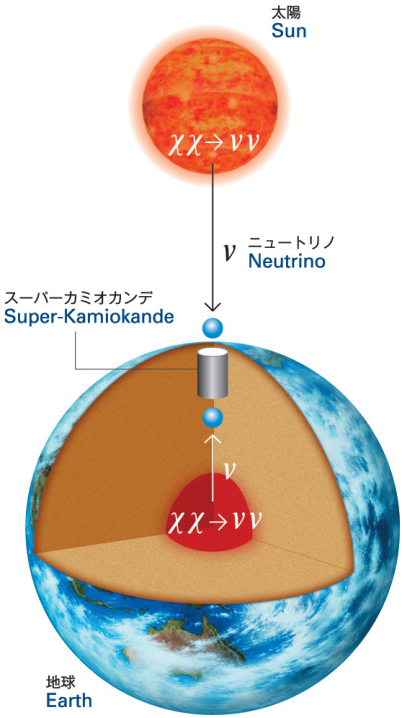




PRD86, 052009 (2012)
IHEP 1305 (2013) 050

$|U_{\tau 4}|^2$<0.066 @99%CL
(0.164 in Super-K)

$|U_{\mu 4}|^2$<0.029 @99%CL
(0.038 in Super-K)

Complementary to other experiments

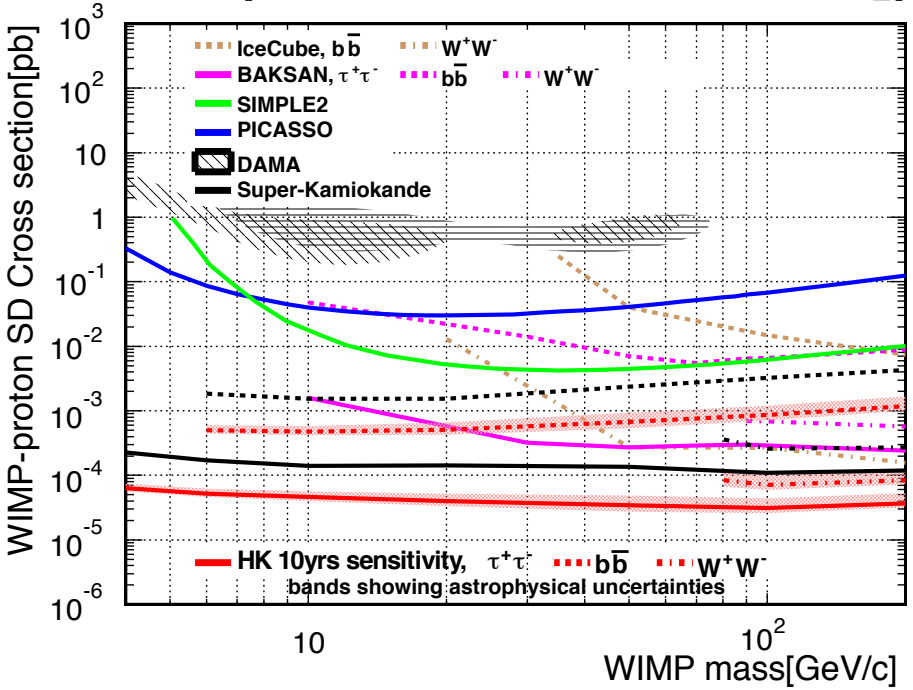



# Search for ν's induced by dark matters

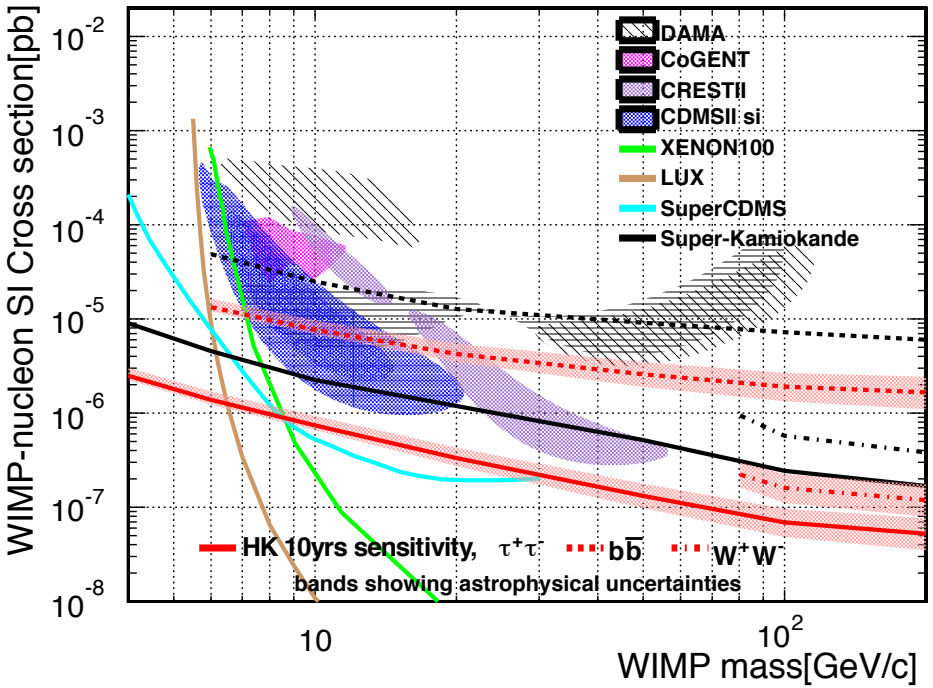
- provide complemental information w/ direct detection experiments
- Sensitive to low mass (GeV/$c^2$) WIMPs

## Expected sensitivity for Solar WIMPs

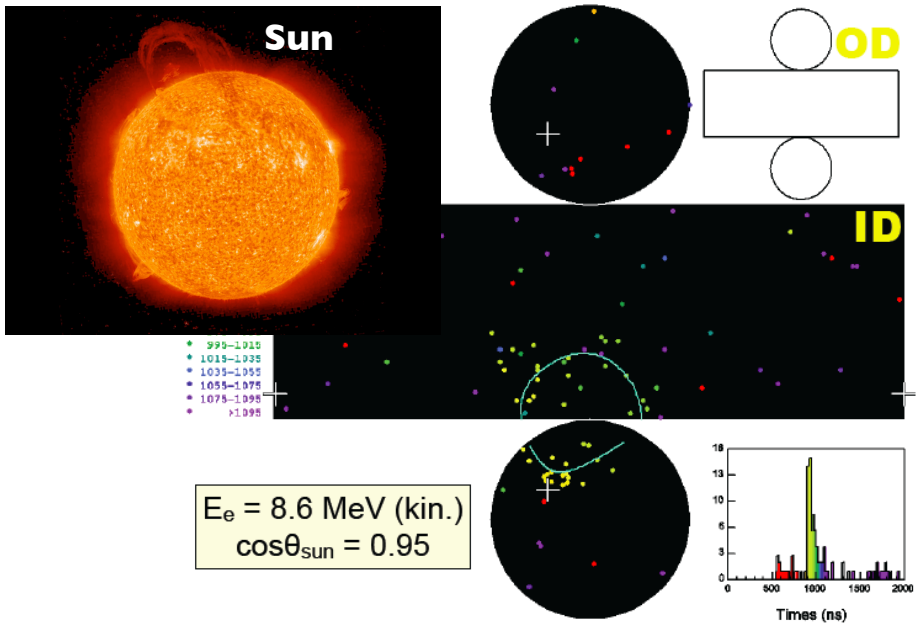
WIMP-proton cross section[pb]

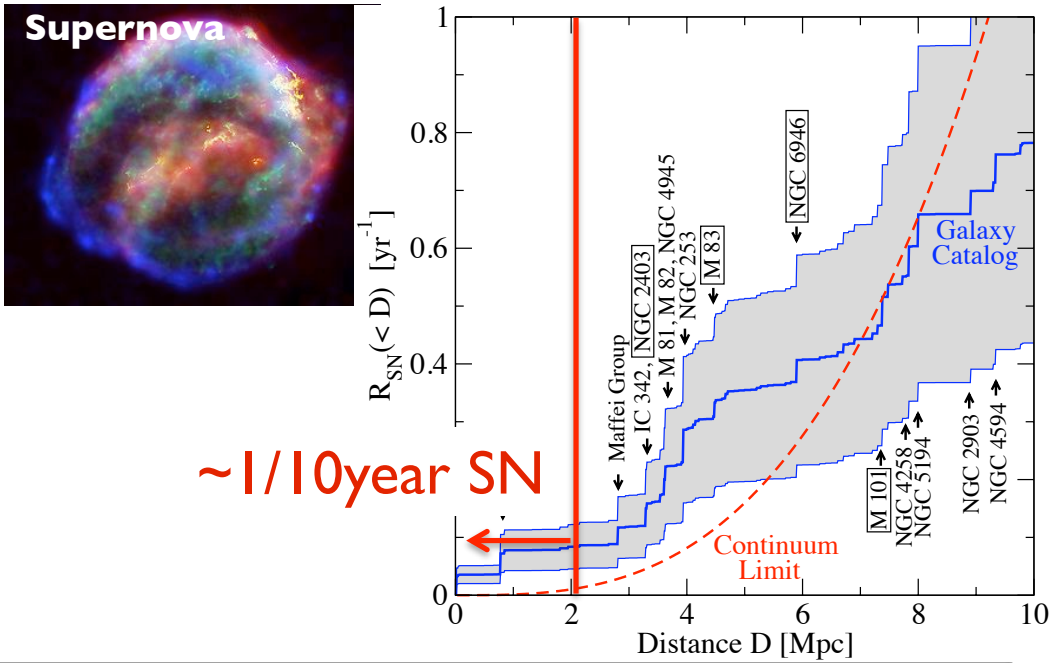



WIMP-nucleon cross section[pb]



# Det. performance for astrophysical ν




- Astrophysical neutrinos such as **galactic supernova, supernova in nearby galaxies, relic SN νs**, solar νs
  - Energy threshold ~5MeV by established techniques of water purification, triggering system, analysis algorithms
  - tagging capability of μ→eνν and nuclear de-excitation γ in p→νK+

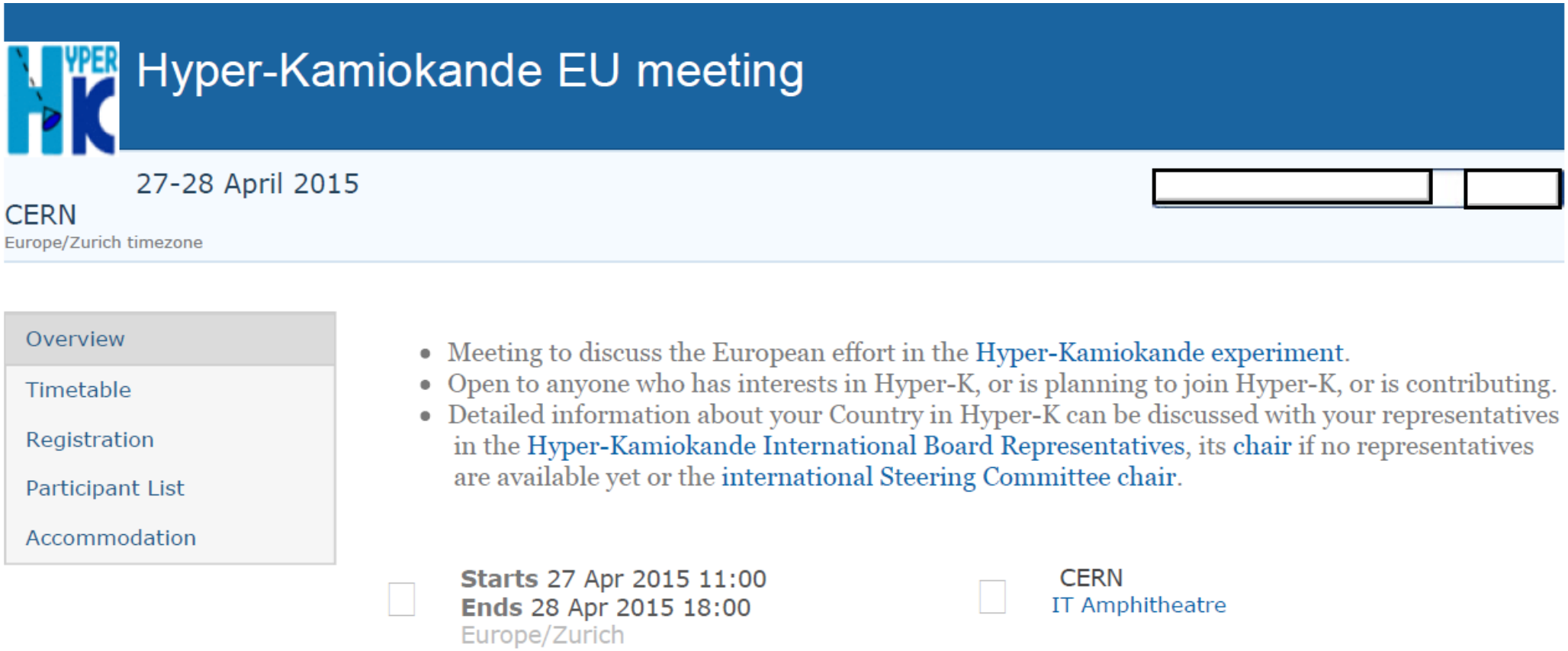
- energy scale stability ~1%
- stable operation (small <1% deadtime for Supernova observation)

# Summary

- **Wide physics topics, many discovery potentials**
  - Proton decay discovery
  - CPV (76% of $\delta$ space at $3\sigma$), $\delta$ precision of $<20^{\circ}$
  - SN bursts, relic SN $\nu$, WIMP annihilation $\nu$ ...
- **Many good results in development works**
  - Cavity and support design
  - Plastic liner
  - 50cm high sensitivity photo-sensors
  - Many rooms to contribute
- **Boost promoting the project**
  - International proto-collaboration has been formed
  - Cooperation with KEK-IPNS/ICRR to develop the project
  - Design Report to be prepared in 2015
  - Open for new collaborators

# Hyper-Kamiokande EU meeting@CERN 27-28 April 2015

- Meeting to discuss the European effort in Hyper-K
- Open to anyone who has interest in Hyper-K, or is planning to join Hyper-K, or is contributing
- http://indico.cern.ch/e/ThirdEUHyperK



Hyper-Kamiokande EU meeting

27-28 April 2015

CERN

Europe/Zurich timezone

Overview

Timetable

Registration

Participant List

Accommodation

- Meeting to discuss the European effort in the Hyper-Kamiokande experiment.
- Open to anyone who has interests in Hyper-K, or is planning to join Hyper-K, or is contributing.
- Detailed information about your Country in Hyper-K can be discussed with your representatives in the Hyper-Kamiokande International Board Representatives, its chair if no representatives are available yet or the international Steering Committee chair.

**Starts** 27 Apr 2015 11:00
**Ends** 28 Apr 2015 18:00
Europe/Zurich

CERN
IT Amphitheatre