Hyper-K physics potentials and R&D

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On behalf of the Hyper-Kamiokande Working Group

Hyper−Kamiokande

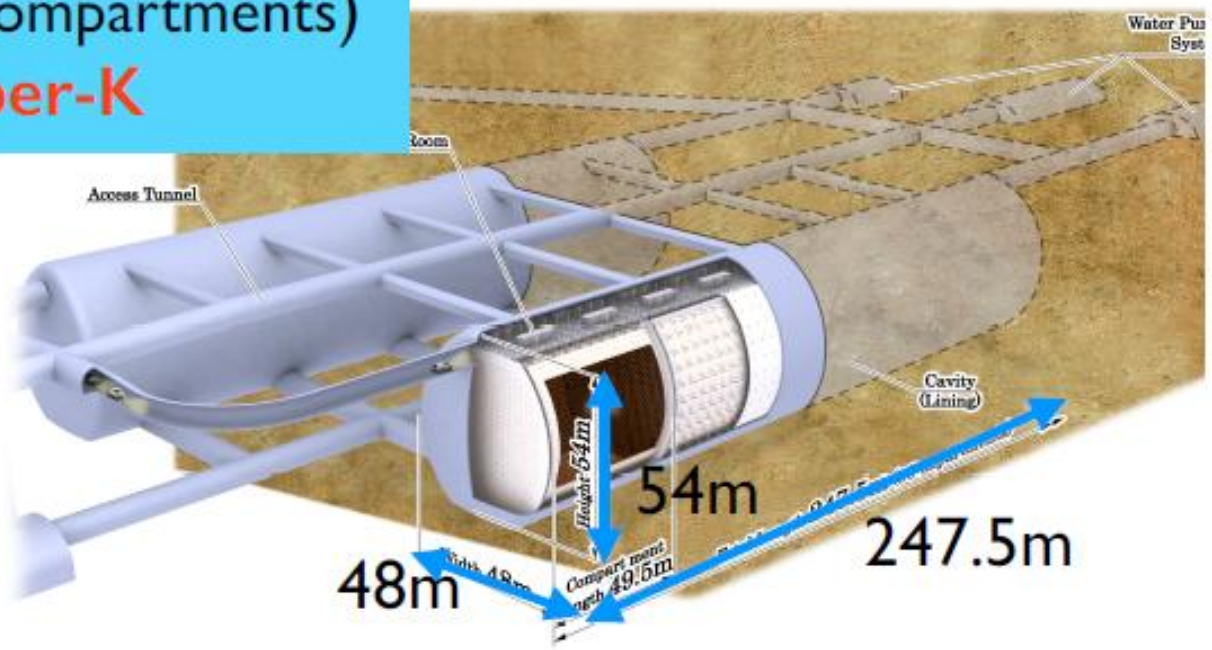
Total volume:	0.99 Mton
Inner volume:	0.74 Mton
Outer volume:	0.2 Mton
Fiducial volume:	0.56 Mton

(0.056Mton × 10 compartments)

x25 of Super-K

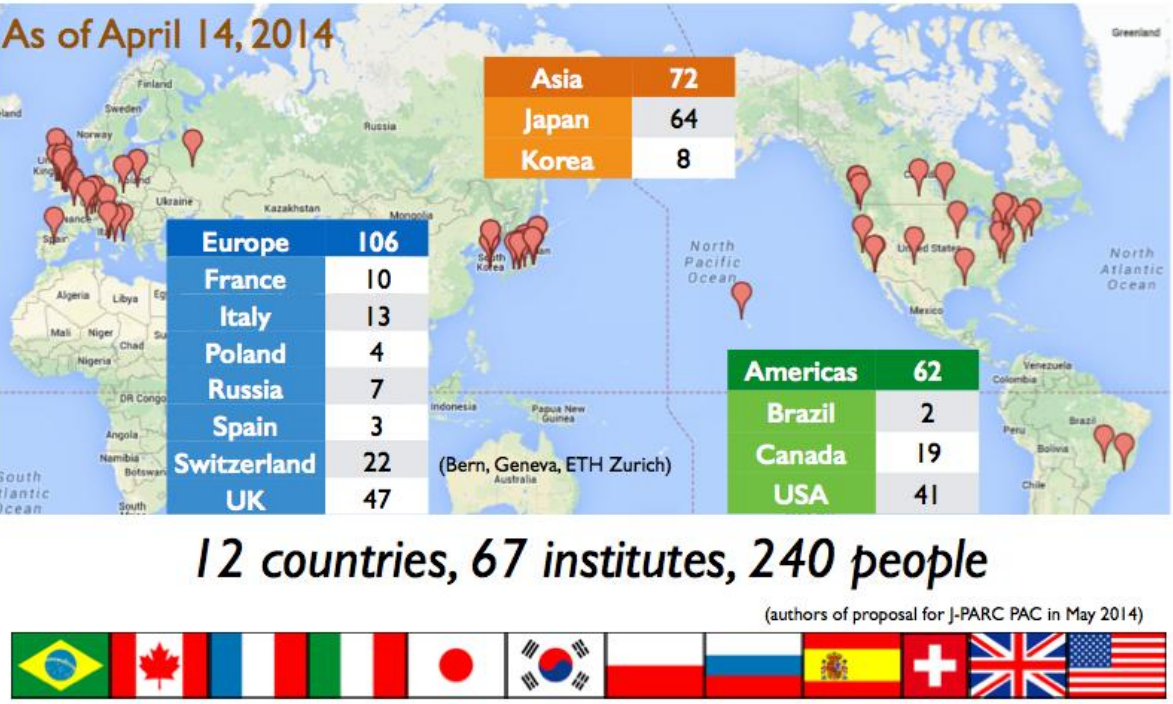
Hyper-K WG,
arXiv:1109.3262 [hep-ex]
arXiv:1309.0184 [hep-ex]

- 99,000 20" PMT for inner-det. (20% coverage)
- 25,000 8" PMT for outer-det.



Multi-purpose detector for a wide range of science

Hyper-Kamiokande International Working Group

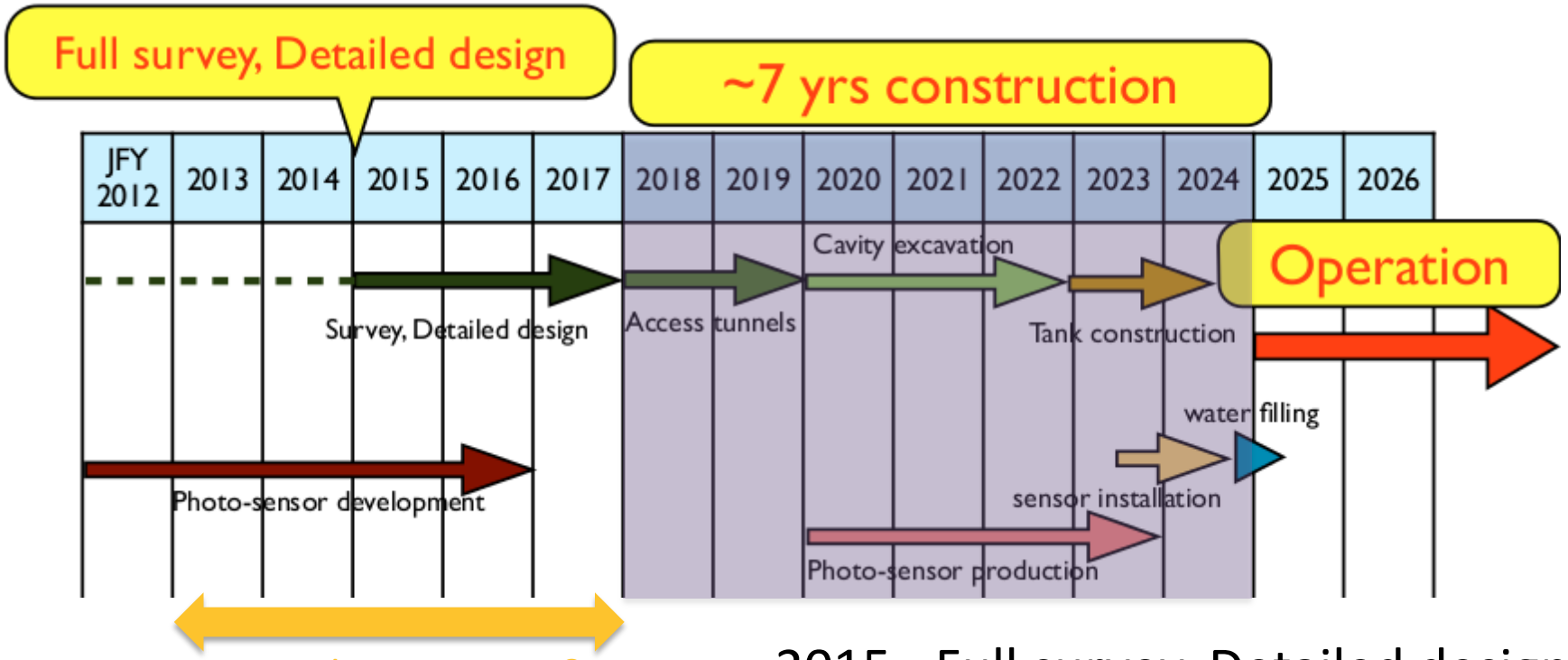


12 countries, 67 institutes, 240 people

(authors of proposal for J-PARC PAC in May 2014)

- Meetings open to international community (twice/year)
- Last (5th) meeting
  - Vancouver in July 2014
  - http://bit.ly/5th-hyperk
- Next meeting:
  Jan 29-31, 2015 in Japan
- Contact information
  http://www.hyperk.org/?page_id=61

Notional Timetable

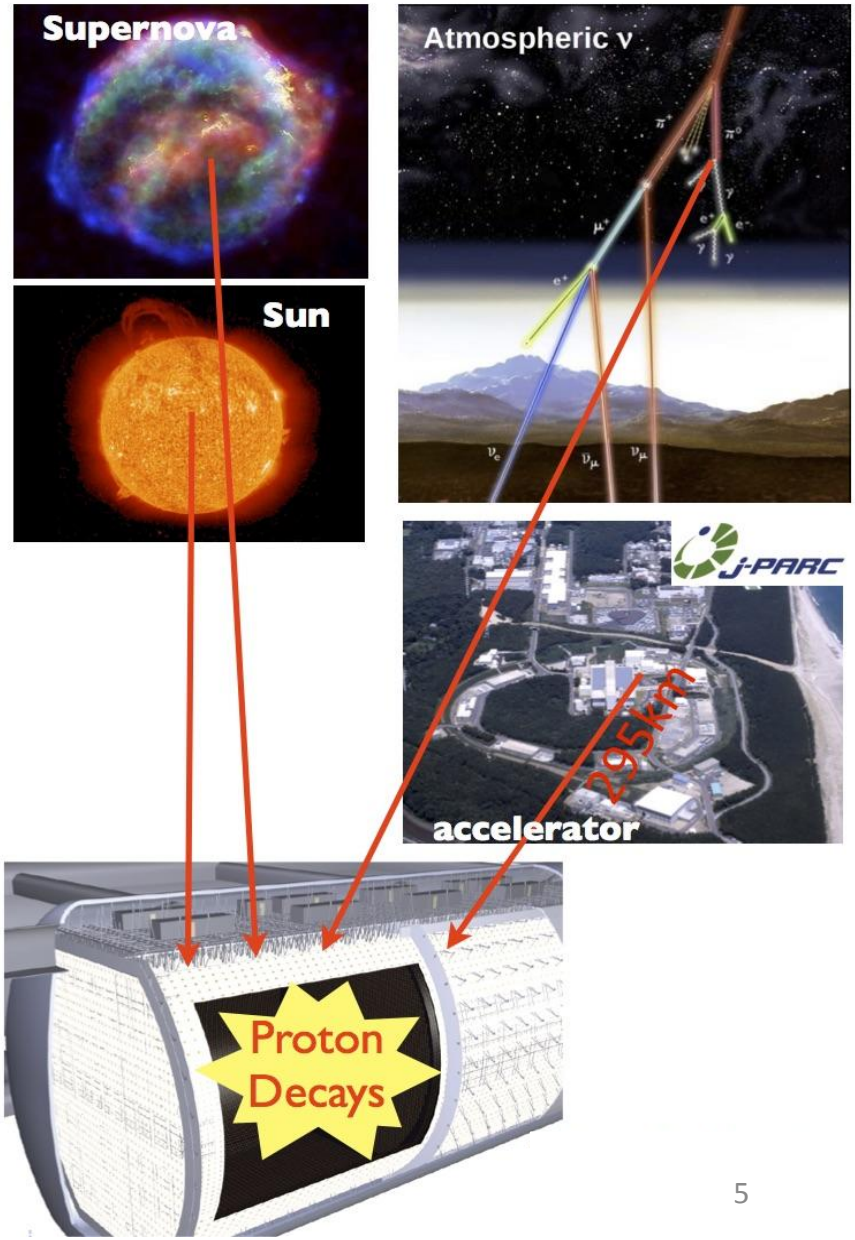


2015- Full survey, Detailed design
2018- Excavation, Construction
2025- Operation

- 5 year grant for R&D and prototype detector in 2013
- HK selected as one of top 27 important large-scale projects in the "Master Plan 2014" of the Science Council of Japan

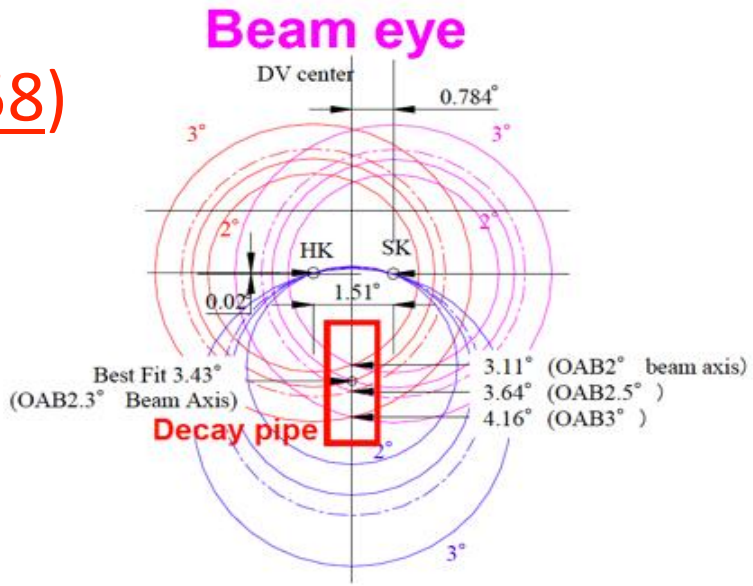
Physics of Hyper-K

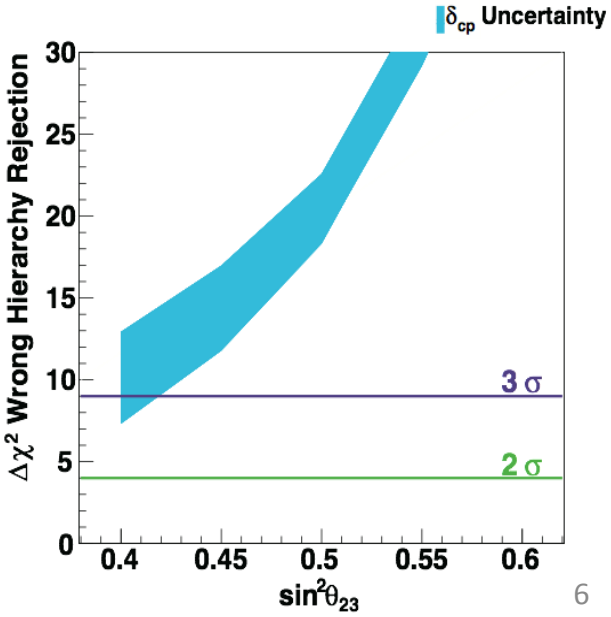
- Neutrino oscillation physics
- Search for nucleon decay
  - Possible discovery with ~×10 better sensitivity than Super-K
  - $e^+\pi^0$: 5.7×10^{34} years, $K^+\nu$: 1.2×10^{34} years (3σ)
- Neutrino astrophysics
  - ~200,000 ν events for SN @ 10kpc (Galactic center)
  - Detection (~830 ν) and study of relic SN neutrinos
- Geophysics (neutrinography of interior of the Earth)



ν oscillation study

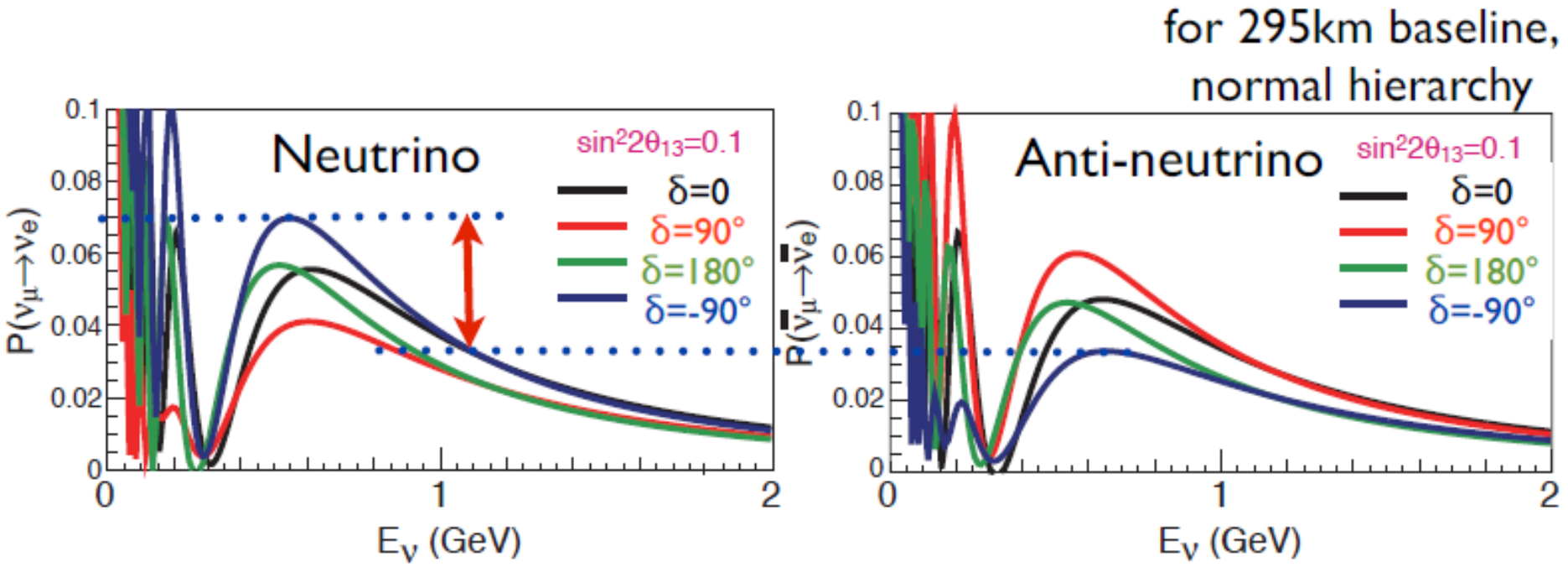
- Long baseline experiment with J-PARC neutrino beam (J-PARC P58)
  - Same baseline as T2K
    - Well understood beam and systematics (NA61 etc.)
    - Reliable sensitivity estimate based on T2K results
  - Main focus on CP asymmetry
- Atmospheric neutrino
  - >3σ determination of mass hierarchy and θ_{23} octant





Measurement of *CP* asymmetry with ν beam

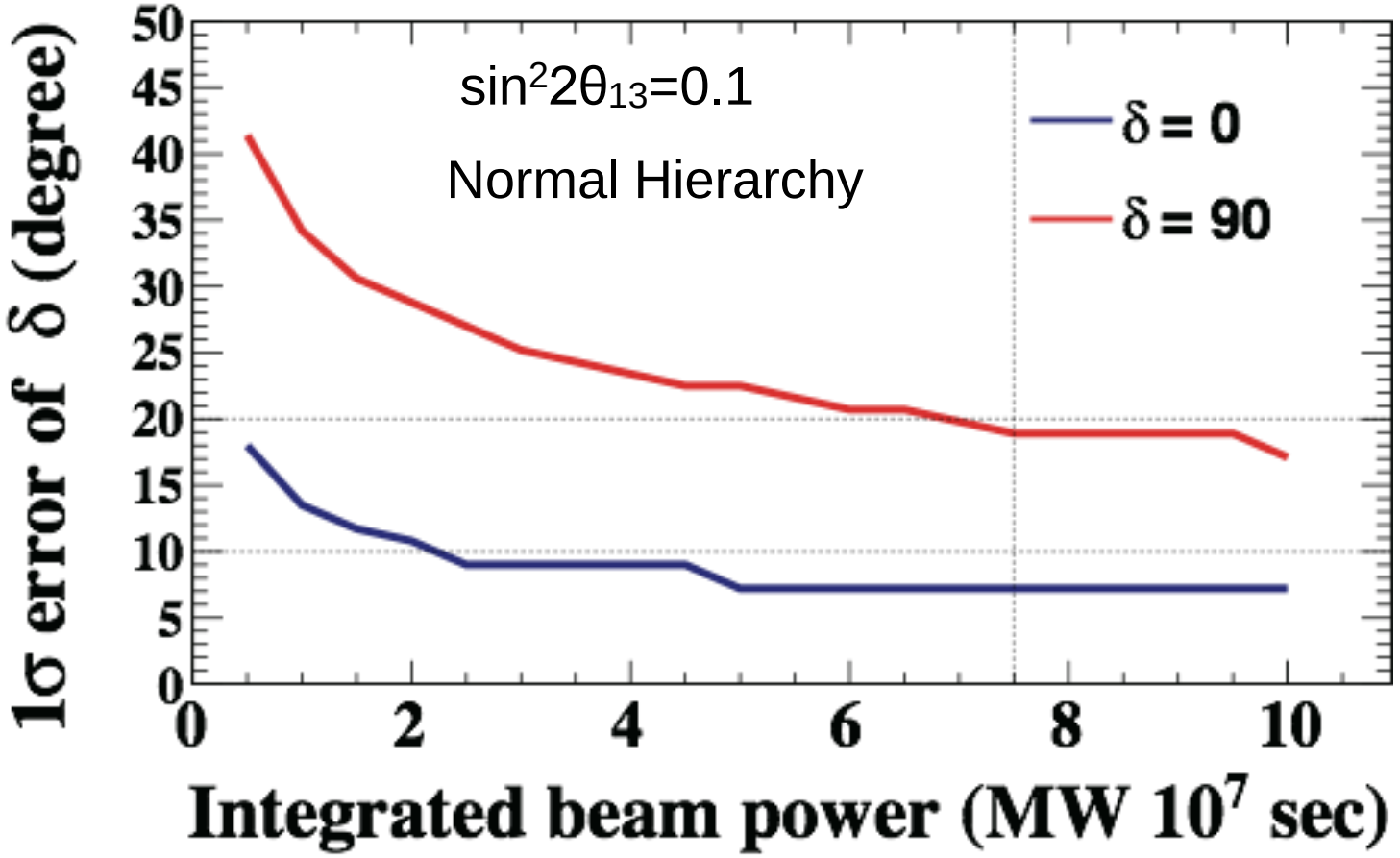
$P(\nu_\mu \rightarrow \nu_e)$: ν_e appearance probability



- Comparison of $P(\nu_\mu \rightarrow \nu_e)$ and $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$
  - Max. ~±25% change from δ=0 case
  - Sensitive to exotic (non-MNS) CPV source

Expected uncertainty of δ (1σ)

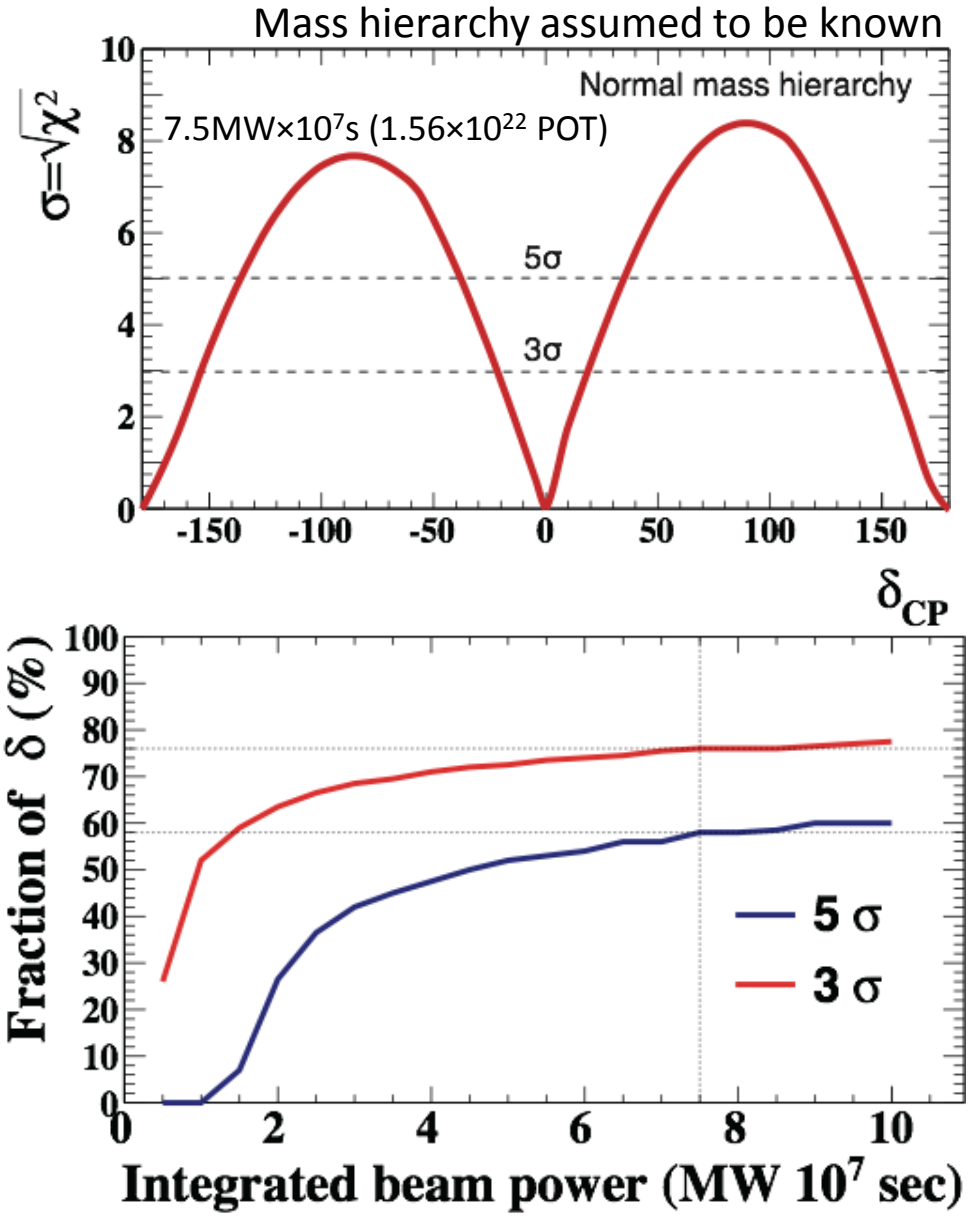
Mass hierarchy assumed to be known



- 8°-19° depending on the true value of δ

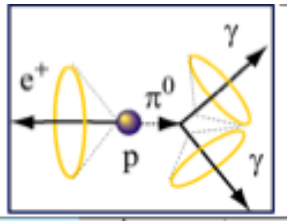
Sensitivity to CP violation

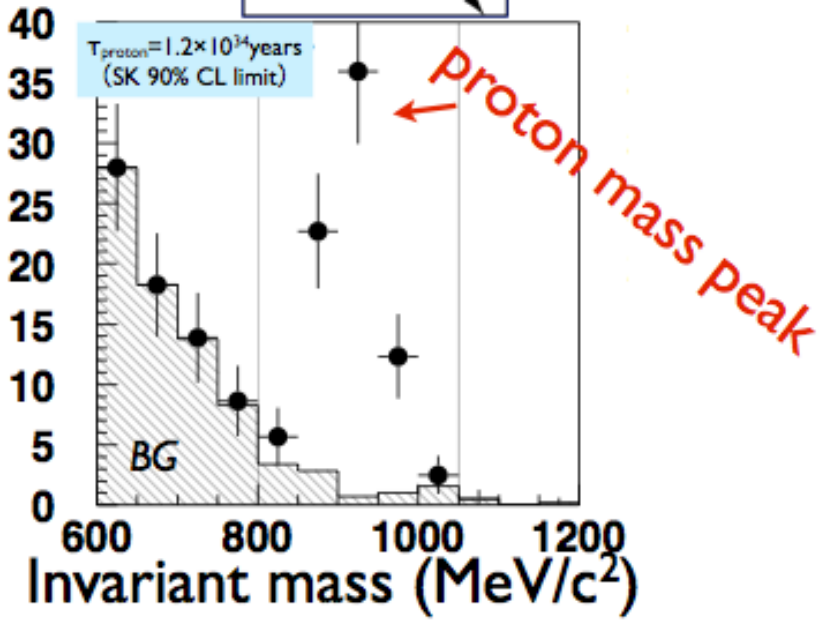
- Exclusion of sinδ=0
  - –>3σ for 76% of δ
  - –>5σ for 58% of δ
- Possible to establish CP violation in the lepton sector!



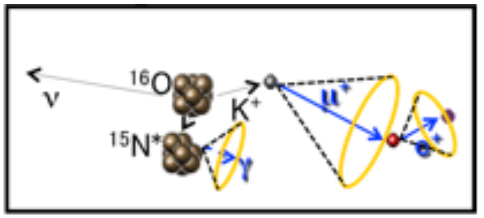
Proton decay sensitivity

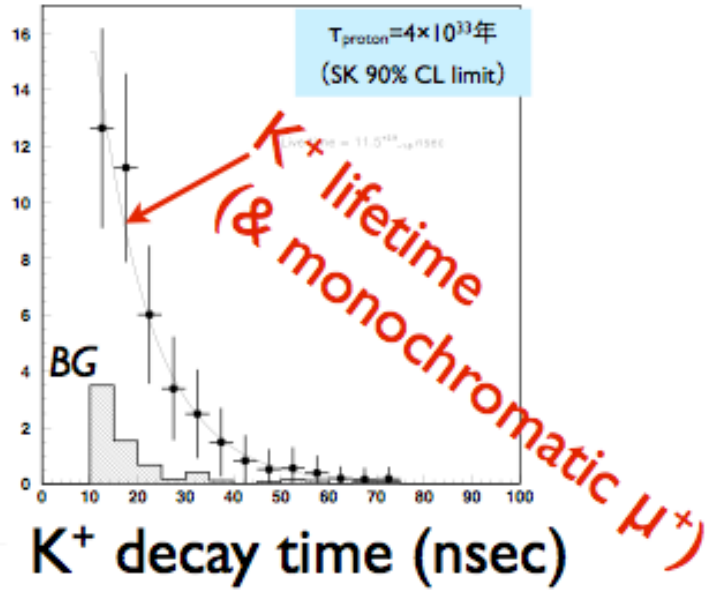
$p \rightarrow e^+\pi^0$





$p \rightarrow \nu K^+$





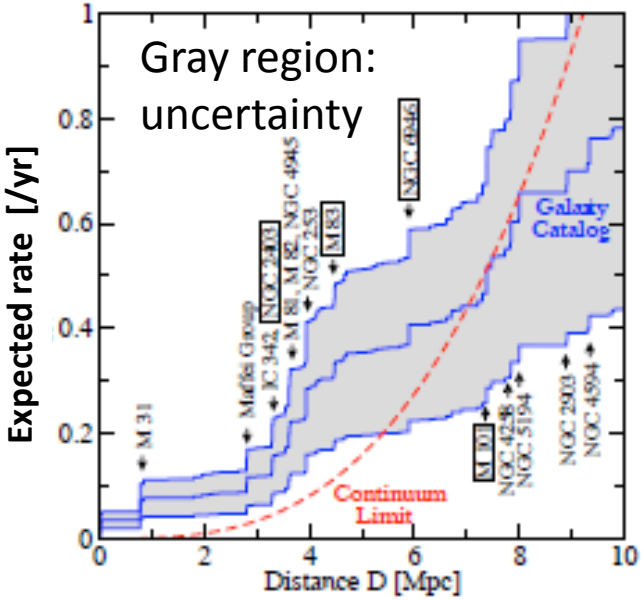
- Discovery reach (3σ)
  - $\tau(p \rightarrow e^+\pi^0) \sim 5.4\times10^{34}$years (HK 10yrs)
- Limit (90%CL)
  - $\tau(p \rightarrow e^+\pi^0) > 1.3\times10^{35}$years (HK 10yrs)

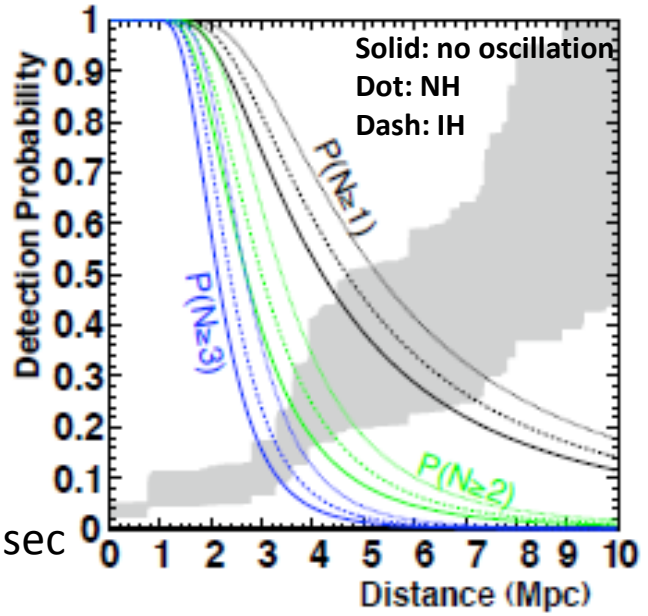
- Discovery reach (3σ)
  - $\tau(p \rightarrow \nu K^+) \sim 1.2\times10^{34}$years (HK 10yrs)
- Limit (90%CL)
  - $\tau(p \rightarrow \nu K^+) > 3.2\times10^{34}$years (HK 10yrs)

Good discovery potential, 90% CL sensitivity of 10^{34}~10^{35} yrs

Neutrino astrophysics

- Supernova burst neutrino
  - >50% efficiency with >3 multiplicity for <2Mpc SN (~1/10yrs expected)
  - Huge statistics if SN in our Galaxy
    - ~250k events @ 10kpc
- Supernova relic neutrino
  - ~800 events in 10 years
  - History of heavy element synthesis in the universe
- Precision measurements of solar neutrino
  - Spectrum upturn, day/night asymmetry
- Indirect WIMP Search



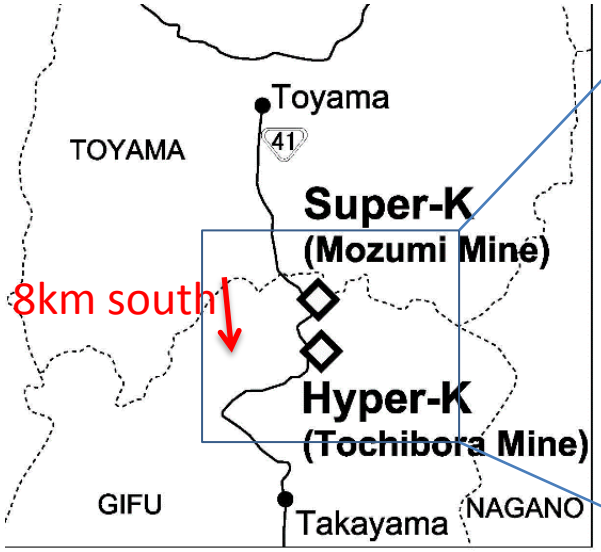


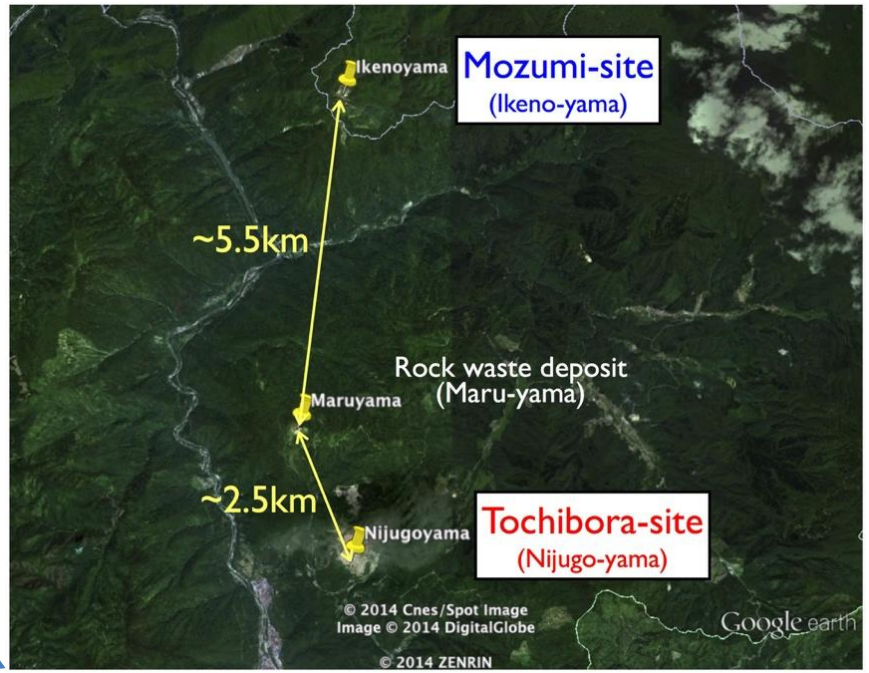
*N: Event multiplicity from a single SN in 10 sec

Detector Site

Candidate site : Tochibora mine in Kamioka

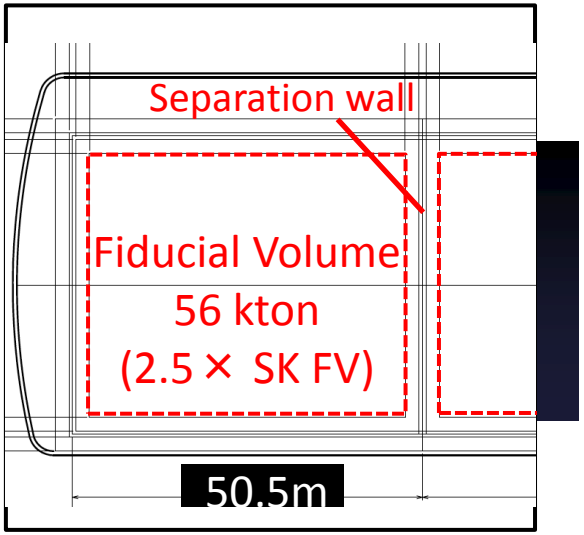
- ~8km south from Super-K
- Identical baseline (295km) and off-axis angle (2.5^{o}) to Super-K for J-PARC beam
- Overburden ~650m (~1755m.w.e.) cf. SK ~2700m.w.e.



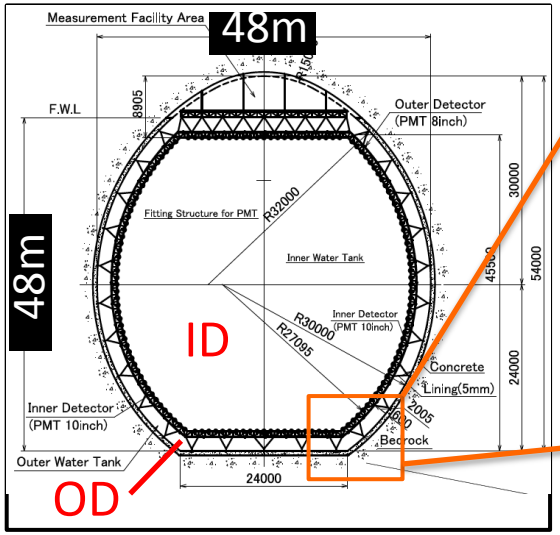


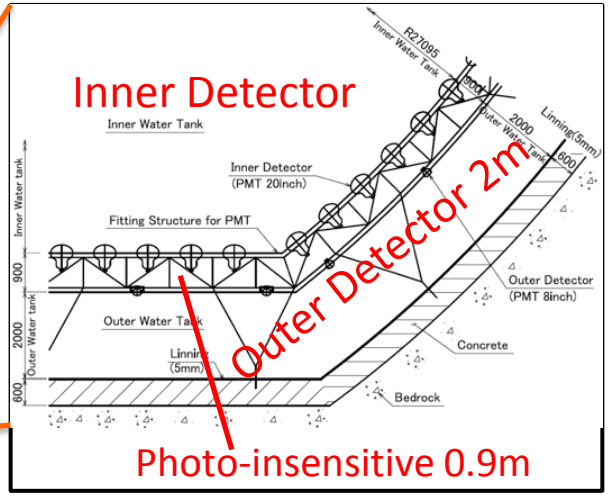
Overall Detector Design

Side view



Cross-sectional view



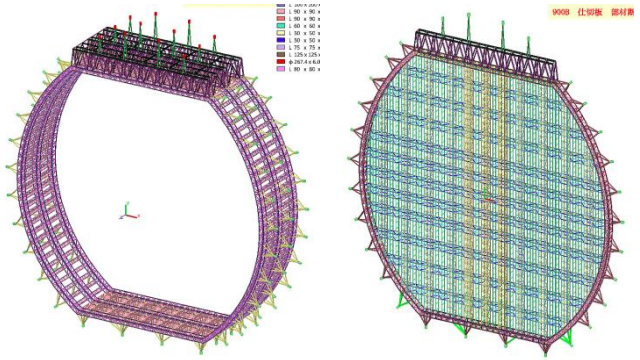


- 2m thick Outer Detector
- Optically separated compartments : 5 × 2
- Water depth : 48m

- SUS304 framework designed for supporting

  PMTs with covers, cables, HUBs (= underwater elec. boxes), pipes, load on the roof, etc.

SUS304 frames



Ongoing R&D

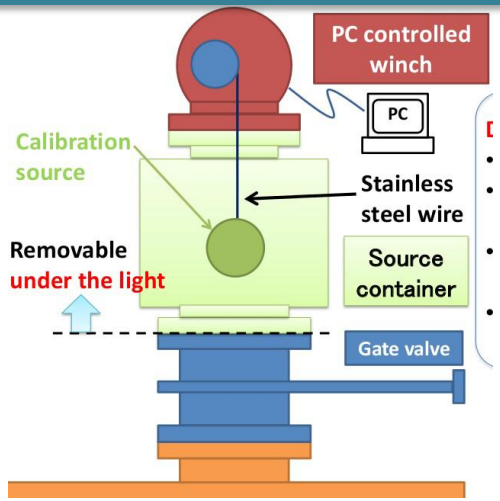
- Calibration
  - Source deployment
  - Calibration sources
- Photosensor
- Electronics & DAQ
- Software & computing
- Prototype
- Near detector
- etc.

Calibration

- Based on the techniques established with the SK calibration
- For Hyper-K
  - 20 times larger than SK → automated calibration system
  - Egg-shaped cross section → 3D source positioning system

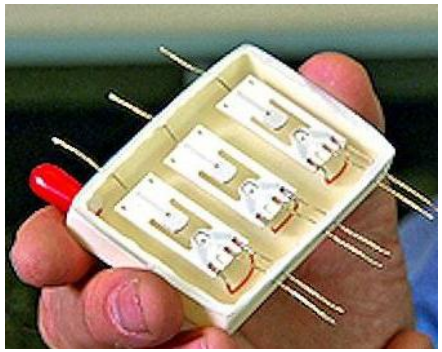
  Design utilizing experiences in several experiments
  (SK, SNO, Borexino, KamLAND, Daya Bay, …)
- Several ongoing R&D activities

Semi-automated source deployment

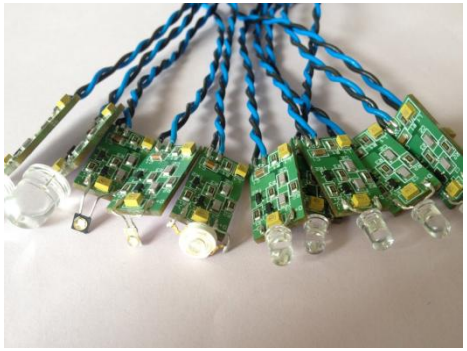


Advanced calibration sources

Compact neutron generator

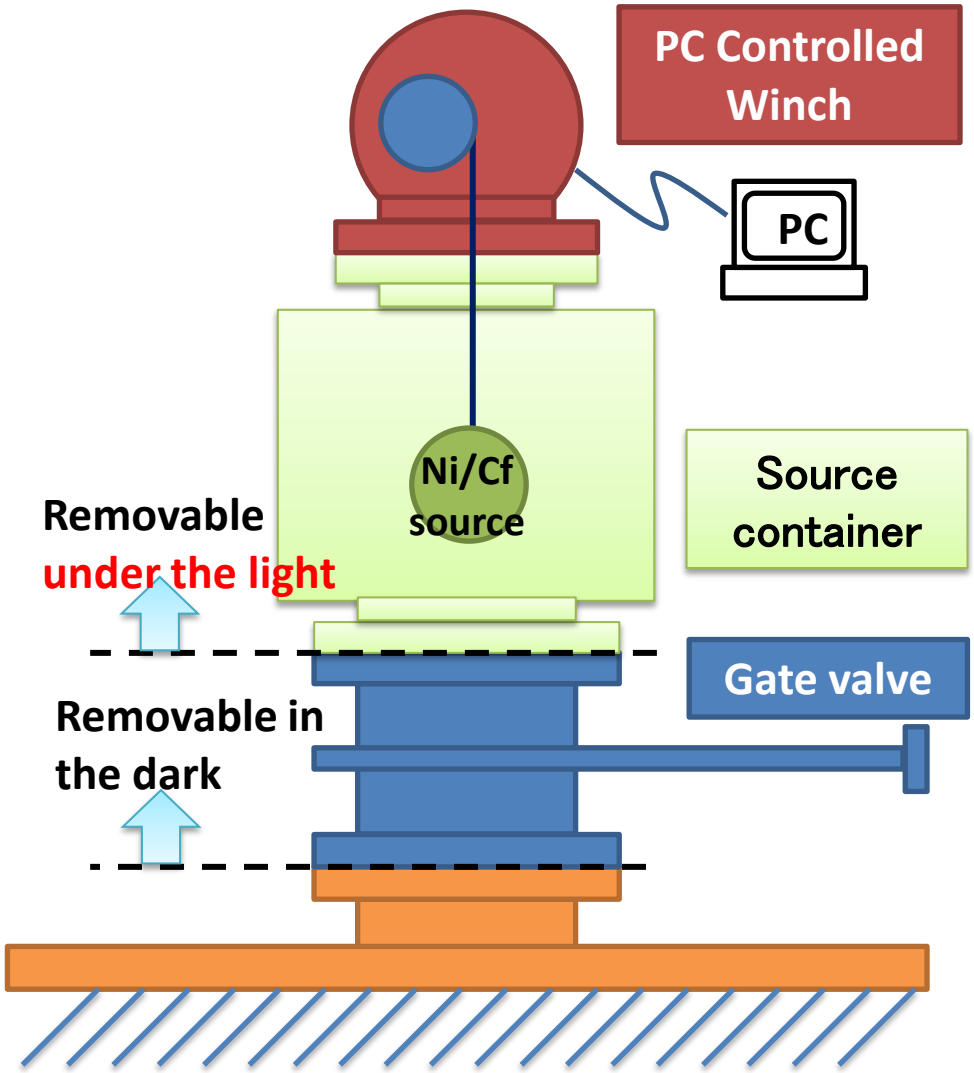


LED



IEEE TRANSACTIONS ON PLASMA SCIENCE, VOL. 40, NO. 9, SEPTEMBER 2012

Source Deployment System



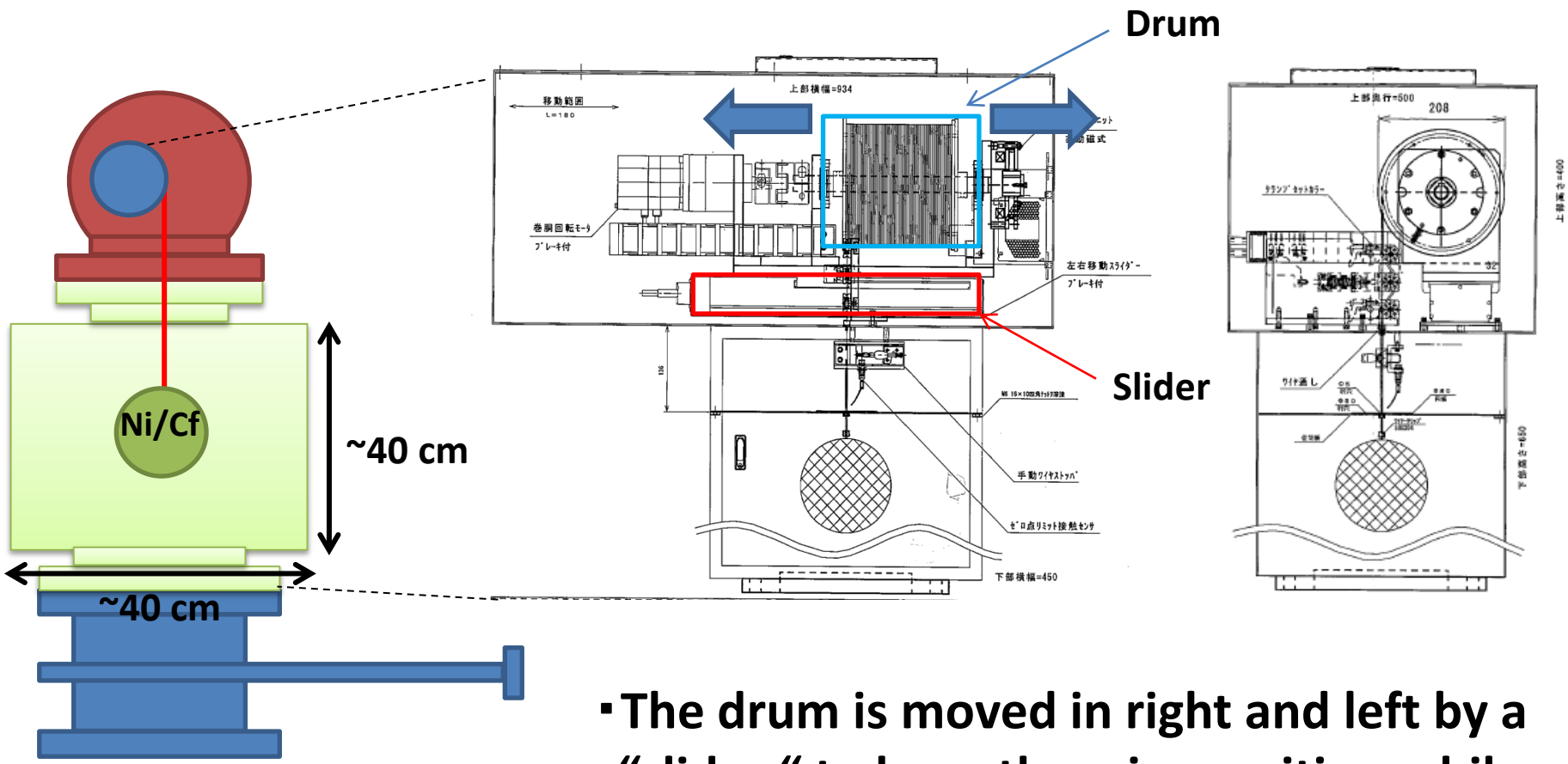
Automation of the source movement & calibration in z-direction

Design requirements

- Safe for the detector.
- Movable in Z (vertical) direction.
- Position precision < ±5mm.
- Monitor the wire tension

- First Ni/Cf source
- Other sources in the future

Design of the Deployment System

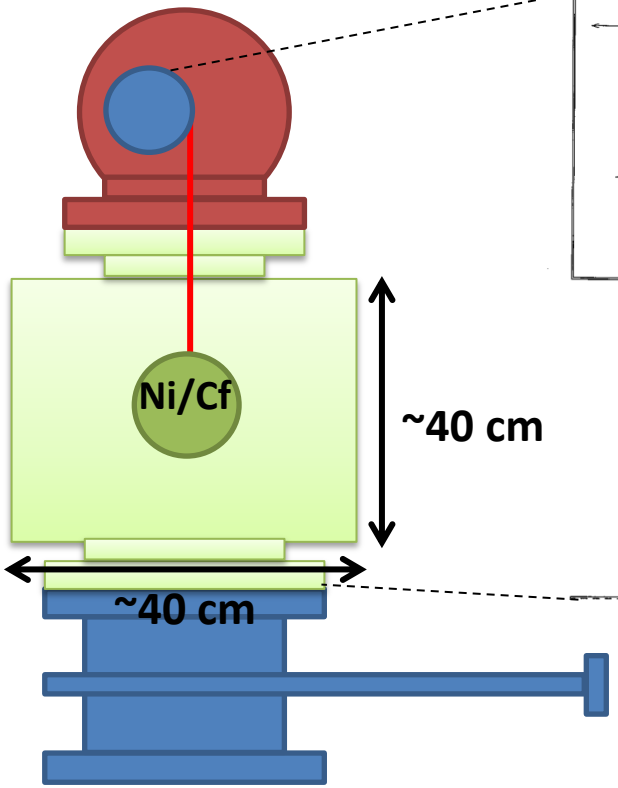


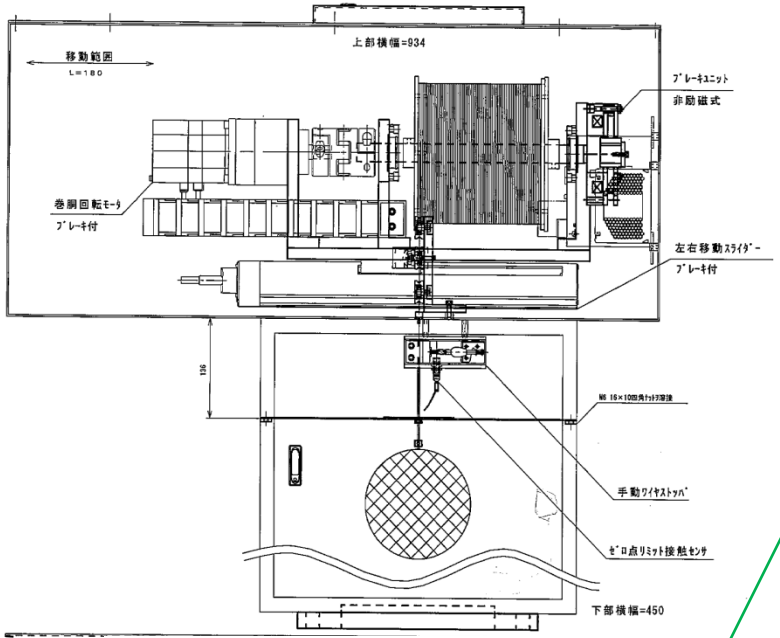
- The drum is moved in right and left by a “slider “ to keep the wire position while paying out or winding it.

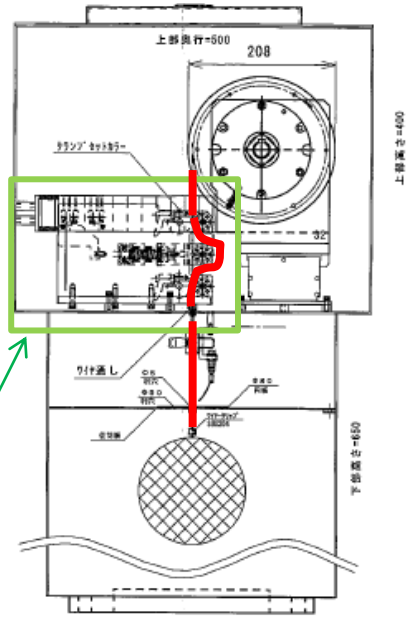
Design fixed.

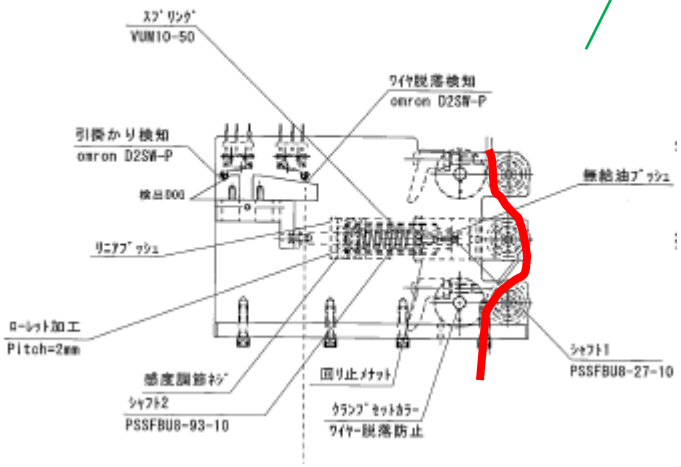
Now manufacturing !

Design of the Deployment System







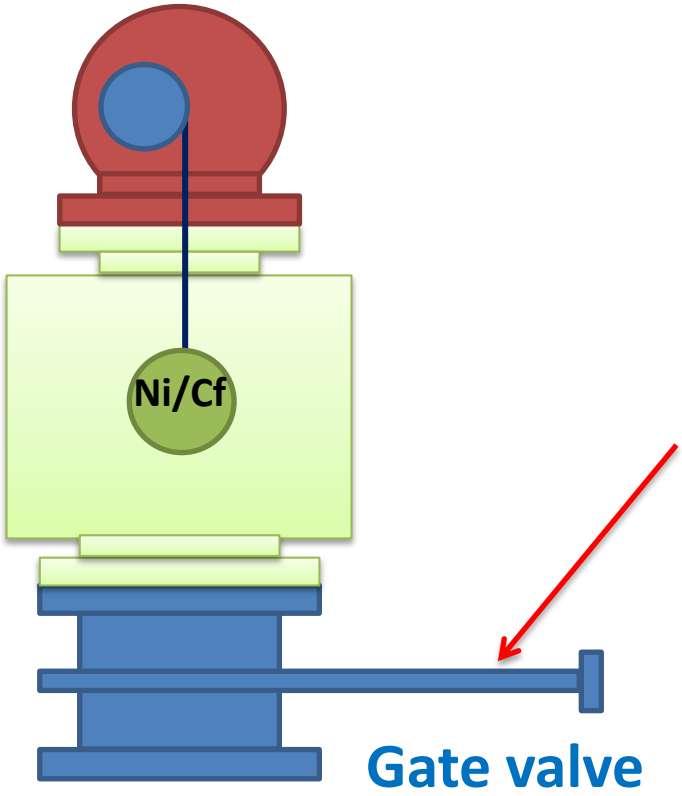


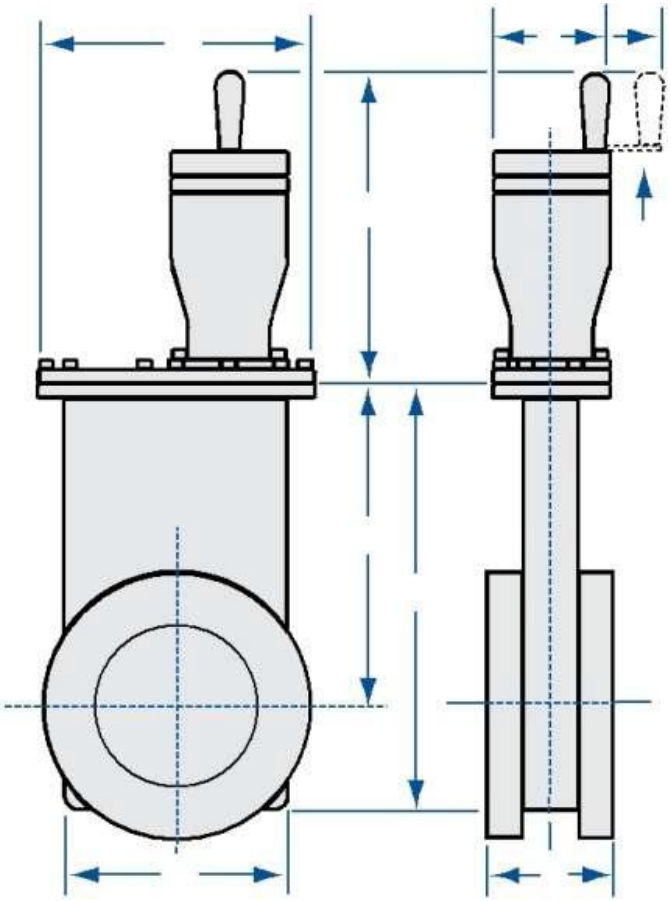
Design fixed.

Now manufacturing !

Tension sensor

Design of the Deployment System



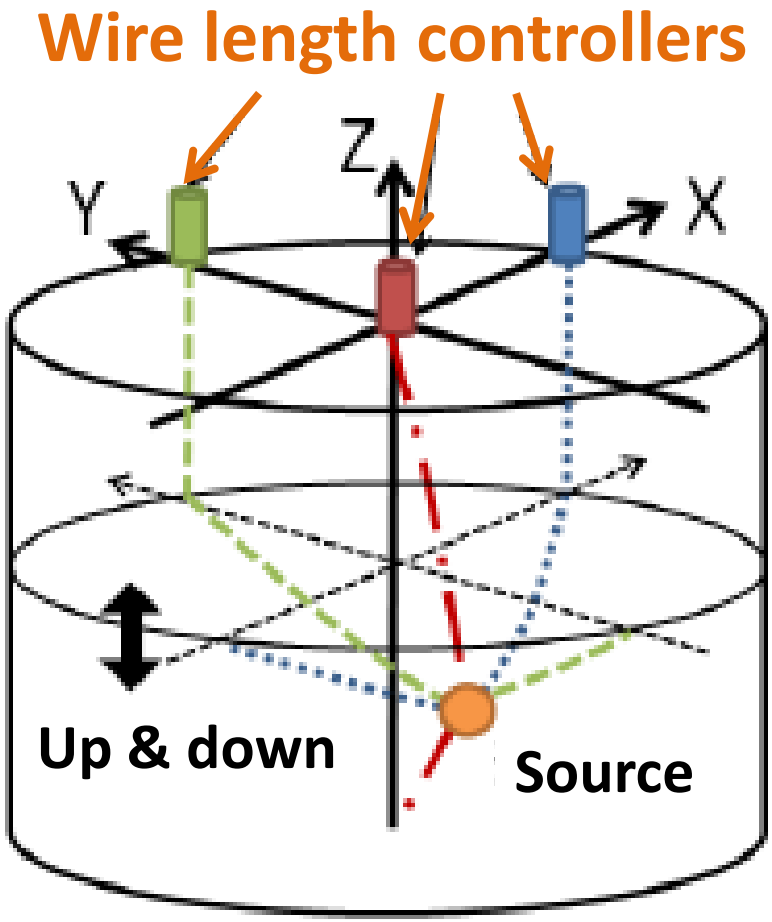


Gate valve shields the light.

Schedule

FY 2014 March
  Completion & delivery
FY 2015
- 1st half
  - –Test in the air
  - –Optimization of the control software
- 2nd half
  - –Test in water & SK

FY 2016
- Continuous running in SK
- R&D in HK prototype?



3D deployment system in the HK prototype?

Photosensor Candidates

Inner Detector : 99,000 50cmϕ photosensors (11,129 in SK)
→ 20% photocathode coverage (40% in SK)
Outer Detector : 25,000 20cmϕ photosensors (1,885 in SK)

Super-K PMT

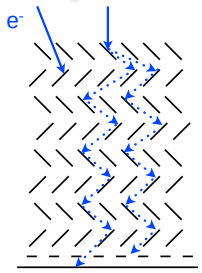
- Guaranteed (used ~20yrs)
- Expensive

High-QE/CE PMT

- Same technology
  → lower risk

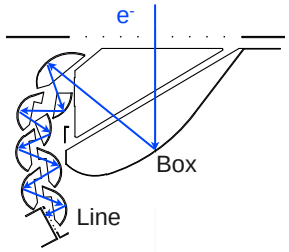
High-QE Hybrid PD

Avalanche diode



Venetian-Blind dynode

- various drift pass
- might miss a dynode



Box-Line dynode

- unique drift pass
  → high timing & 1PE Q resolution
- large acceptance → high CE

Testing in a water Cherenkov detector

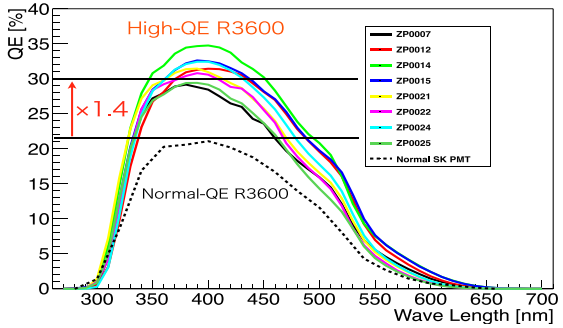
- To confirm the usability of new photosensors in Hyper-K
- Initial prototypes produced, and installed in summer 2013

20cm HPDs

for testing the new technology

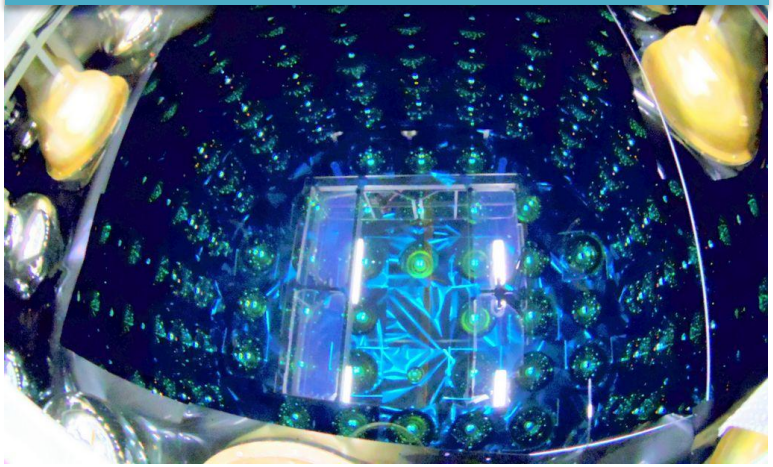
50cm High-QE SK PMTs

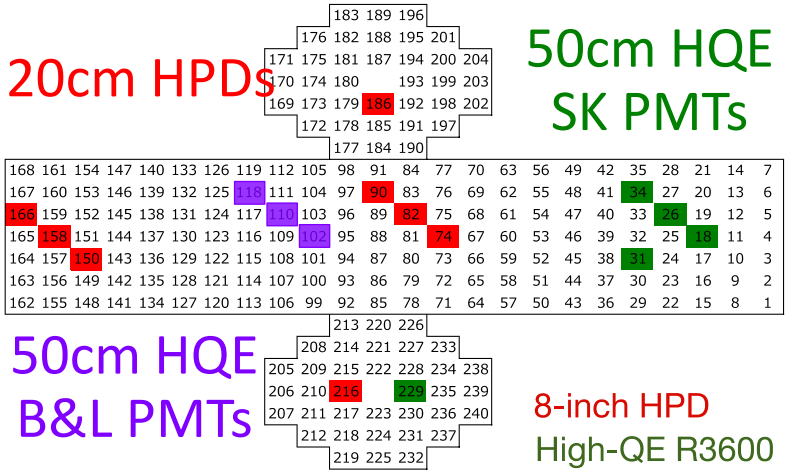
for testing HQE photocathode



- **50cm HQE Box-Line PMTs** are just installed in this summer.

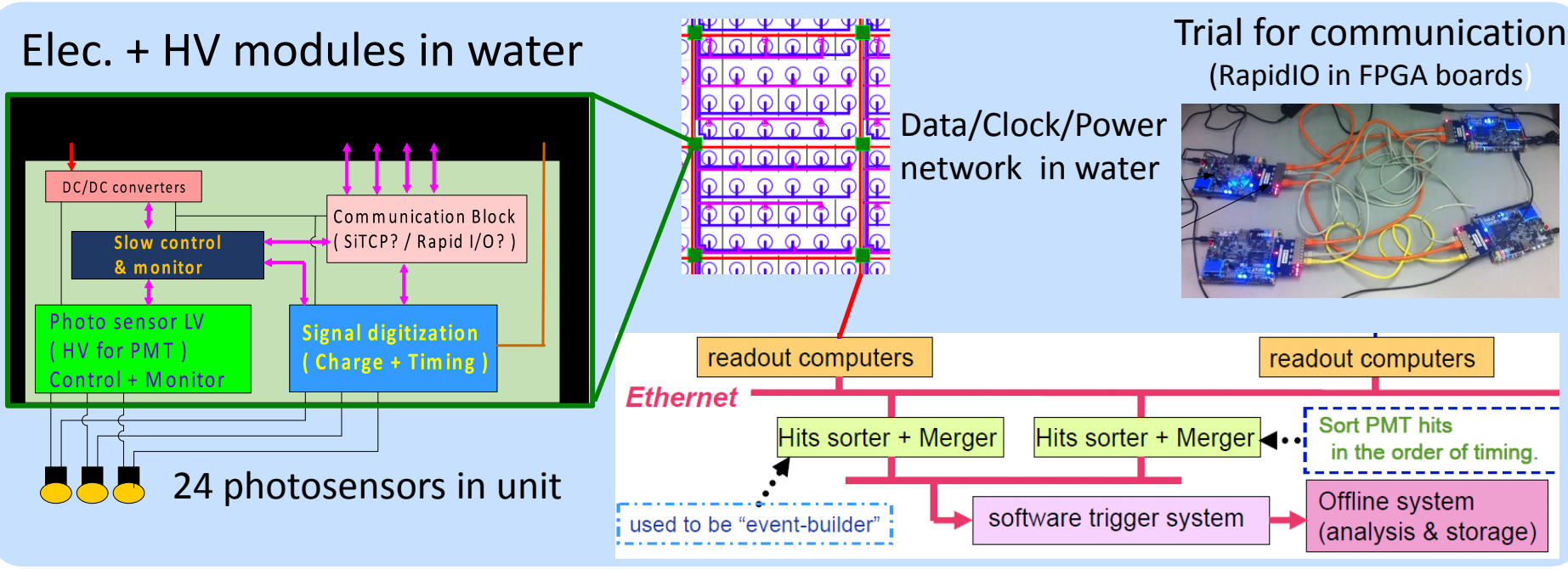
EGADS detector in Kamioka mine
(200 ton scale model of SK)





~230 normal SK PMTs as reference

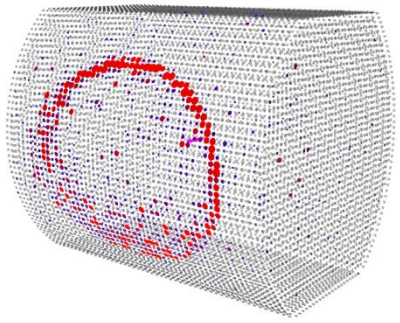
Electronics and DAQ



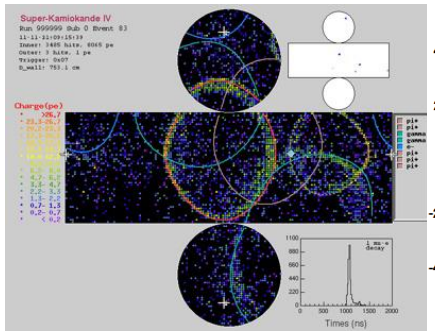
- Planning to put photosensor power-supplies & electronics in water
- Investigating a few options for front-end elec. (QTC+TDC / FADC)
- DAQ system also being designed
  - nominal starting point : current Super-K DAQ
    → digitizing all signals (T&Q) + defining events with software
- To be tested with the WČ prototype detector

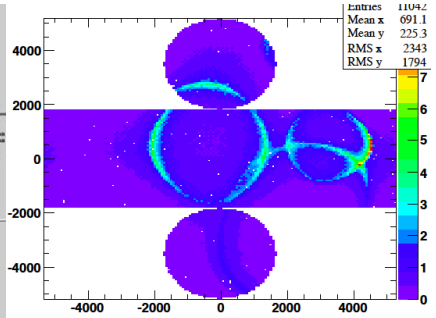
Software and Computing

- HK dedicated detector simulation being ready
  - Based on “WCSim”, a GEANT4 WČ detector simulator
  - Performance of new photosensors implemented



- Event reconstruction software
  - Based on the continuously-improving SK software
  - fiTQun : new reconstruction algorithm developed for SK/T2K
  - Under tuning for HK





- Computing model proposed
  - Concepts : Cloud computing, Virtualization, and Digital preservation
  - Solid expertise from T2K and LHC in the UK
- More works ongoing (GitHub code-repository, public web page)

Prototype Detector

We need a prototype detector for R&D

Test items in the prototype

- Photosensors
  - Long term endurance test for ~100 sensors
- Electronics & DAQ
- Automated calibration system
  - In 3D
- etc

Basic plan

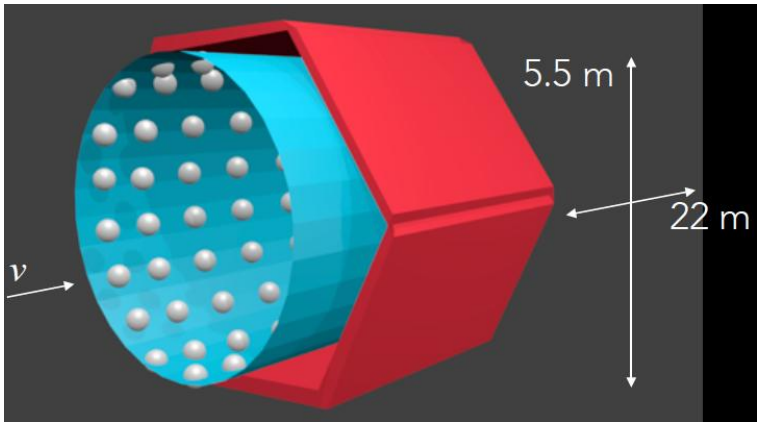
- Modification and improvement of EGADS 200t WC detector
- Completion in Sep. 2017 ?

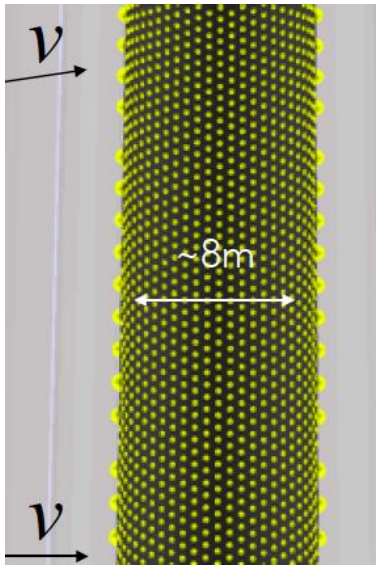
WG of Japan, US, UK, Canada & Spain
Is planning be organized.

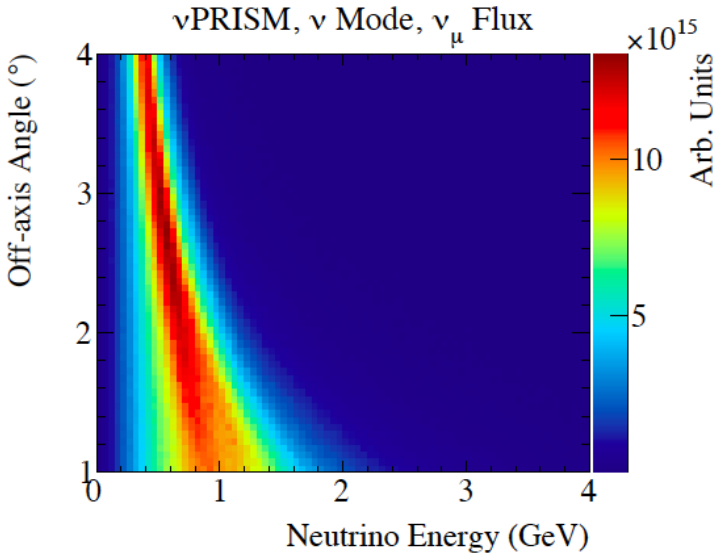
Near Detector Concepts

“ νPRISM ” (1km)

- tall (~50m) WČ detector spanning wide range of off-axis angles
- effectively isolate response in narrow band of energy by comparing interactions at different off-axis angles







“ TITUS “ (2km)

- 2kt WČ detector with HPDs and LAPPDs
- Gd for ν / $\bar{\nu}$ discrimination
- Muon range detector, possibly magnetized (MIND)

Summary

- Hyper-K will provide excellent opportunities for wide range of physics topics
  - Neutrino mixing and CP violation
    - CPV sensitivity: >3σ for 76% of δ & >5σ for 58% of δ
  - Proton decays (sensitivity to $>10^{35}$ years)
  - Neutrino astrophisics
- Baseline design for the Hyper-K detector is ready
  - can be constructed with existing techniques
  - utilizing the successful experience in Super-K
- Various R&D work in progress internationally
  - for further performance improvement and cost reduction
  - to be tested in a Hyper-K prototype detector