Hyper-Kamiokande project

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ICRR external review
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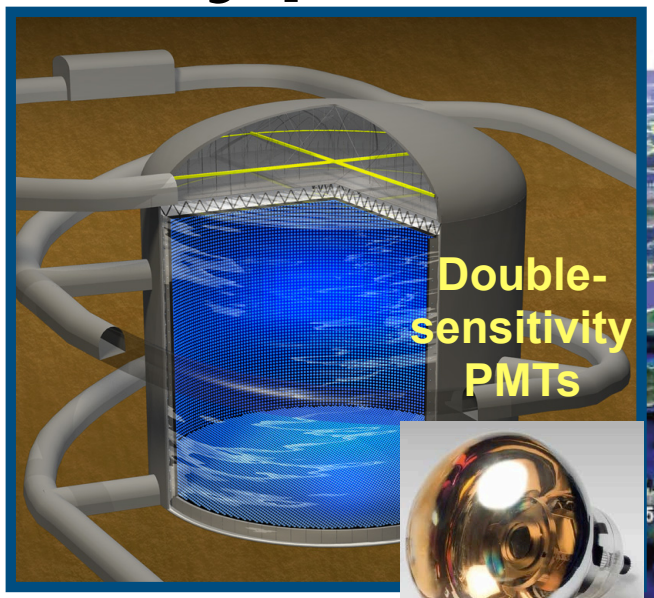
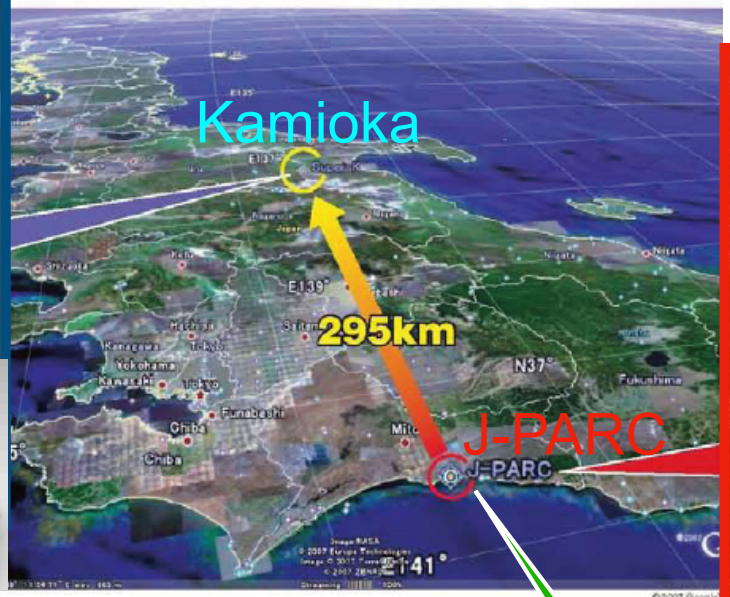
Prologue

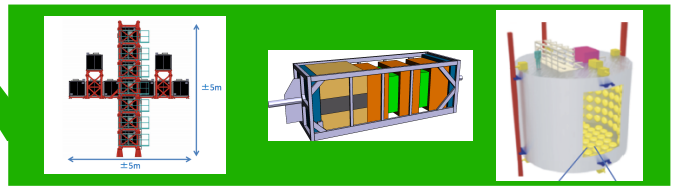
- The discovery of "$\nu_\mu \rightarrow \nu_e$ phenomena" in T2K opens the way to perform experiments to measure leptonic *CP* violation.

- Hyper-K submitted "Letter of Intents", arXiv: 1109.3262, in 2011.
  - Good reason to do the *CP* measurement in Japan
    - Much experiences and techniques for high performance water Cherenkov detector
    - Existing J-PARC to be upgraded to over Mega Watt.
  - More rich physics topics can be covered by the extension, e.g. proton decay searches and neutrino astrophysics.

Hyper-Kamiokande project







	Super-K	Hyper-K (1st tank)
Site (depth)	Mozumi (1000 m)	Tochibora (650 m)
Number of ID PMTs	**11,129**	**40,000**
Photo-coverage	40%	40% (**×2 sensitivity**)
Mass / Fiducial	50 kton / **22.5 kton**	260 kton / **187 kton**

1. Hyper-K detector to be built with **8.4 times larger fiducial mass** (190 kiloton) than Super-K and to be instrumented with **double-sensitivity PMTs**.
2. J-PARC neutrino beam to be upgraded from 0.5 to 1.3 Mega Watt
3. New and upgraded near detectors to control systematic errors

Milestones since April 2012

• 2013.3 Selected as an important large-scale project in Masterplan2013 by Science Council of Japan (SCJ).

• 2015.1 International proto-collaboration has been formed.

→International project, cooperative works for R&D, designing, physics sensitivity study

• 2015.1 ICRR and the Institute of Particle and Nuclear Studies (IPNS) of KEK signed a memorandum of understanding (MoU) for cooperation on the Hyper-K project.

→Two host institutes

• 2016.2 Hyper-K Advisory Committee (HKAC) meeting (1st round)

→Review by external experts of technology and physics

• 2016.2 Hyper-K Design Report [KEK Preprint 2016-21 / ICRR-Report-701-2016- 1]

• 2016.6 KEK's Project Implementation Plan (KEK-PIP) set top priority to the J-PARC upgrade for Hyper-Kamiokande.

• 2017.2 Selected as a important large-scale project in Masterplan2017 by SCJ.

• 2017.3 Recommended as a ICRR's next project by the ICRR future project review committee's report .

• 2017.7 Selected in Roadmap2017 by MEXT.

→Budget request by UTokyo and KEK started

• 2017.9 HKAC meeting (2nd round)

• 2017.10 The University of Tokyo launched Next-Generation Neutrino Science Organization (NNSO), where ICRR, Kavli IPMU, and the School of Science cooperate to promote the project and host the detector construction.

• 2018.5 Revised Hyper-K Design Report [arXiv: 1805.04163]

• 2018.8 Seed funding has been allocated within MEXT budget request for JFY2019.

Japanese funding prospect

- A priority project in the MEXT Roadmap 2017
  - Its importance and urgency are recognized by the Japanese government.
- Seed funding for FY2019 has been allocated.

MEXT requests us to

- Strengthen the international collaboration (including the budgetary contribution).
- Reduction of the construction cost by detailed investigation of the detector design.
- Also, before 2017, we were requested to strengthen the structure of the host institution (in the Univ of Tokyo).

- UTokyo/KEK will submit budget request again this summer.
- We are preparing for starting construction in 2020.

- Physics cases
- Organization
- Design, R&D, and International sharing

CP violation

Only known CPV source=KM phase
Other CPV necessary for the matter-dominated universe

→ Search for CPV in lepton sector

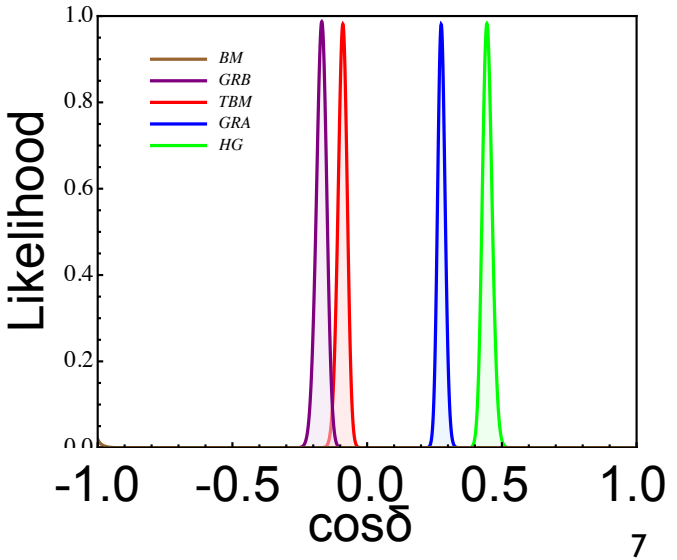
- Leptogenesis scenario only with ν's Dirac CP phase

  S. Pascoli et al., PRD 75, 083511 (2007) PDG review 2014

  $|\sin\delta_{CP}| > \sim 0.6$

- Flavor symmetry prediction on δ_{CP}

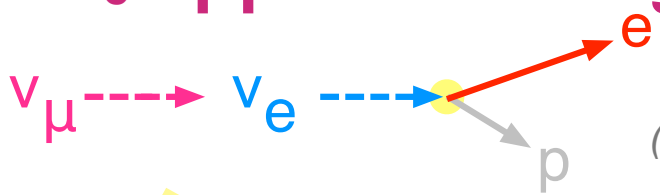
  e.g. Petcov 1504.02402v1 (right plot)



We need not only CPV discovery, but also precision measurement to test hypotheses.

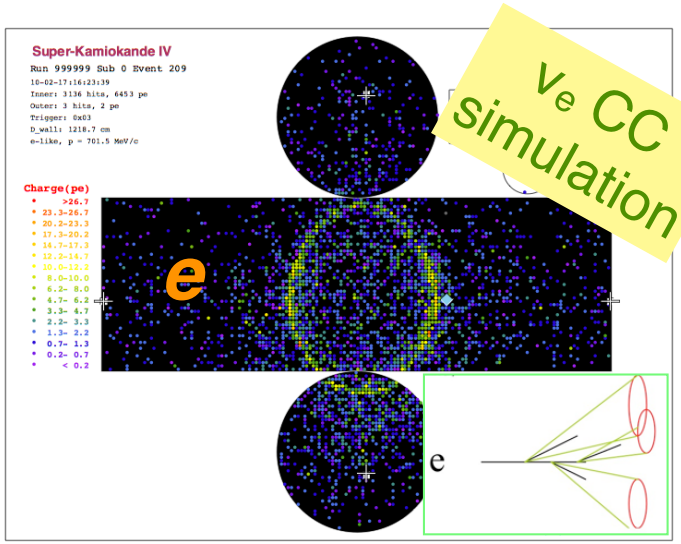
J-PARC ν_μ ($\bar{\nu}_\mu$) beam (~0.6GeV)

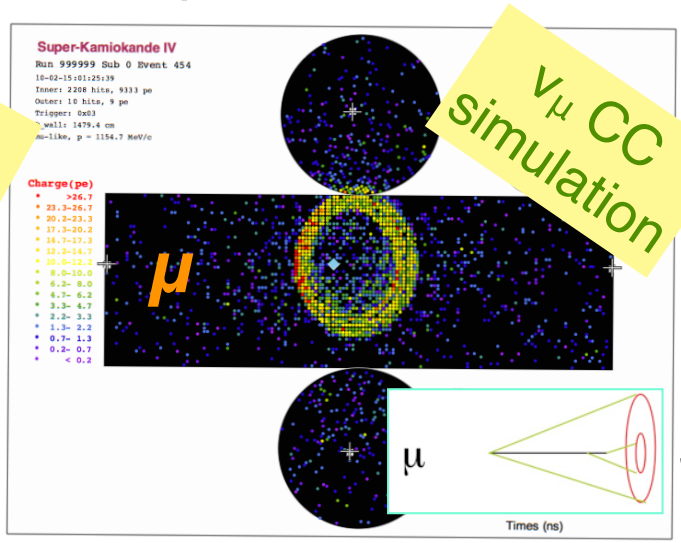
ν_e appearance signal = single e event

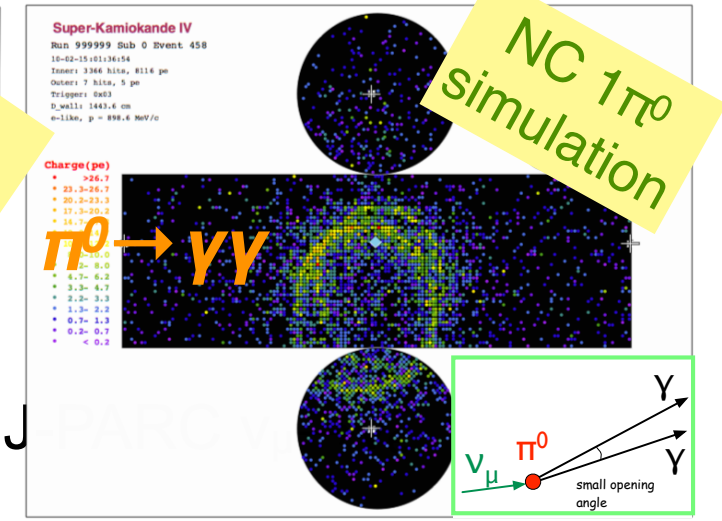


CCQE : $\nu_e + n \rightarrow e + p$

(dominant process at J-PARC beam energy)

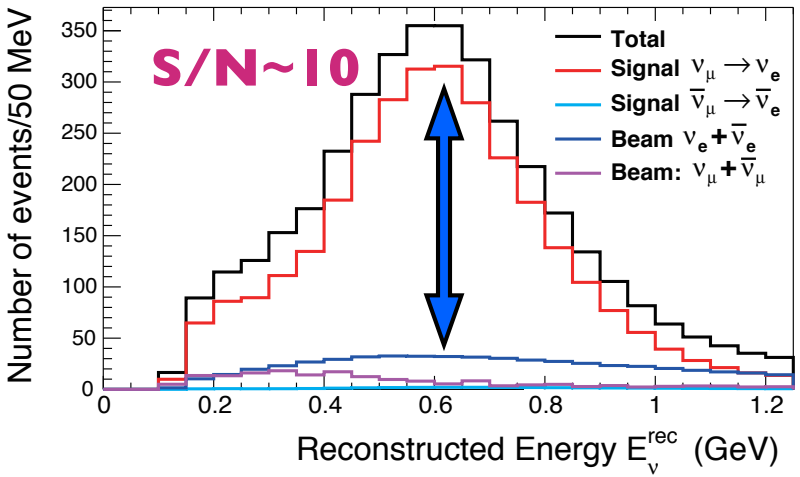






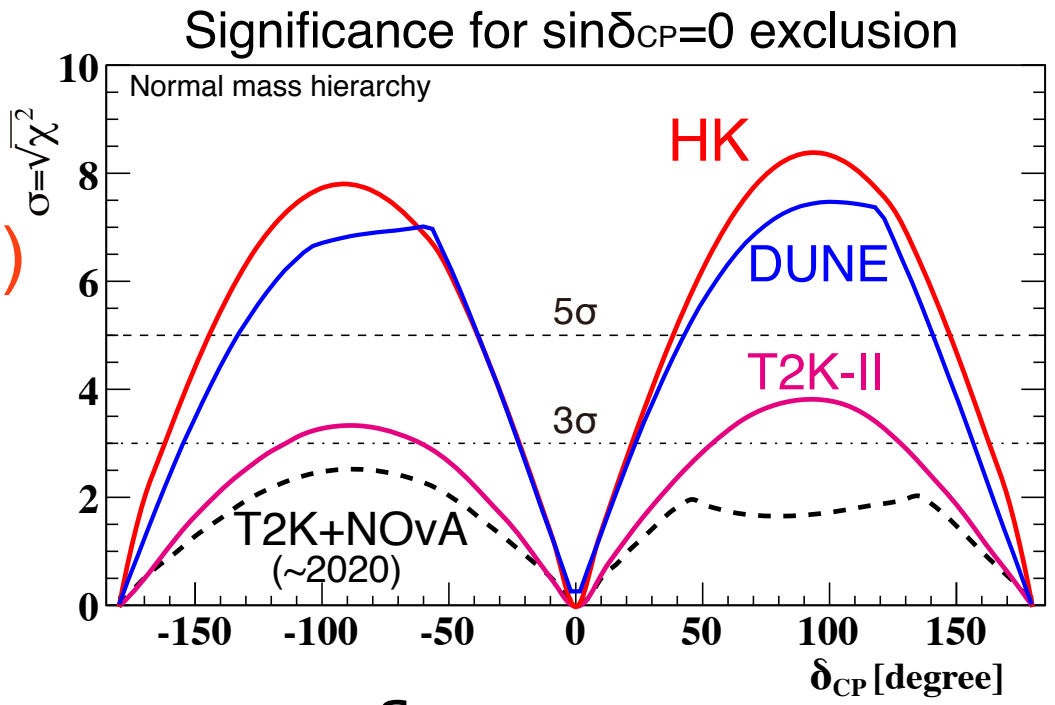
- High background rejection
  - >99.9% ν_μCC, 99% NC π^0 rejection
  - keeping 60% ν_e signal efficiency
- **Unique CPV measurement**
  - High statistical, clean (S/N~10)
  - Simple Eν reconstruction by charged lepton kinematics (for CCQE)
  - Less matter effect (fake CPV effect)

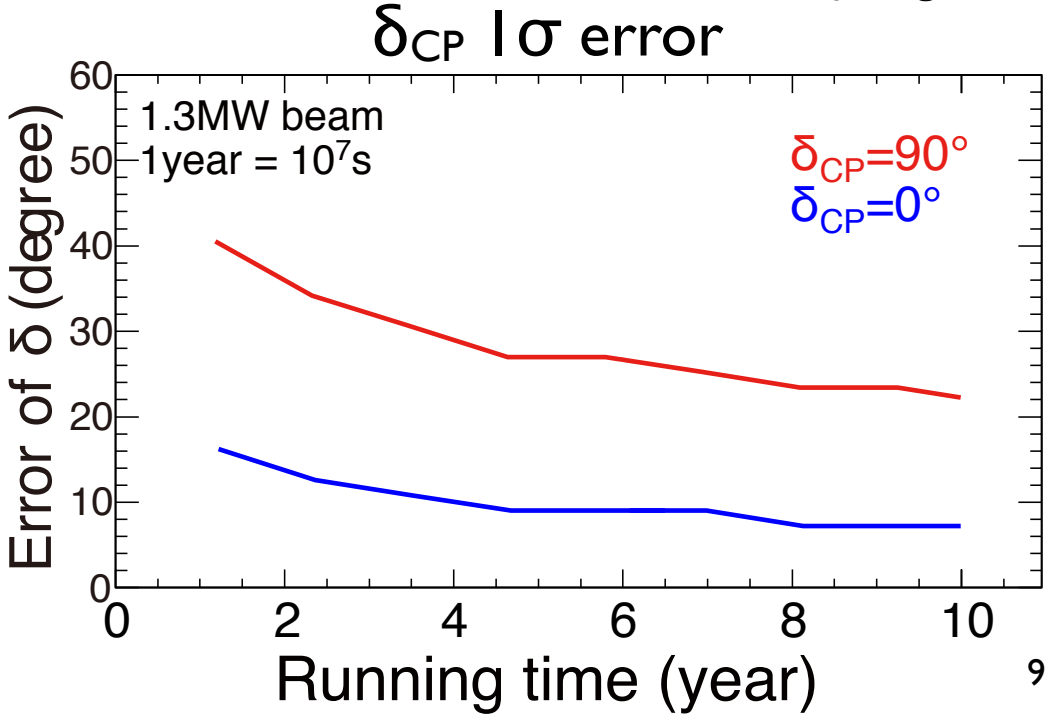
Appearance ν mode



CPV sensitivity

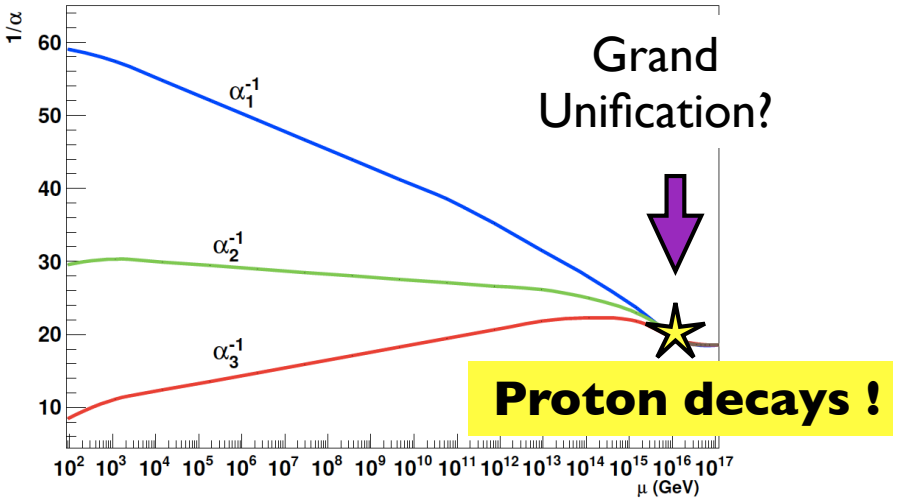
- Exclusion of $\sin\delta_{CP}=0$
  - 8σ for $\delta=-90°$ (T2K best fit)
  - 80% coverage of δ parameter space for CPV discovery w/ $>3\sigma$
  - Test of CPV origin
- δ_{CP} precision measurement
  - 22° for $\delta=-90°$
  - 7° for $\delta=0°$



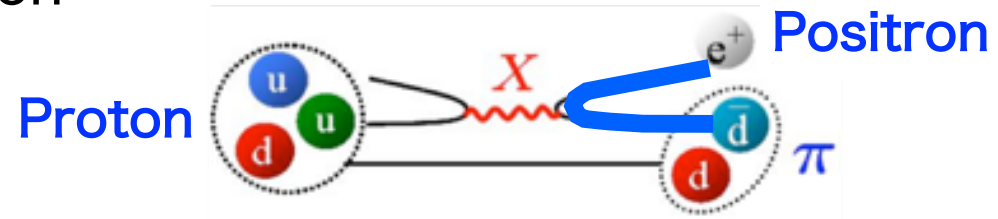


Nucleon Decay Searches

- Test of Grand Unified Theories
  - Look for direct transition of quarks to leptons→Direct test of GUT
  - Unique (Unreachable by colliders)
- $p \rightarrow e^+\pi^0$: Dominant decay mode predicted by many general GUT
  - HK's high mass and unbound proton will enable us to reach (τ_{proton} / Br) ~10^{35} years
- Ambitious physics goals
  - Determination of GUT scale
  - Gauge symmetry group, test of SUSY models



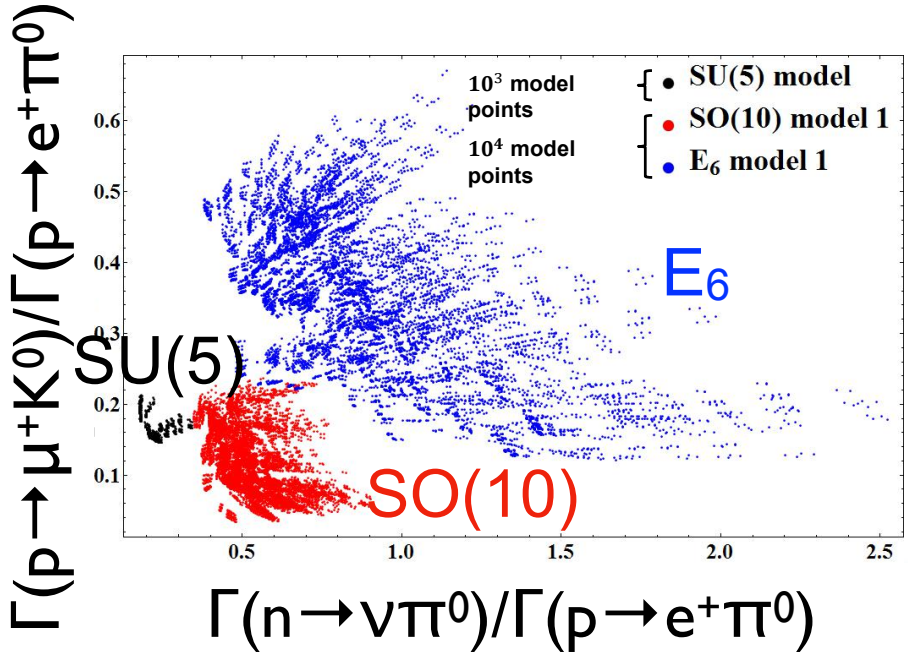
$p \rightarrow e^+\pi^0$



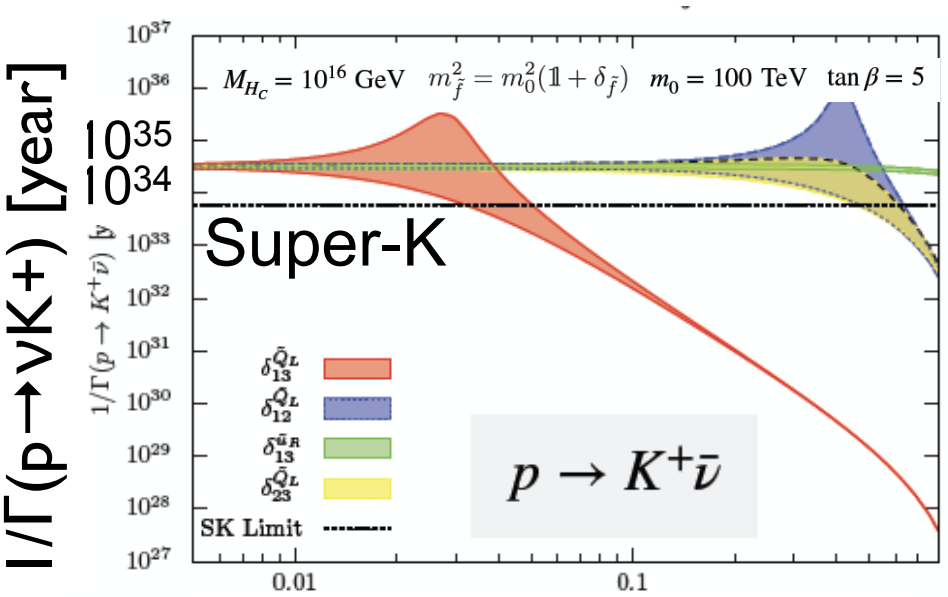
$$\Gamma(p \rightarrow e^+\pi^0) \sim \frac{g^4 m_p^5}{M_X^4}$$

Strong cases

- We could identify details of unification picture, e.g. gauge group and other symmetries
  - $\Gamma(n\to\nu\pi^0)/\Gamma(p\to e^+\pi^0)$ depends on SU(5), SO(10), E_6 (Y. Muramatsu)

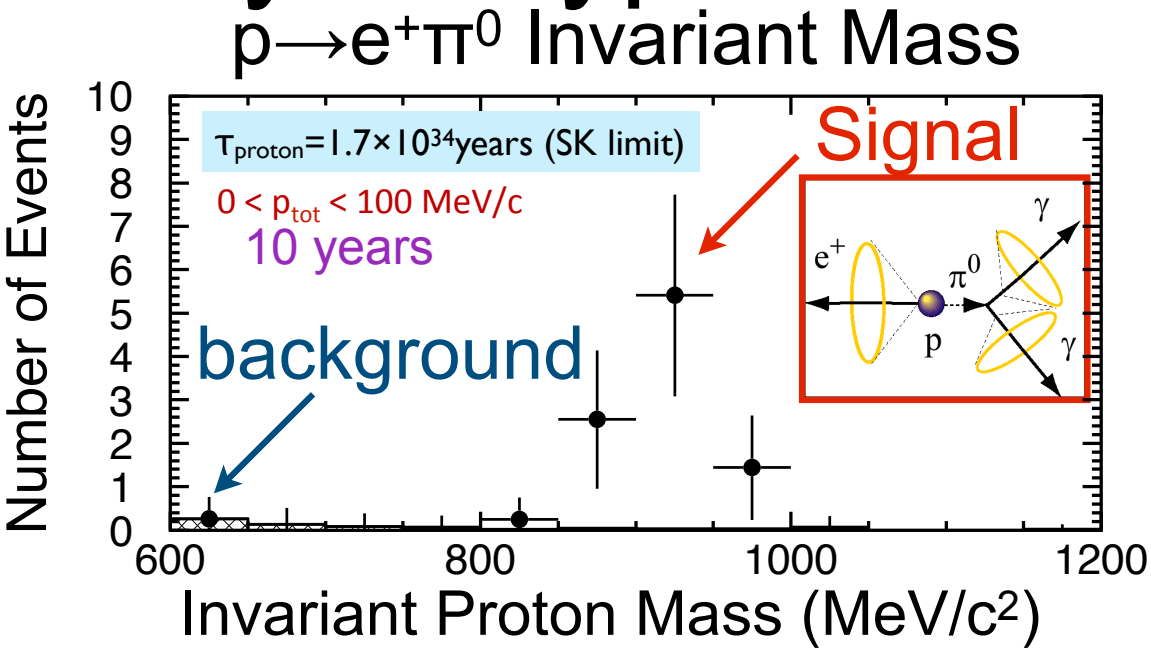


- P-decay Br. ratio could tell us flavor structure of SUSY particles.
  - Decay branches depends on the size of sfermion mixing. (N.Nagata and S.Shirai, JHEP 1403, 049 (2014))

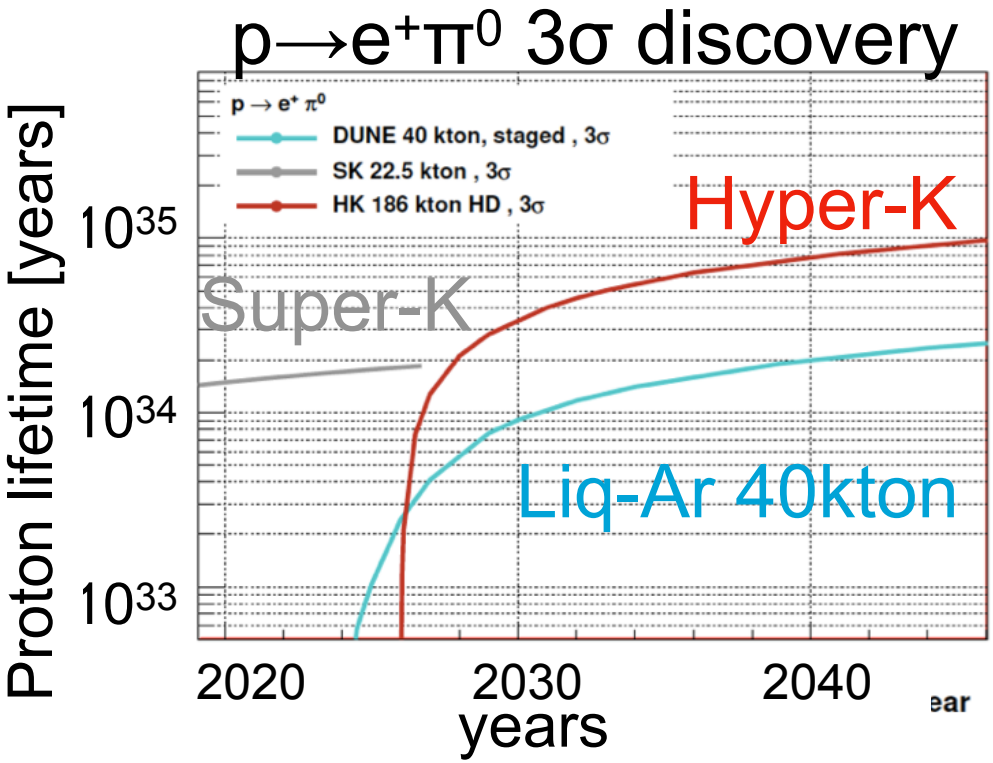


$p \rightarrow e^+\pi^0$ discovery in Hyper-K

- Invariant proton mass would be a compelling evidence
- Reach to 10^{35} yrs
- BG free search possible: 0.06 BG/Mton・year



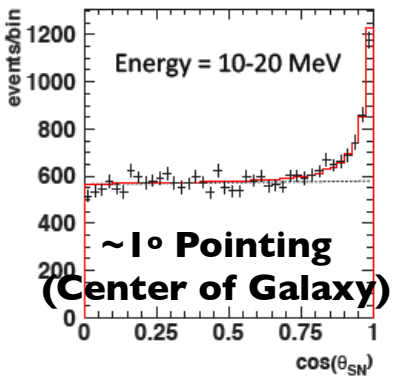
	p_{tot}<100MeV/c		100<p_{tot}<250MeV/c	
	Sig. ε(%)	Bkg (/ Mtyr)	Sig. ε(%)	Bkg (/ Mtyr)
HK	18.7	0.06	19.4	0.62



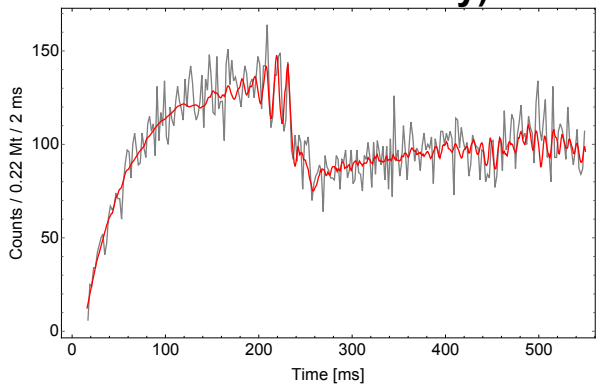
Neutrino Astrophysics

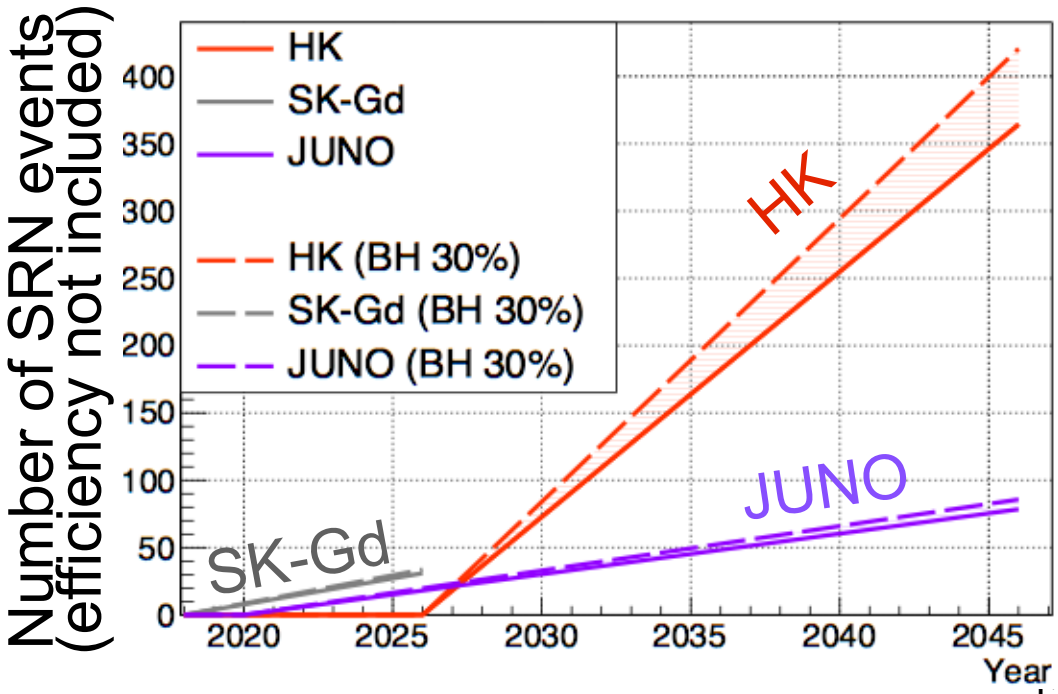
- ~10MeV neutrino astronmy with **(1)ν direction, (2)ν energy, (3) arrival time by (4) high mass** (22kt→190kt)

- **Solar ν_e** → solve **2σ tension** w/ reactor $\bar{\nu}_e$, 1st detection of Hep ν
- **~Mpc reach of SN ν burst**
  - **Explosion mechanism (drived by neutrinos?)**
  - **Instance of BH/NS formation**
  - **~1° pointing→ Alert to telescopes including GW telescopes**
- **SN diffuse ν**
  - **Fraction of dim SN's and BH formation**
  - **SN (and start formation) history in the ν spectrum**



SASI (standing accretion shock instability)





Host institutes (UT and KEK)

- UTokyo/ICRR launched a institute for HK detector construction: Next-generation Neutrino Science Organization (NNSO)
  - ICRR (22), IPMU (4), School of Science (3). Earthquake Research Institute (7) has participated in February 2019.
  - Steering Committee : T. Kajita (director), M. Nakahata, M. Shiozawa, S. Moriyama, M. Yokoyama, H. Aihara, K. Tokushuku (KEK-IPNS director), Naohiro Saito (J-PARC center director), Takashi Kobayashi, T. Nakaya, Y. Itow, K. Mitsuda, Y. Ushiroda, H. Takami
- KEK : Continuous J-PARC power upgrade, reached to 0.5MW.
- UT/KEK : HK review committee by external experts
  - Milind Diwan, Anne-Isabelle Etienvre, Junji Hisano, Klaus Kirch, Andrew J. Lankford, Masaki Mori, Toshinori Mori (chair), Katsunobu Oide, David Sinclair, Jim Strait, Yifang Wang, Jiro Yamatomi (chair of sub-committee)
  - Cavern&Tank sub-committee : T. Ono, N. Kotake, S. Tanaka, T. Yamaguchi, J. Yamatomi(chair), K. Endo
- Hyper-Kamiokande experiment Financial Forum
  - Foreign agency representatives and researchers from interested countries
  - Kickoff meeting on January 11th, 2019 @ UTokyo campus
  - 2nd meeting will be held on June 27-28, 2019

1st HK Financial Forum

2019/1/11 1st HKFF meeting@UT

Foreign agency representatives and researchers from 14 countries

https://www.u-tokyo.ac.jp/focus/en/articles/z0208_00026.html

The First Meeting of the Hyper-Kamiokande Experiment Financial Forum
Representatives from 14 countries participate

Institute for Cosmic Ray Research

January 23, 2019

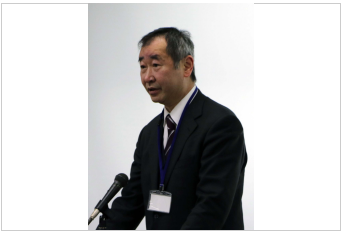
The first meeting of the Hyper-Kamiokande Experiment Financial Forum (HKFF), in which foreign agency representatives gathered to engage in discussion with host organizations and project members, was held at Kojima Hall, Hongo Campus, the University of Tokyo on January 11th, 2019.

About 50 participants atend the first meeting of HKFF

Hyper-Kamiokande (HK) is a new world-leading international scientific research project aiming to start its operation in the second half of the 2020s. The HK detector is planned to have eight times larger fiducial mass than its predecessor detector, Super-Kamiokande, and it is equipped with newly developed high-sensitivity photosensors. The aim of HK is to elucidate the Grand Unified Theory and the history of the evolution of the universe through an investigation of proton decay and CP violation (the difference between neutrinos and antineutrinos), together with the observation of neutrinos from supernova explosions.

In October 2017, the Next-Generation Neutrino Science Organization (NNSO) was established in the University of Tokyo by the Institute for Cosmic Ray Research (ICRR), the Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU), and the School of Science to cooperate in pioneering the future of neutrino physics programs through the development of neutrino research techniques and detector technologies. Professor Takaaki Kajita, the director of NNSO, invited foreign agency representatives and researchers from 14 countries (Armenia, Brazil, Canada, France, Italy, South Korea, Poland, Russia, Spain, Sweden, Switzerland, UK, USA and Japan) and about 50 people gathered to hold discussions.

Prof. Kajita Calls on Participants to Further Solidify International Collaboration



Prof. Kajita at the opening address of the first meeting

Presdent Gonokami saying "HKFF will be the first step towards our fruitful collaboration"

In the meeting, Professor Kajita made an opening address saying, "The forum was established to offer a place for agencies to find out the details of the Hyper-Kamiokande project including its goals, timelines and the organizational structure, and to share information on interests and constraints of each country and region. We'd like to have discussions to identify the necessary tasks to further solidify the international collaboration." The President of the University of Tokyo, Makoto Gonokami, said, "Of course, this project cannot be realized by the University of Tokyo alone. Cooperation with international partners, as well as the High Energy Accelerator Research Organization (KEK) and other institutes in Japan, is indispensable. We look forward to closely working with you in the future, and hope that this meeting will be the first step towards our fruitful collaboration and the success of realizing this exciting project."

MEXT Research Promotion Bureau Director-General Isogai Says They Intend to Do Their Utmost to Realize the Project

Also, Mr. Keisuke Isogai, the director-general of the Research Promotion Bureau in the Ministry of Education, Culture, Sports, Science and Technology (MEXT), commented, "We at MEXT intend to do our utmost to realize the project as soon as possible in light of the project's extraordinary scientific significance."

Mr. Isogai speaking at the HKFF

The potential foreign partners discussing their contributions to the HK

The forum looks forward to reviewing progress again towards realizing the project.

About 25 Participants Make a Visit to the Super-Kamiokande

Forum has been established: 2nd meeting on June 27-28

Hyper-Kamiokande Group

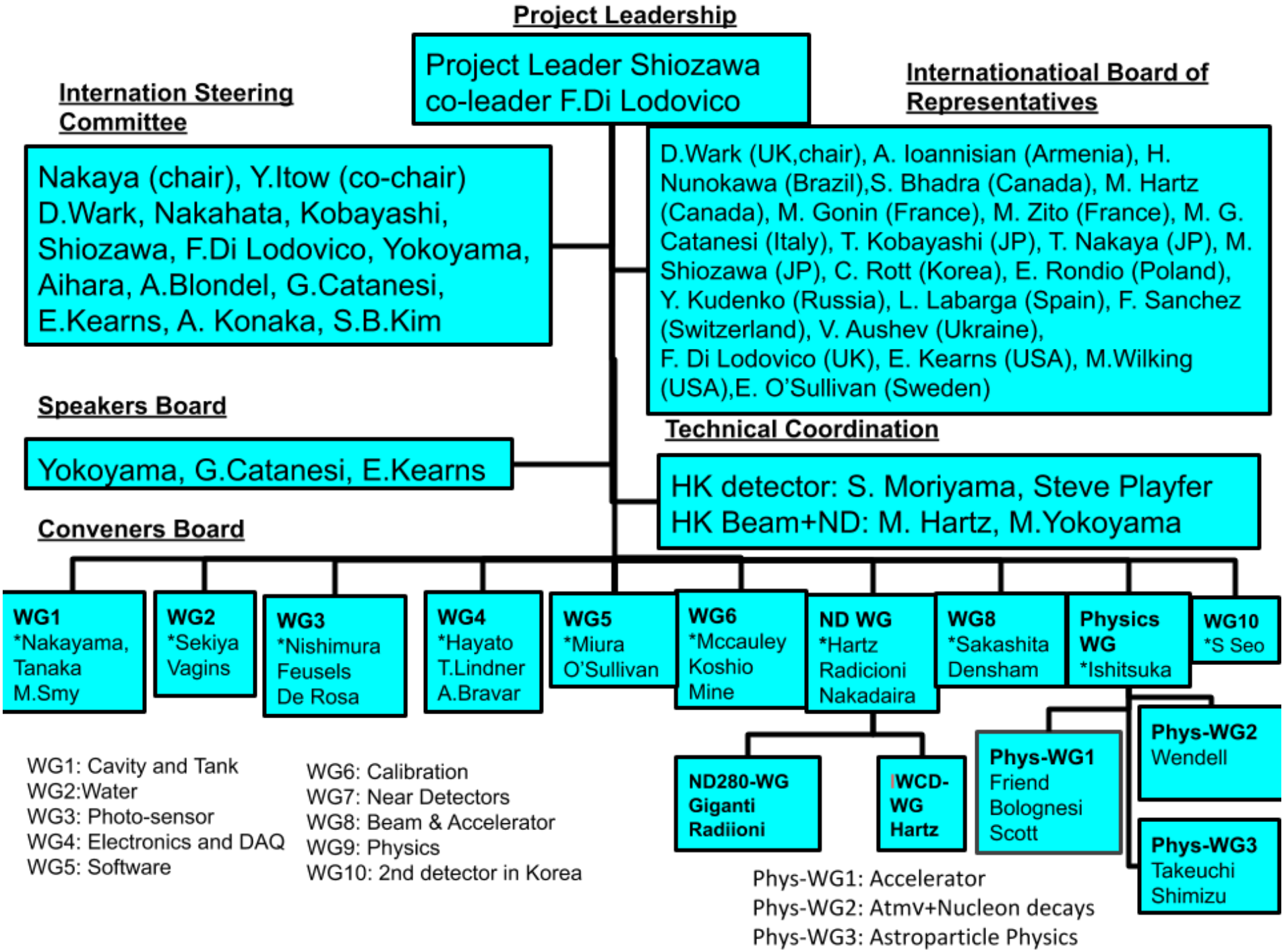
17 countries

82 institutes, ~300 members

Hyper-K meeting@Kashiwa, January 2019

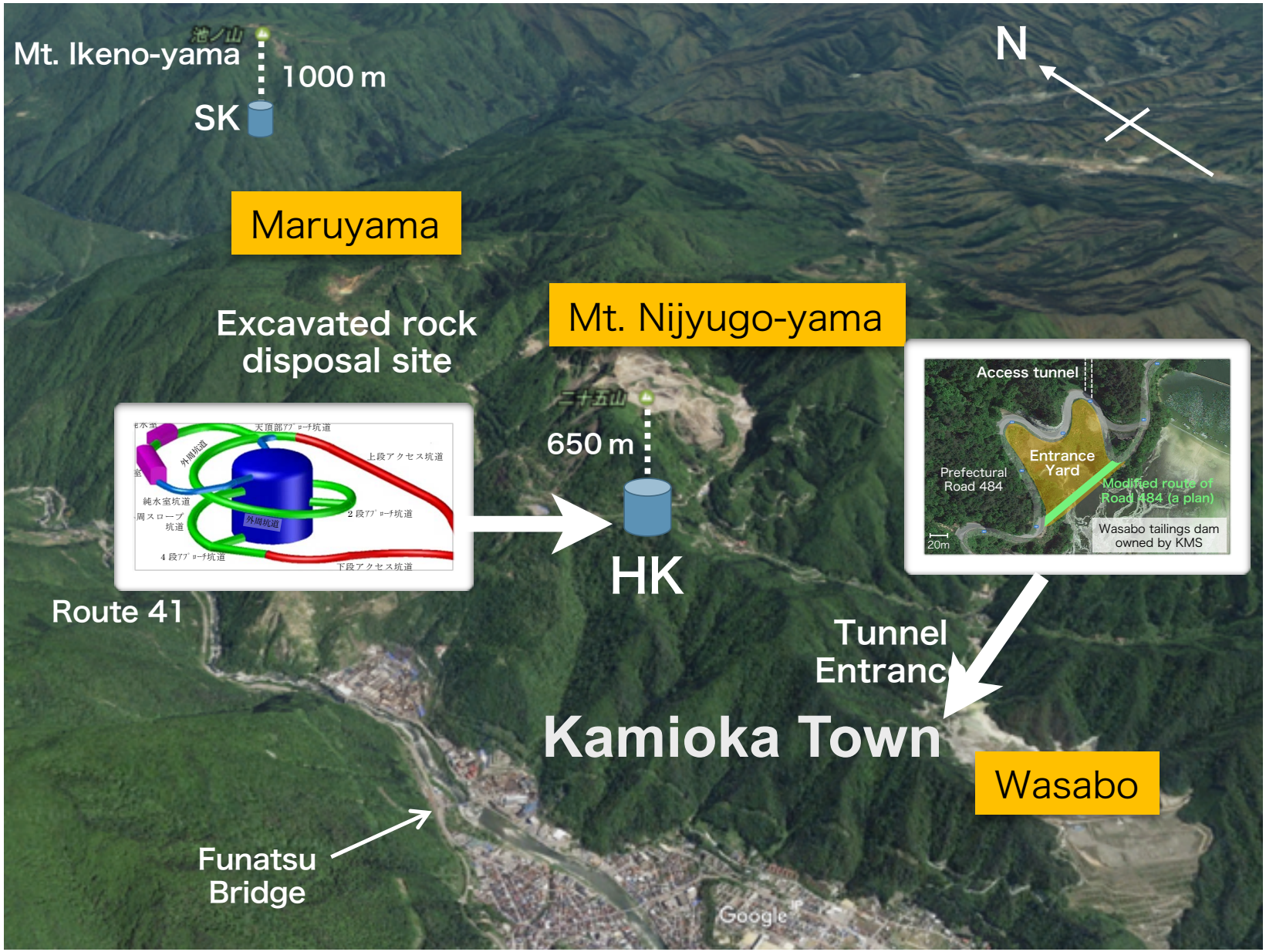
- New countries
  - Germany (Aachen)
  - India (Harish-Chandra Research Institute, Indian Institute of Technology, Tezpur University)
- New Institutes
  - Canada: Victoria, BCIT, Carleton
  - Poland: AGH, Jagiellonian, Silesia, Institute of Nuclear Physics PAN
- Japanese institutes
  - Osaka city, Okayama, KEK, Kobe, Kyoto, Kyoto Sangyo, TIT, Tokyo, Tohoku, Nagoya, Miyagi educational
  - New institutes include Tokyo Science, Yokohama, Keio universities

Proto-collaboration Structure



Detector Location

- 8km south of Super-K, 295km from J-PARC
- 650m rock overburden

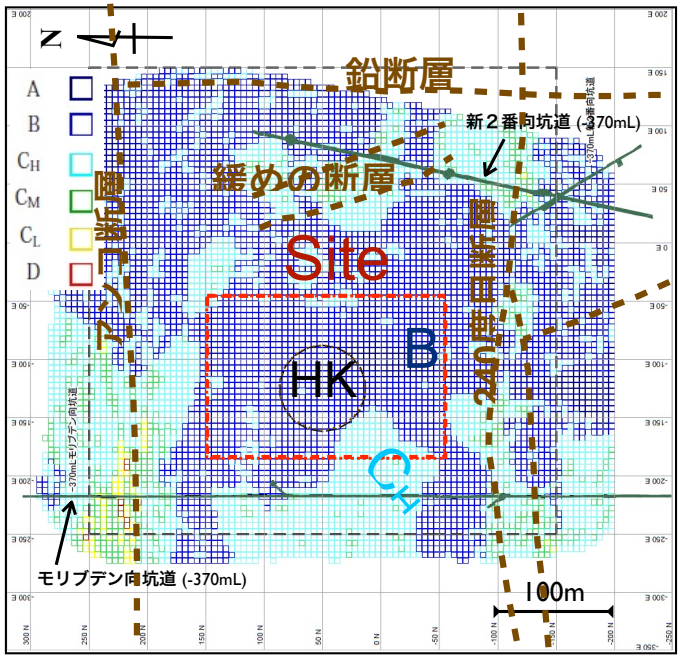


Cavern study

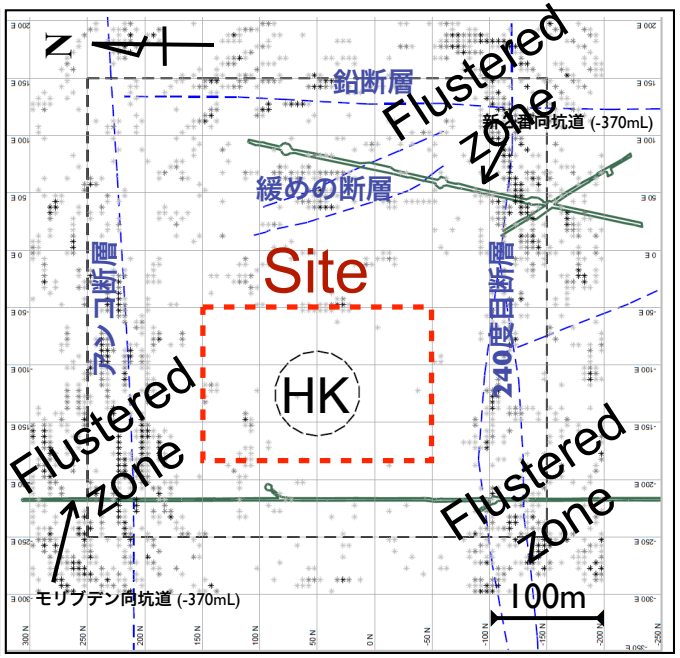
We successfully identified the candidate position suitable for the large cavity

- dominated by sound and intact rock mass
- no significant flustered zone

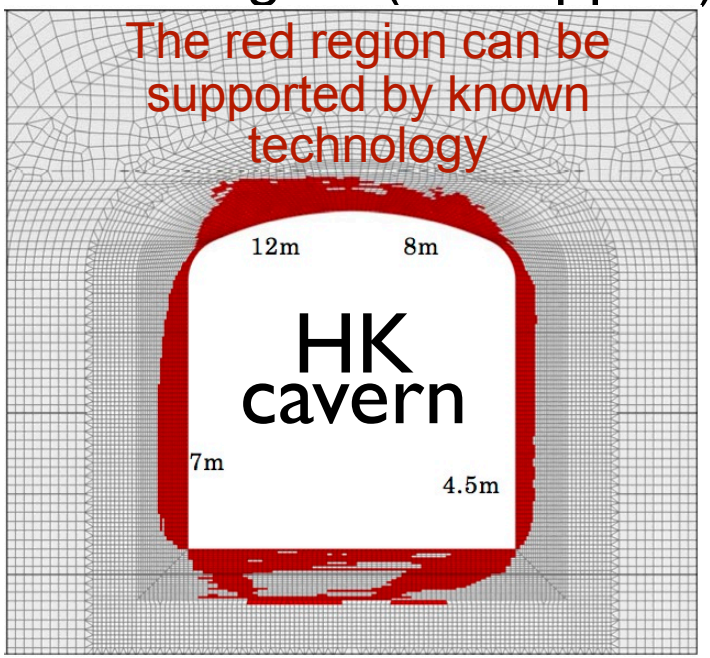
3D Rock class dist.



Flustered zone



Plastic region (no support)



(2017.8)HK Advisory committee concluded:
"The level of feasibility of cavern and tank construction is now satisfactory."

Ongoing study for Cavern&Tank

- Close investigation of cost
- preparation for starting construction in 2020

✓Cavern, Access, Tank

- ✓Multiple design proposals
- ✓Investigation by consulting companies

✓Entrance yard

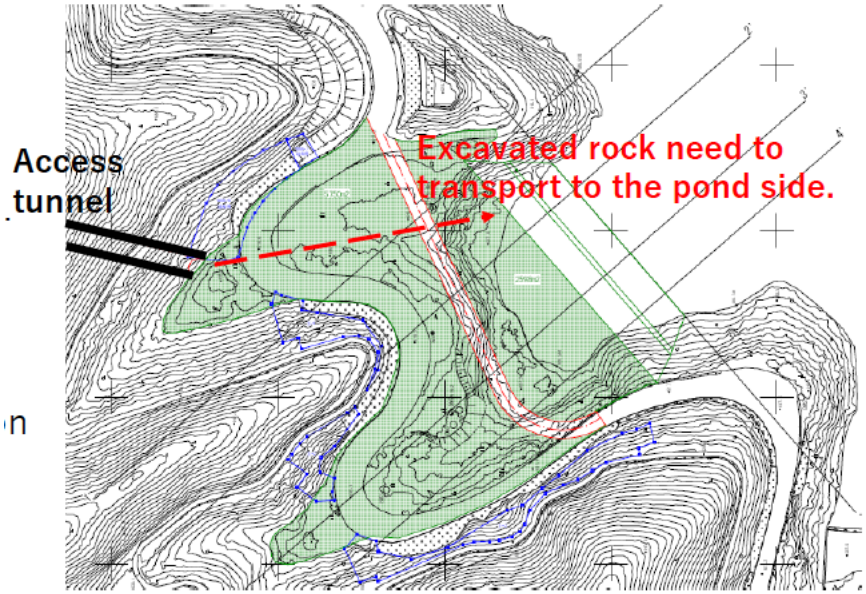
- ✓Geological survey, design optimization

✓Waste rock disposal

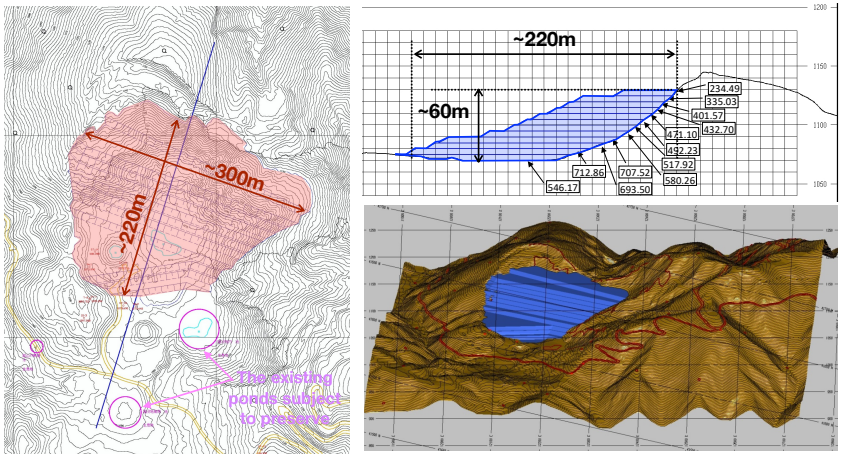
- ✓Geological survey, design of transportation road

✓Power distribution for excavation & operation

- ✓Contract w/ electric power company



Accumulating the excavated rock



- Established the design of the excavated rock accumulation

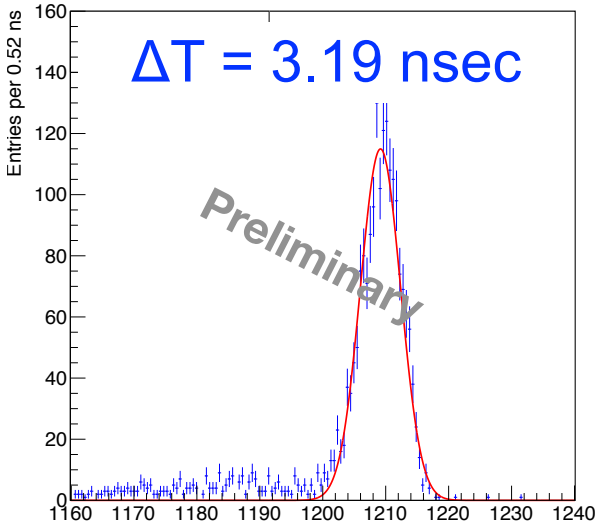
New PMT

- Photon-sensitivity, timing resolution, pressure tolerance enhanced by ~2
- Good prospect for real experiment
- 136 PMTs in Super-K

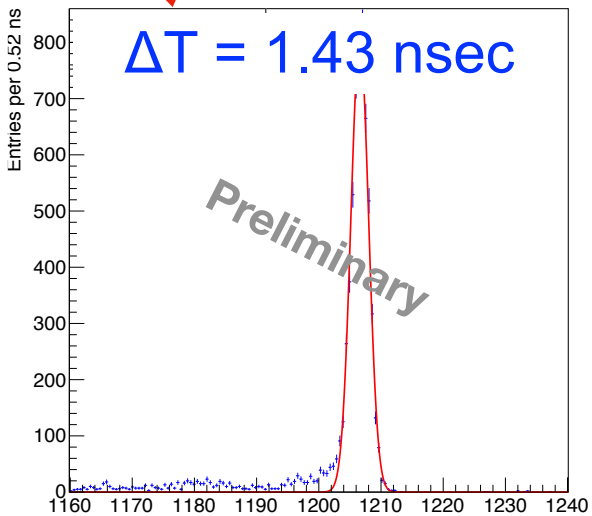
summer 2018 @ Super-K

- Ongoing R&D includes
  - long-term performance evaluation in Super-K
  - dark rate reduction, cover & light-concentrator development

SK PMT



HK PMT



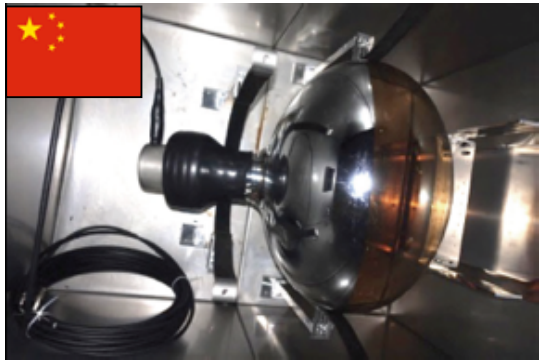
International Contributions to the Construction and Operation

1. Agreement among the Hyper-K group
   - Japan and foreign partners will make their best efforts to realize “Photo-detection system.”
   - Potential foreign contributions include PMTs, their covers, readout electronics, HV power supply, data acquisition system, geomagnetic field compensation coils, and calibration system.
   - Should include resources needed for the design, production, installation, operation, and maintenance.
2. We also need international contributions to
   - Computing and storage resources for Hyper-K observation and simulation data
   - Water purification system upgrade for astrophysical neutrinos
   - Neutrino beam-line power-upgrade (J-PARC)
   - New and upgraded near detector system
   - Calibration, and others

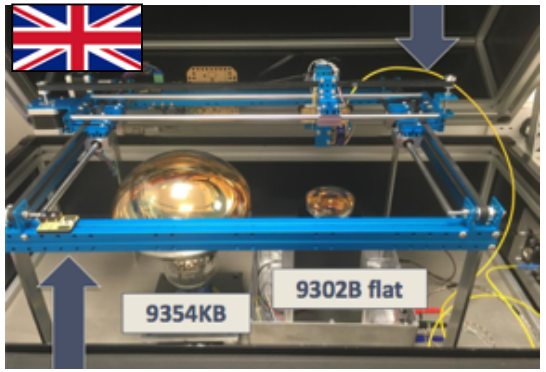
International sharing under discussion

Multi-PMT module

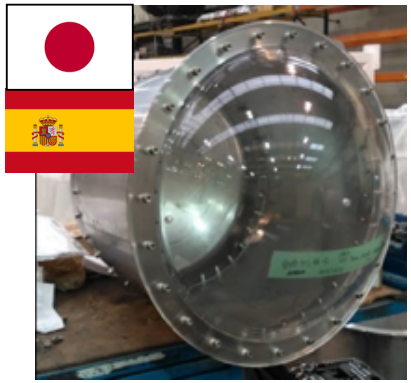
MCP-PMT



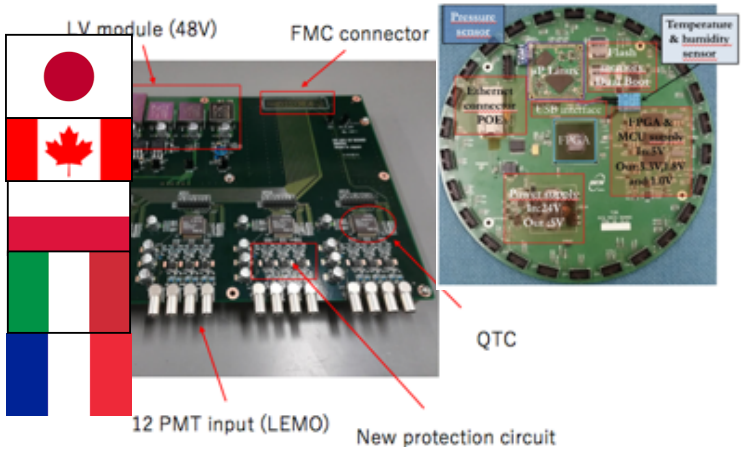
OuterDetector



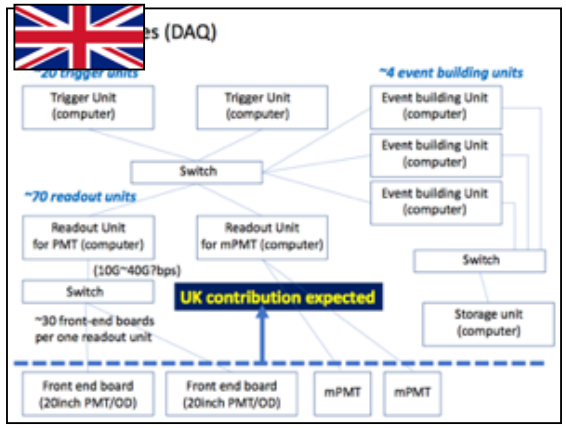
PMT cover



Electronics



DAQ



- Preparing “Expression of Interests” by each countries
- To be reviewed in the HK Advisory committee on June 25-26 and HK Financial Forum on June 27-28

Summary since April 2012

1. We have formed international proto-collaboration for design, R&D, and physics studies
   - Broad Physics topics with discovery potentials and competitiveness

2. UT and KEK cooperate to promote the HK
   - NNSO for HK construction in UTokyo
   - HK Advisory Committee
   - HK Financial Forum

3. Funding prospect
   - Listed in Roadmap2017
   - UT/KEK started budget request