August. 26, 2014@NuFact2014

Asia Neutrino Strategy

-- mainly accelerator neutrino beams --

T. Nakaya (Kyoto)

Comments

Comments

1. In ~15 years, we have great progress on neutrino physics, especially neutrino oscillations.
2. Even so, we cannot describe the neutrino mass term in Lagrangian because we do not know the origin of very light neutrino mass yet (Dirac or Majorana, how to couple with a Higgs boson).
3. It is an exciting time to explore a symmetry between quark and lepton and to understand the hierarchy of mass orders and the mixing patterns. Some theorists predict that the measured quark/neutrino parameters (masses and mixings) support SU(5) **GUT**.

$E_6 \longrightarrow SO(10) \longrightarrow SU(5)$

a GUT

1. Unifications
   1. Gauge Interactions (w/ SUSY)

$$SU(5) \supset SU(3)_C \times SU(2)_L \times U(1)_Y$$

   2. Matter

$$\boxed{Q \;\; U^c_R \;\; E^c_R} \;\; \boxed{D^c_R \;\; L} \;\; \boxed{N^c_R}$$

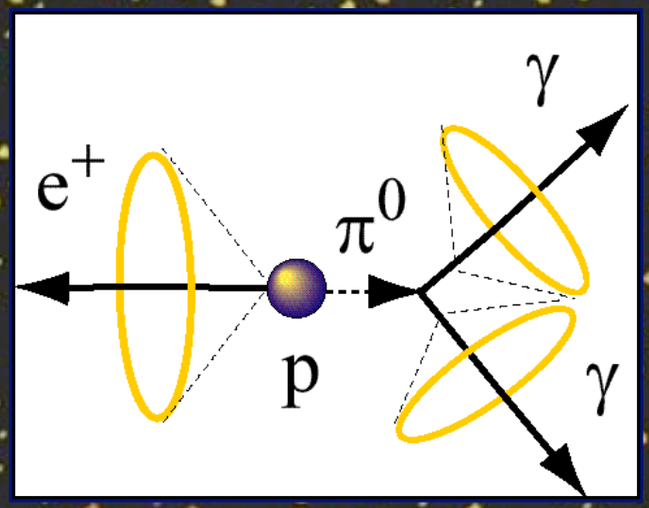
$$10 \;\; + \;\; \bar{5} + 1 \;\; = \;\; 16$$

- $10_i(Q_i)$ has a stronger hierarchy than $\overline{5}_i(L)$
- Hierarchies
  - Mixing: lepton (large) >> quark (small)
  - Masses: Up >> Down, Electrons >> Neutrinos

Comments 2

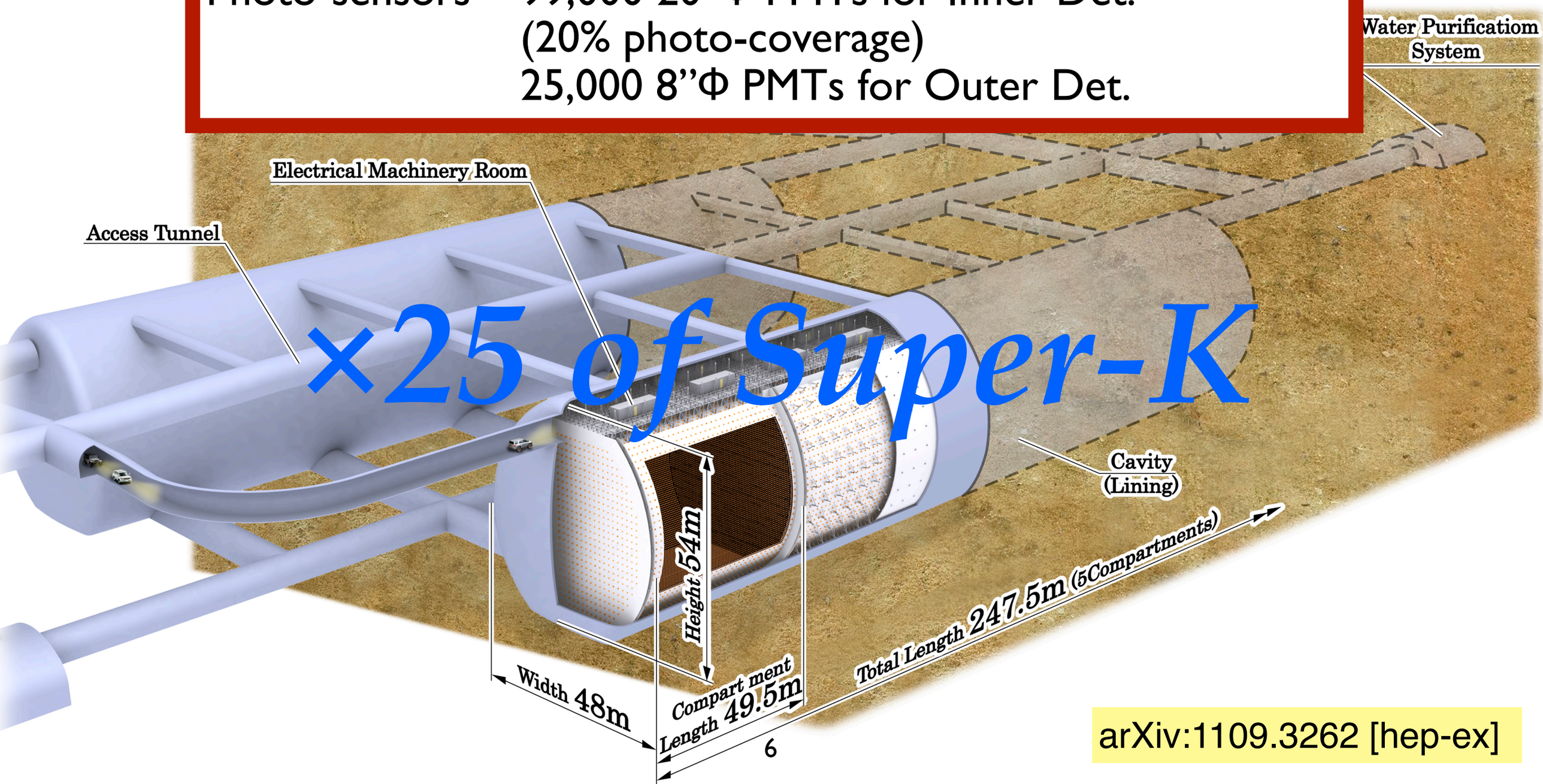
- In the next-generation neutrino facilities, we should address
  - **Proton Decay**
    - **Direct evidence of GUT**
  - **Neutrino CP violation**
    - Discovery: the first measurement
    - Relation between CKM and PMNS
    - Another CP violation in Leptogenesis w/ heavy right-handed Majorana neutrinos. Is there a link?
  - Neutrino Mass (and the order)
  - Neutrino is Majorana or NOT.
  - and more .. (Are right-handed neutrinos dark matters? Right-handed neutrino may not be too heavy and decay..)

Proton Decay



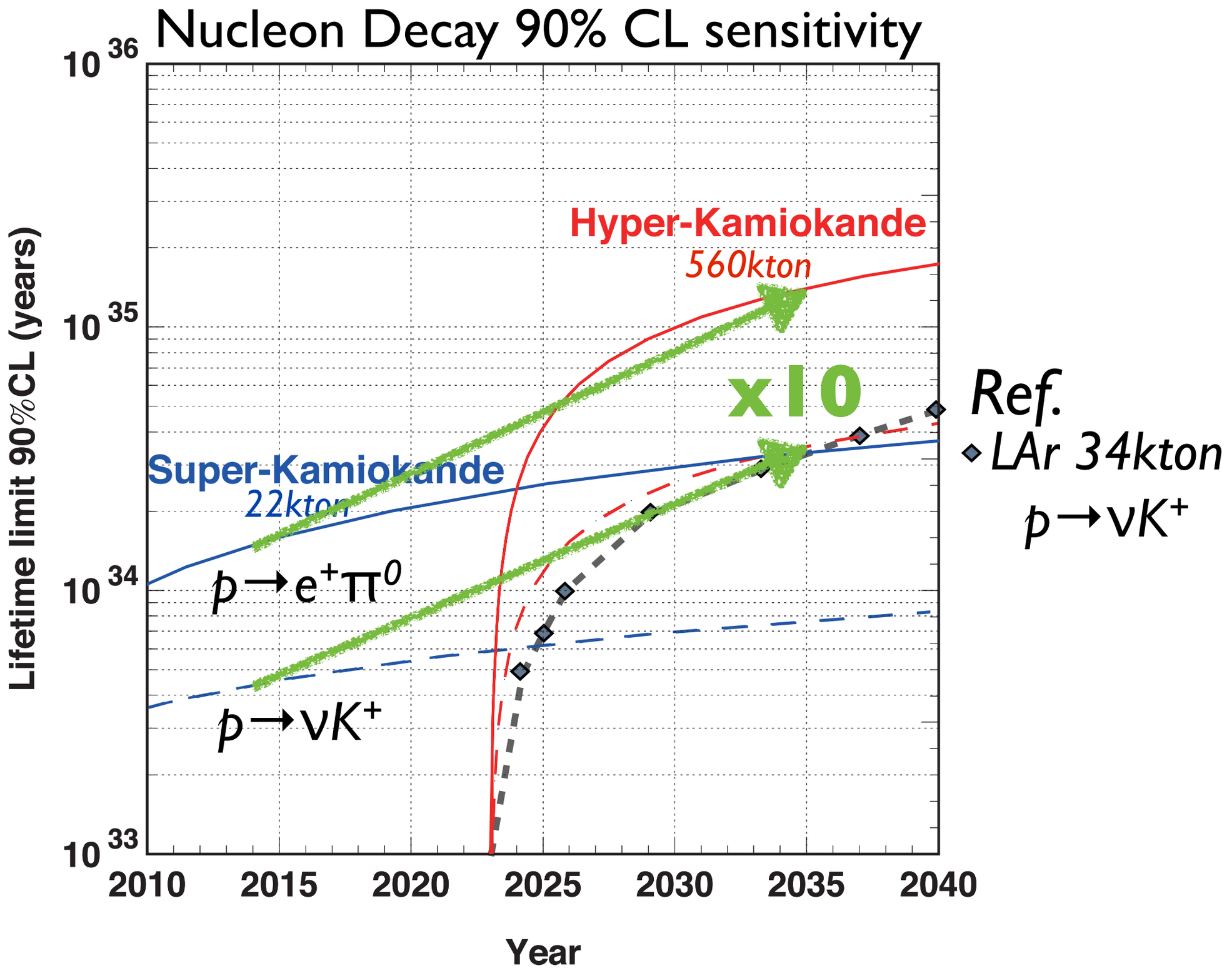
Hyper-Kamiokande Overview

Total Volume	0.99 Megaton
Inner Volume	0.74 Mton
Fiducial Volume	0.56 Mton (0.056 Mton × 10 compartments)
Outer Volume	0.2 Megaton
Photo-sensors	99,000 20”Φ PMTs for Inner Det. (20% photo-coverage) 25,000 8”Φ PMTs for Outer Det.



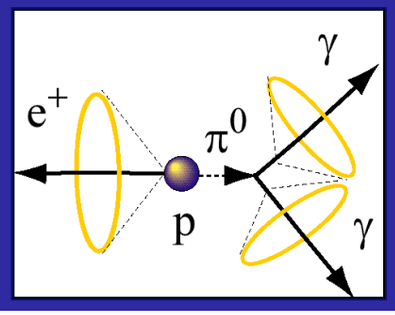
arXiv:1109.3262 [hep-ex]

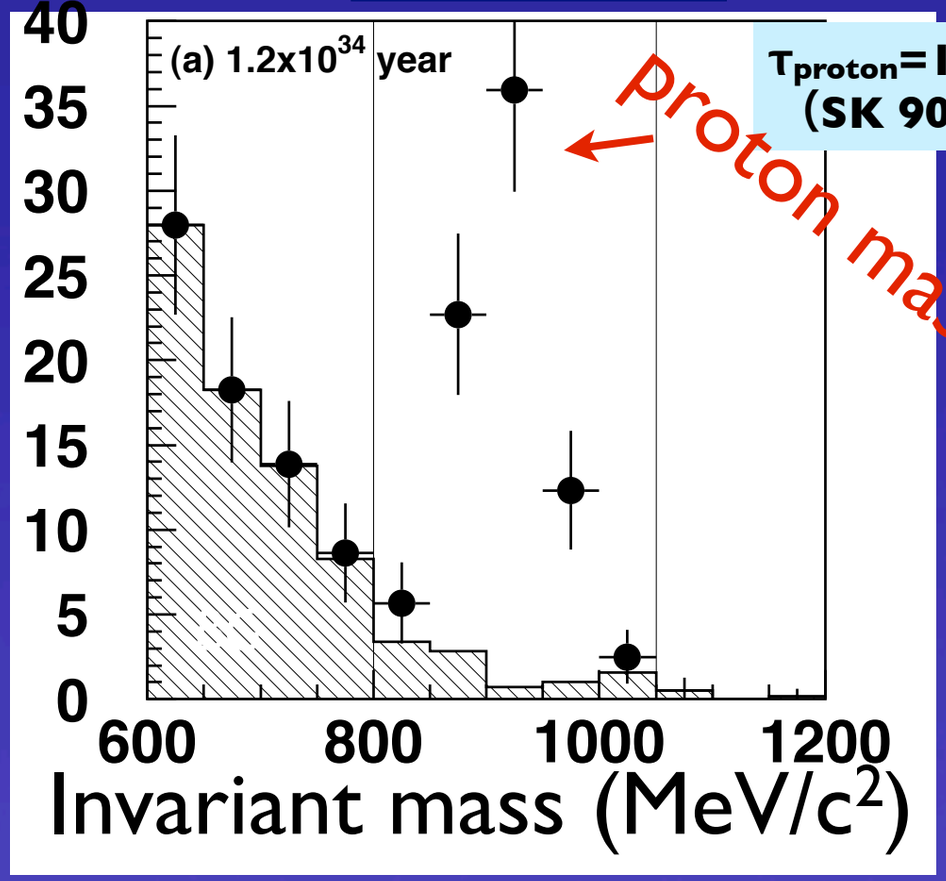
Proton Decay in Hyper-Kamiokande



GUT tests by Proton Decay Search

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



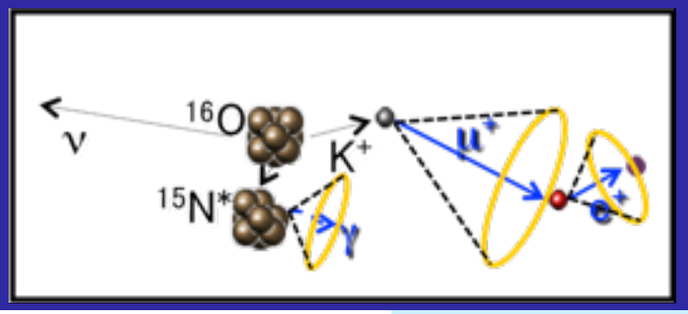


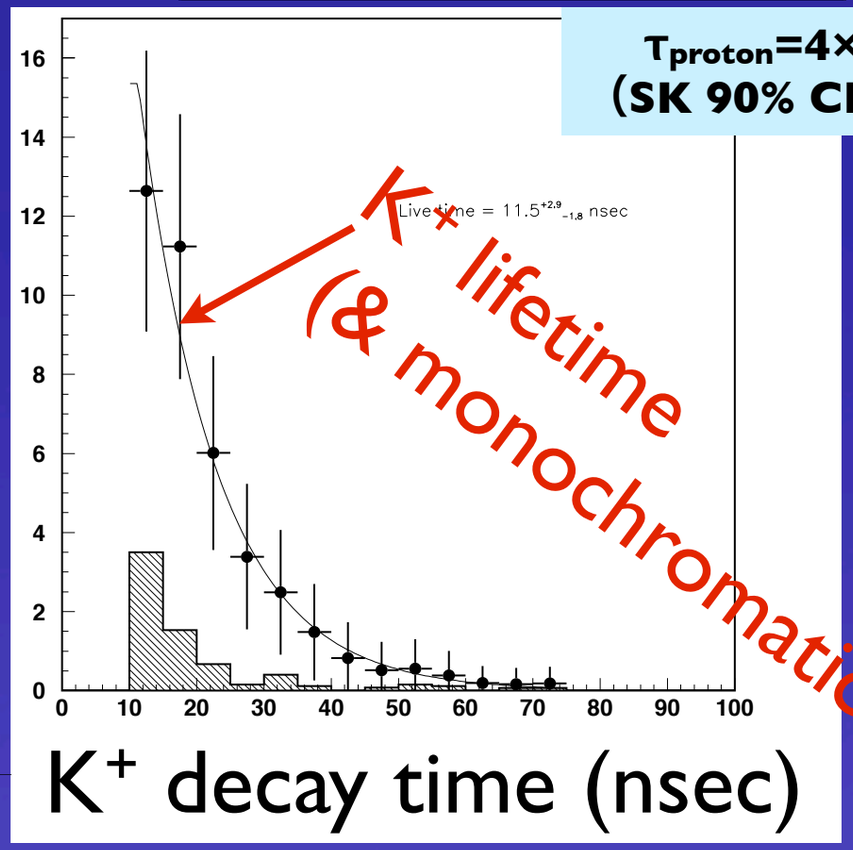
Proton mass peak

T_{proton}=1.2×10³⁴years
(SK 90% CL limit)

- Discovery reach (3σ)
  - τ(p→e⁺π⁰)~5.4×10³⁴years （HK 10yrs）
- Limit (90%CL)
  - τ(p→e⁺π⁰)>1.3×10³⁵years （HK 10yrs）

$p \rightarrow \nu K^+$





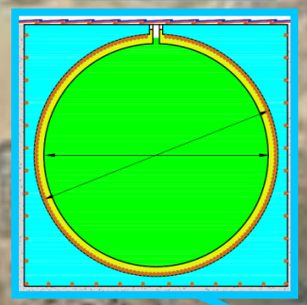
K⁺ lifetime (& monochromatic μ^+)

T_{proton}=4×10³³y
(SK 90% CL limit)

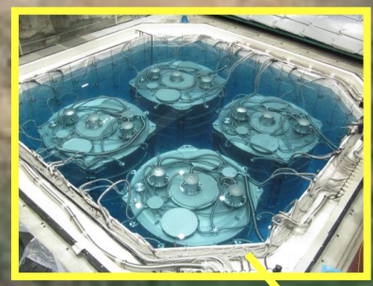
- Discovery reach (3σ)
  - τ(p→νK⁺)~1.2×10³⁴years （HK 10yrs）
- Limit (90%CL)
  - τ(p→νK⁺)>3.2×10³⁴years （HK 10yrs）

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

JUNO

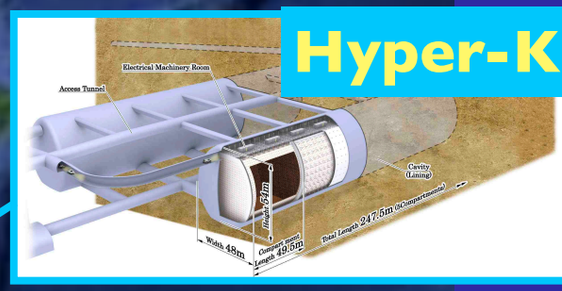


Daya Bay

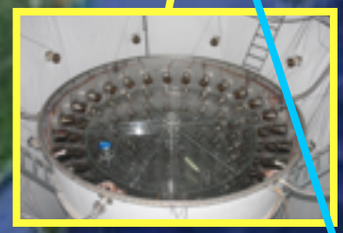


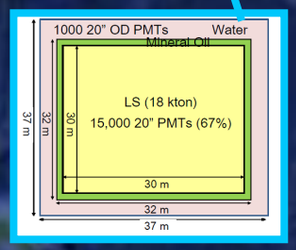
KamLAND

Hyper-K



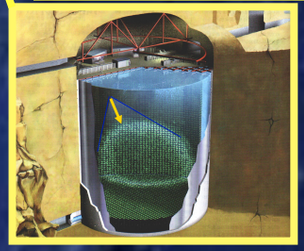
RENO





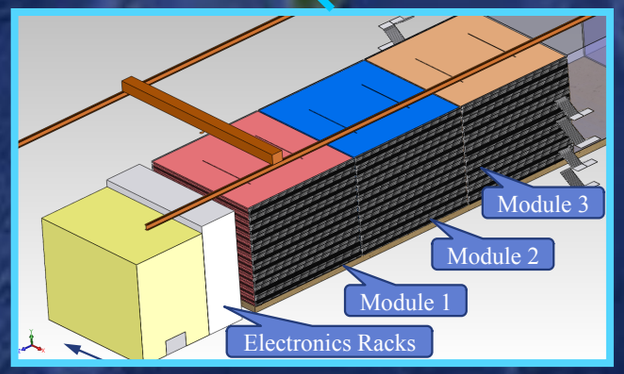
RENO50

J-PARC



Super-K

INO



Neutrino experiments in Asia

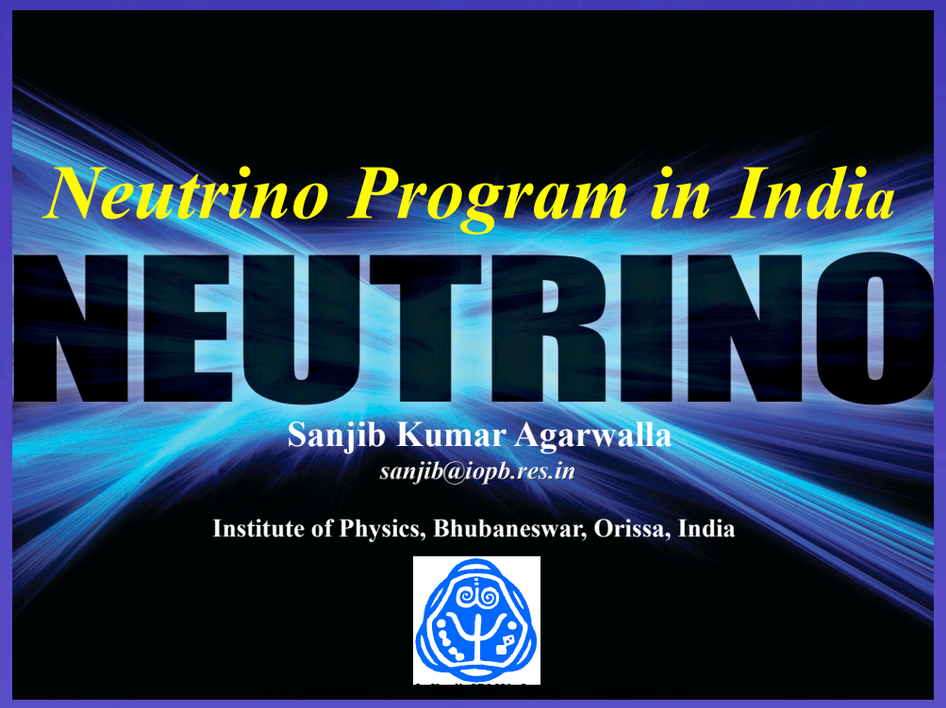
ICFA Neutrino Panel: Asian Neutrino Community Meeting (2013/11/13)

http://indico.ipmu.jp/indico/conferenceDisplay.py?ovw=True&confId=26

Neutrino Program in China

Jingyu Tang
Institute of High Energy Physics, CAS

ICFA Neutrino Panel – Asian Community Meeting
Nov.13, 2013, Kashiwa City, Chiba, Japan



Neutrino Experiments in Asia

(running experiments and future experiments)

1. China
   1. Daya Bay (reactor): θ_{13}, Δm_{ee}^2
   2. JUNO (reactor): θ_{12}, Δm_{21}^2, sign(m_{31}^2)
   3. MOMENT (muon decay): δ_{CP}
2. India
   1. INO-ICAL (atmospheric): sign(m_{31}^2), θ_{23}, Δm_{32}^2
3. Japan
   1. T2K (beam): θ_{13}, θ_{23}, Δm_{32}^2, δ_{CP}
   2. Super-K (atmospheric, solar, astro): θ_{12}, Δm_{21}^2, θ_{23}, Δm_{32}^2
   3. KamLAND (reactor, Xe $\beta\beta$): θ_{12}, Δm_{21}^2, ν-less $\beta\beta$
   4. Hyper-K (beam, atmospheric, solar, astro-origin): θ_{13}, θ_{23}, Δm_{32}^2, δ_{CP}, sign(m_{31}^2)
4. Korea
   1. RENO: θ_{13}, reactor E_ν spectrum (~5MeV)
   2. RENO-50: θ_{12}, Δm_{21}^2, sign(m_{31}^2)

Neutrino Experiments in Asia

(running experiments and future experiments)

1. China
    1. Daya Bay: running
    2. JUNO: under construction
    3. MOMENT: under planning
2. India
    1. INO-ICAL: under construction
3. Japan
    1. T2K: running (w/ accelerator upgrade planned)
    2. Super-K: running
    3. KamLAND: running
    4. Hyper-K: Funding for R&D is available. A full proposal is being prepared for negotiation with funding agency
4. Korea
    1. RENO: running
    2. RENO-50: a proposal for R&D is submitted. A full funding is under request.

Neutrino Experiments in Asia

1. There are several running and future neutrino projects in Asia.
2. A strategy of Asia stands on rich and well-balanced INTERNATIONAL programs hosted in individual countries. We will support each other.
   1. China: Daya Bay -> JUNO, MOMENT
   2. India: INO-ICAL
   3. Japan: SK/T2K -> Hyper-K, KamLAND
   4. Korea: RENO -> RENO50

Neutrino Experiments in Asia

(running experiments and future experiments w/ accelerators)

1. China
   1. Daya Bay
   2. JUNO
   3. MOMENT
2. India
   1. INO-ICAL
3. Japan
   1. T2K
   2. Super-K
   3. KamLAND
   4. Hyper-K
4. Korea
   1. RENO
   2. RENO-50

From Report on ICFA Asian Neutrino Community Meeting (2014/2/15)

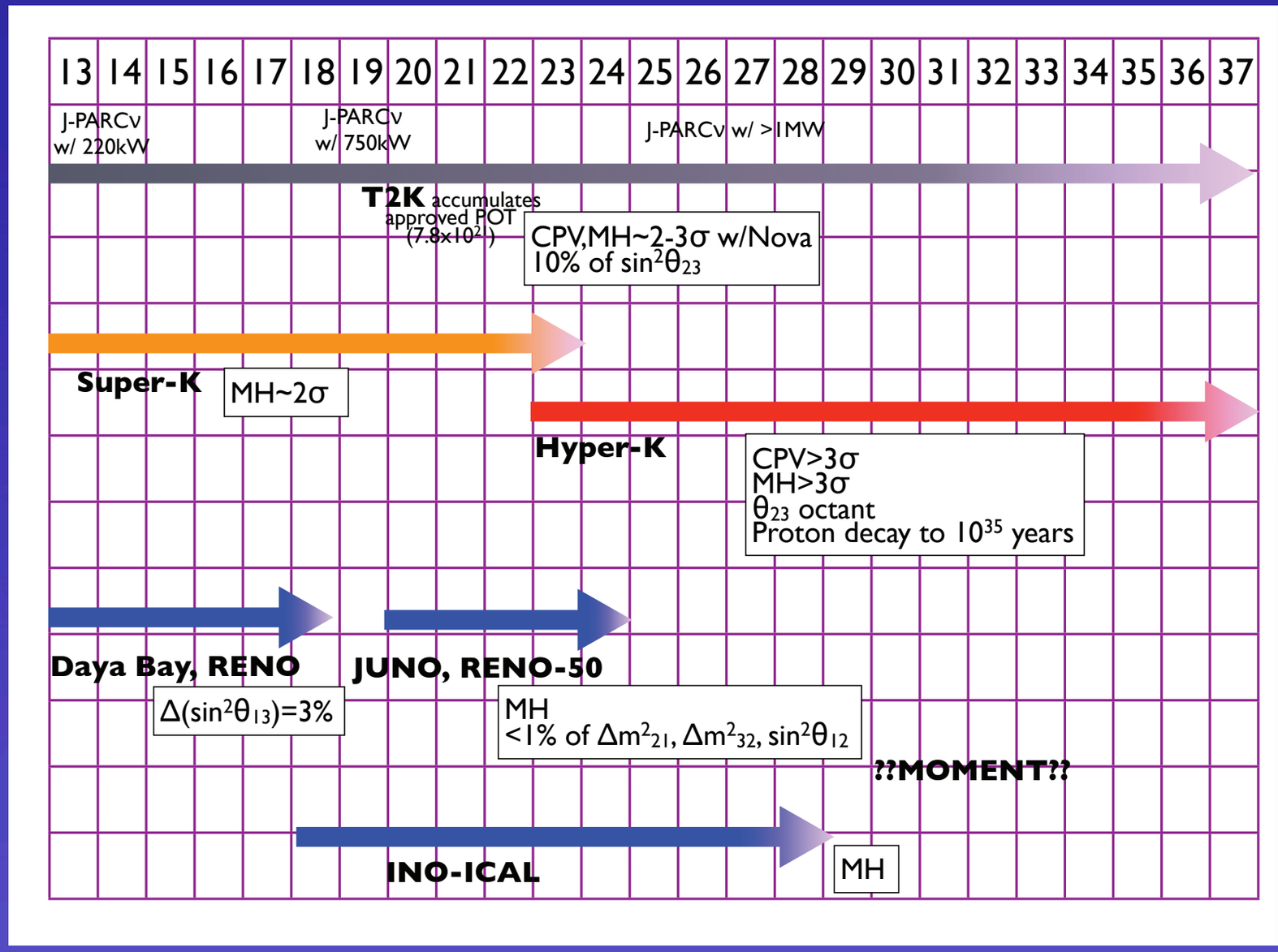
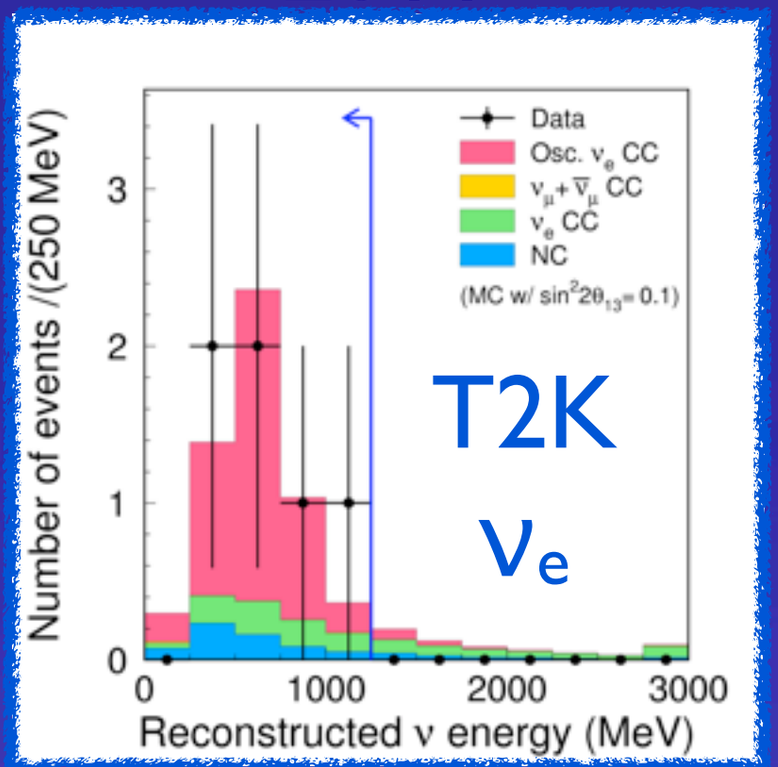


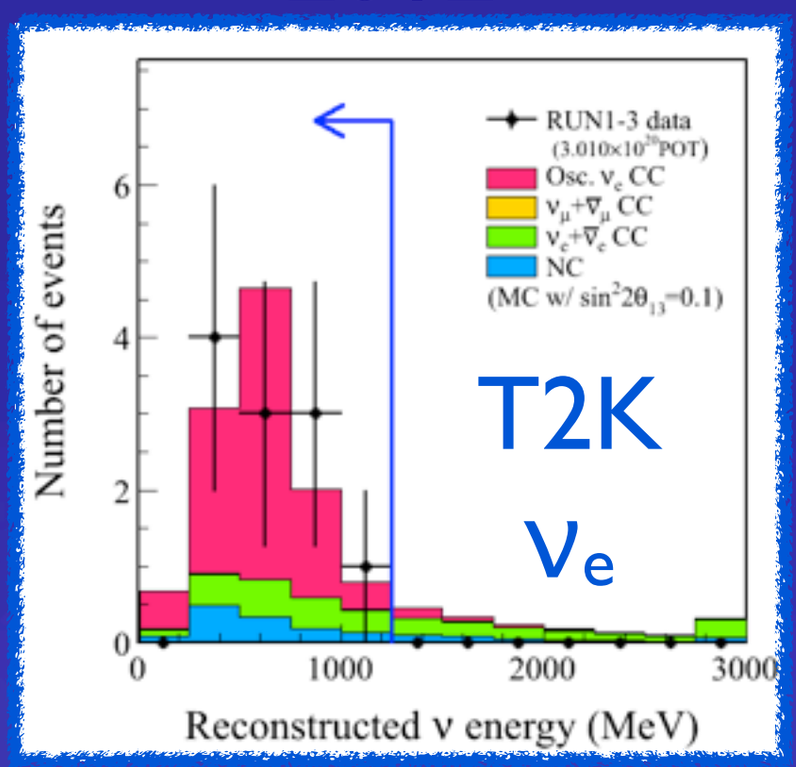
Figure 1: Working timeline of neutrino oscillation experiments in Asia and their expected sensitivities.

Large θ_{13} opens the window to study CPV

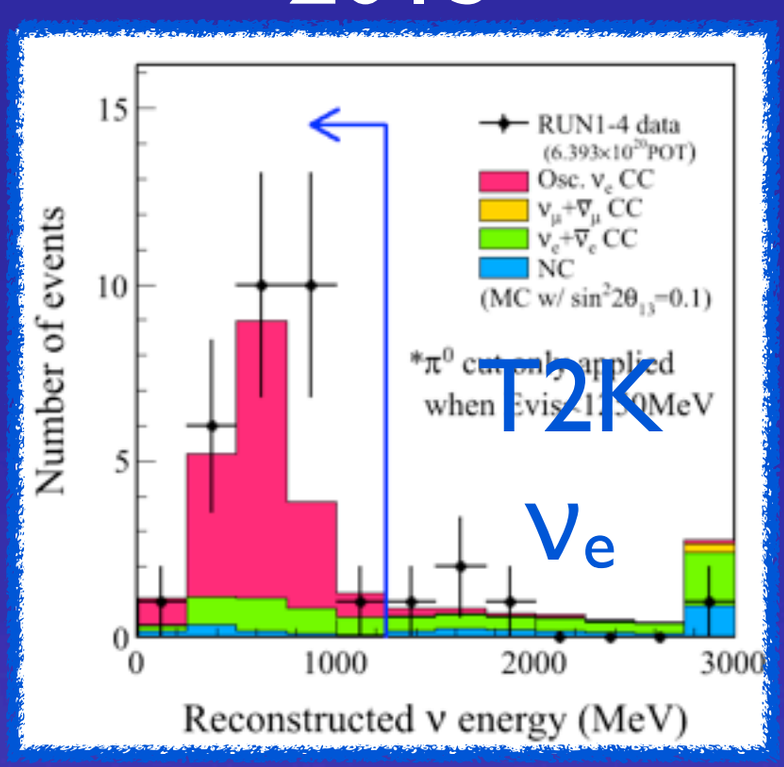
2011

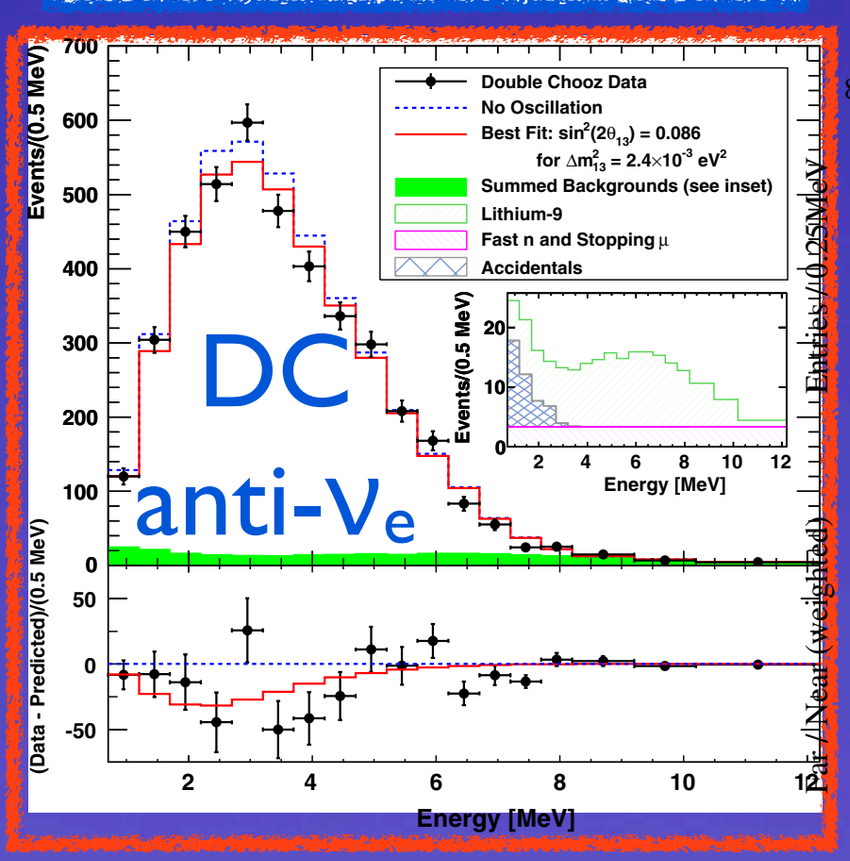


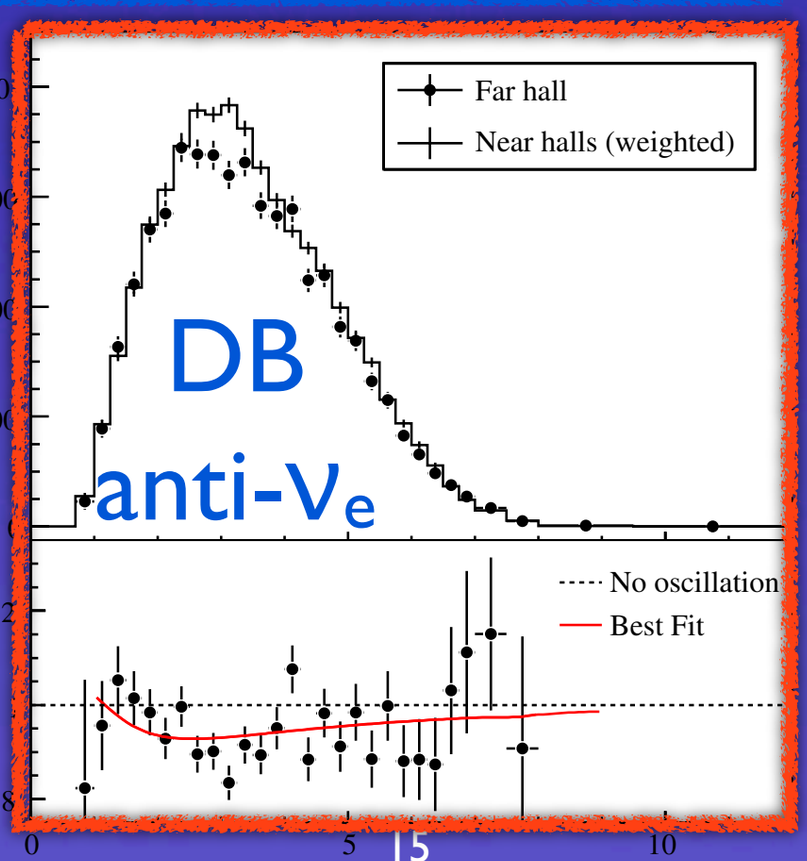
2012

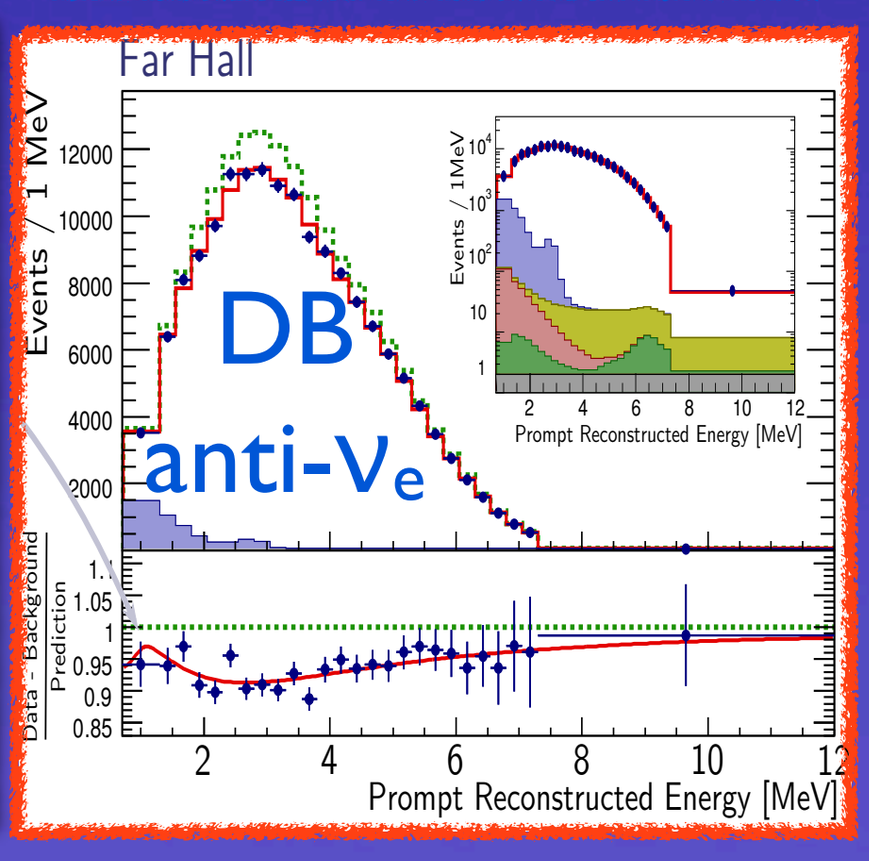


2013









CP violation in 3 generation mixing

$$
\begin{aligned}
P(\nu_\mu \to \nu_e) \;=\;& 4C_{13}^2 S_{13}^2 S_{23}^2 \cdot \sin^2 \Delta_{31} \\
&+8C_{13}^2 S_{12} S_{13} S_{23}(C_{12}C_{23}\cos\delta - S_{12}S_{13}S_{23}) \cdot \cos\Delta_{32} \cdot \sin\Delta_{31} \cdot \sin\Delta_{21} \\
&-8C_{13}^2 C_{12} C_{23} S_{12} S_{13} S_{23} \sin\delta \cdot \sin\Delta_{32} \cdot \sin\Delta_{31} \cdot \sin\Delta_{21} \\
&+4S_{12}^2 C_{13}^2 (C_{12}^2 C_{23}^2 + S_{12}^2 S_{23}^2 S_{13}^2 - 2C_{12}C_{23}S_{12}S_{23}S_{13}\cos\delta) \cdot \sin^2\Delta_{21} \\
&-8C_{13}^2 S_{12}^2 S_{23}^2 \cdot \frac{aL}{4E_\nu}(1-2S_{13}^2) \cdot \cos\Delta_{32} \cdot \sin\Delta_{31} \\
&+8C_{13}^2 S_{13}^2 S_{23}^2 \frac{a}{\Delta m_{13}^2}(1-2S_{13}^2)\sin^2\Delta_{31}
\end{aligned}
$$

Leading $\sin^2\theta_{23}\sin^2 2\theta_{13}\sin^2\left(\frac{\Delta m_{31}^2 L}{4E}\right)$

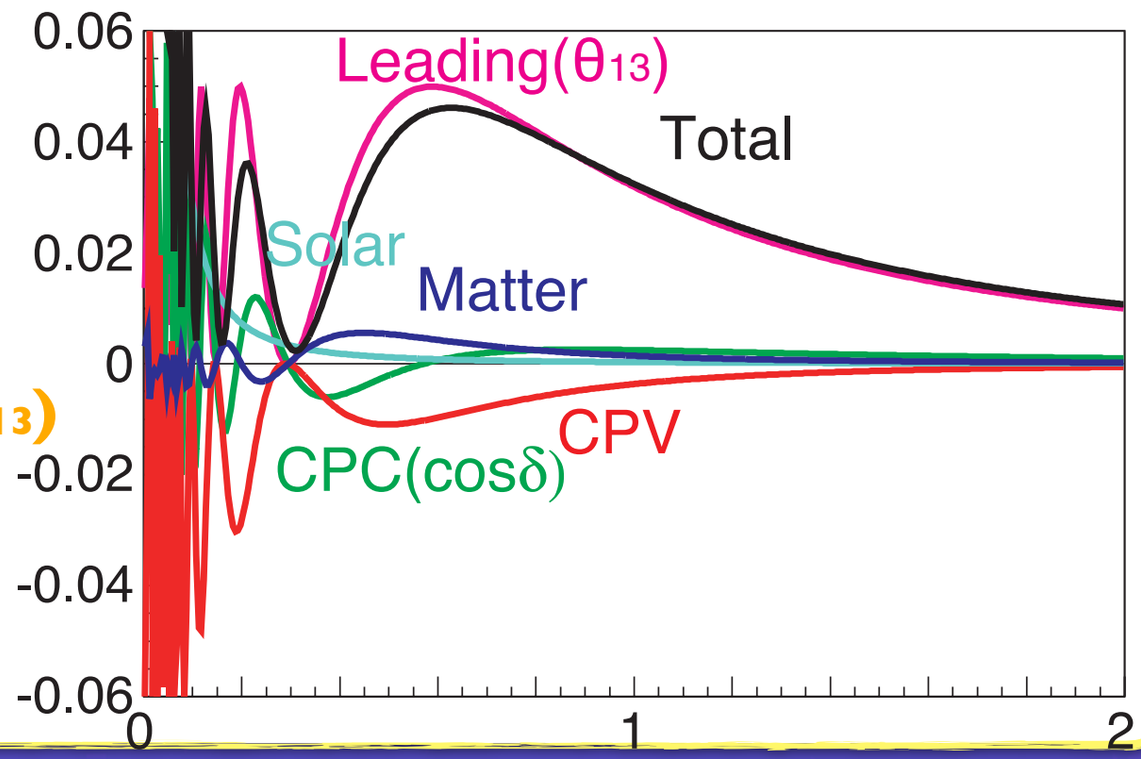
CPV

$$\frac{\sin 2\theta_{12}\sin 2\theta_{23}}{2\sin\theta_{13}}\sin^2 2\theta_{13}\sin^2\frac{\Delta m_{31}^2 L}{4E}\sin\frac{\Delta m_{21}^2 L}{4E}\sin\delta$$

$$\sim \frac{\pi}{4}\frac{\Delta m_{21}^2}{\Delta m_{32}^2}\frac{\sin 2\theta_{12}\sin 2\theta_{23}}{\sin^2\theta_{23}\sin\theta_{13}}\frac{E_{1st\max}}{E}[leading]\sin\delta$$

~0.03 ~11.8 (6.4 from $1/\sin\theta_{13}$)

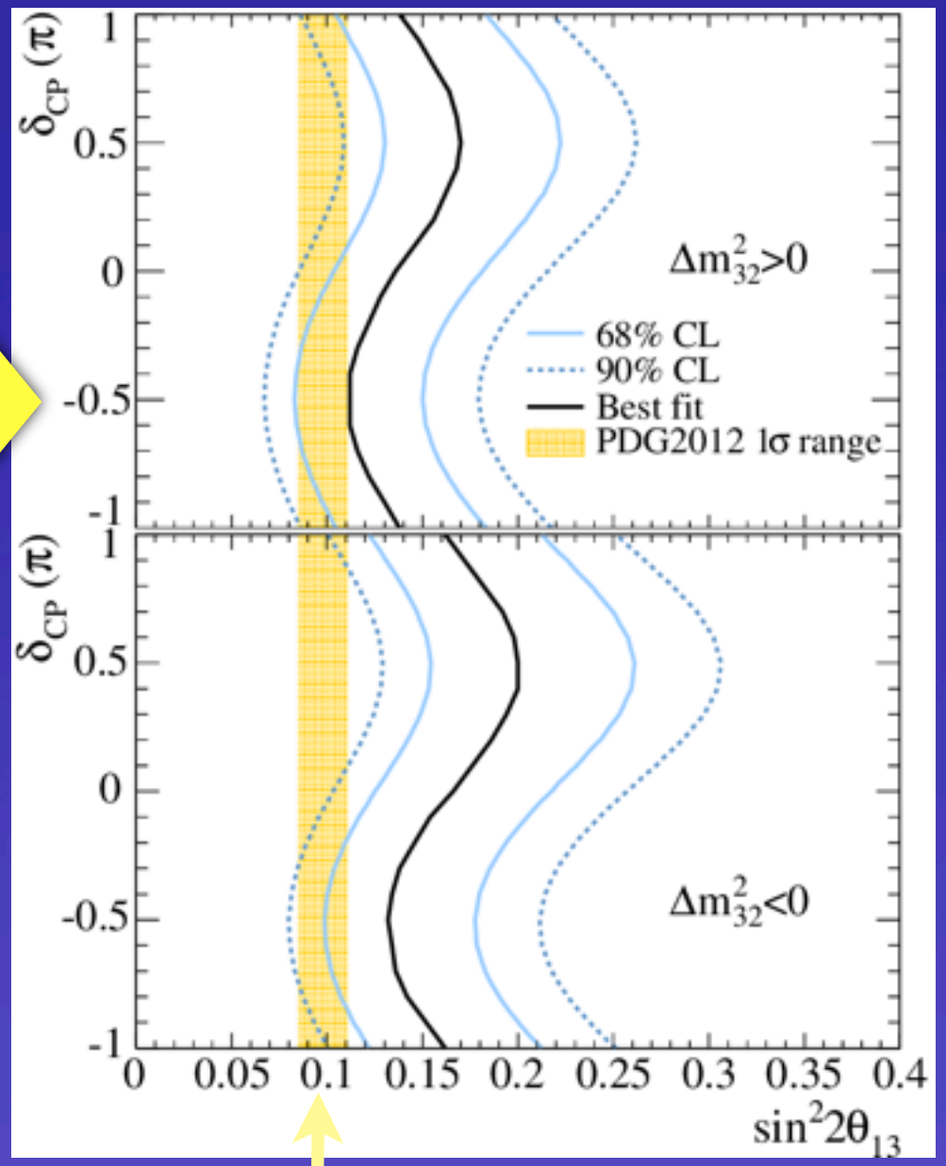
$$\sim 0.27 \times [leading] \times \frac{E_{1st\max}}{E} \times \sin\delta$$



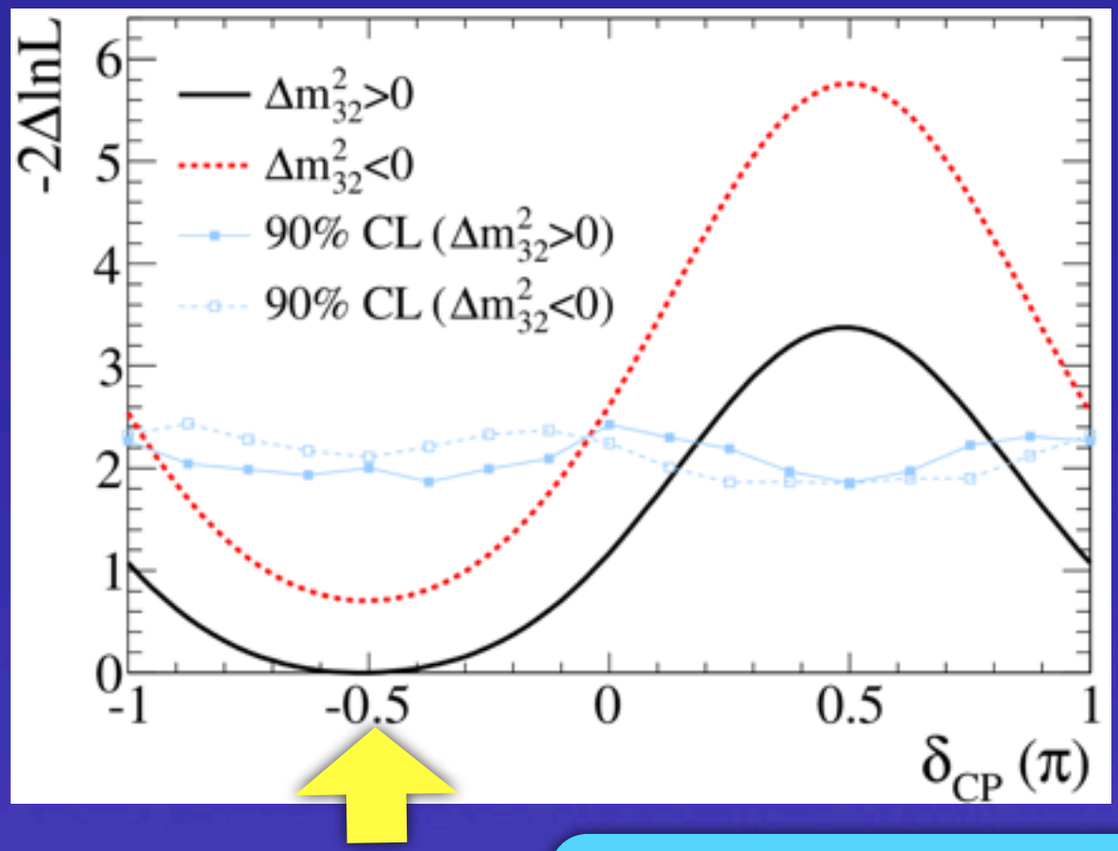
Precision of all parameters are important for δ

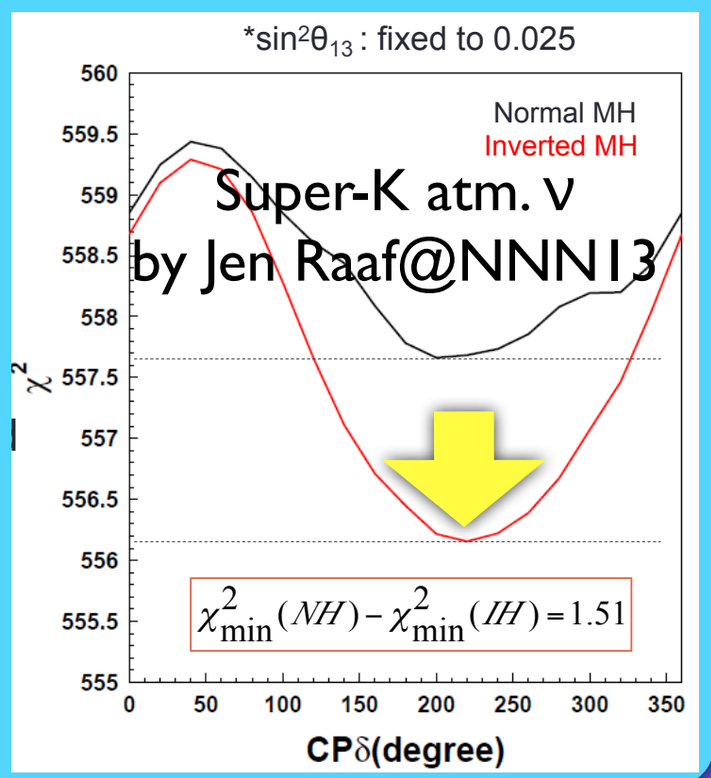
δ_{CP}~$-\pi/2$? from SK/T2K

T2K (PRL **112**, 061802 (2014))



reactor θ_{13} 2012

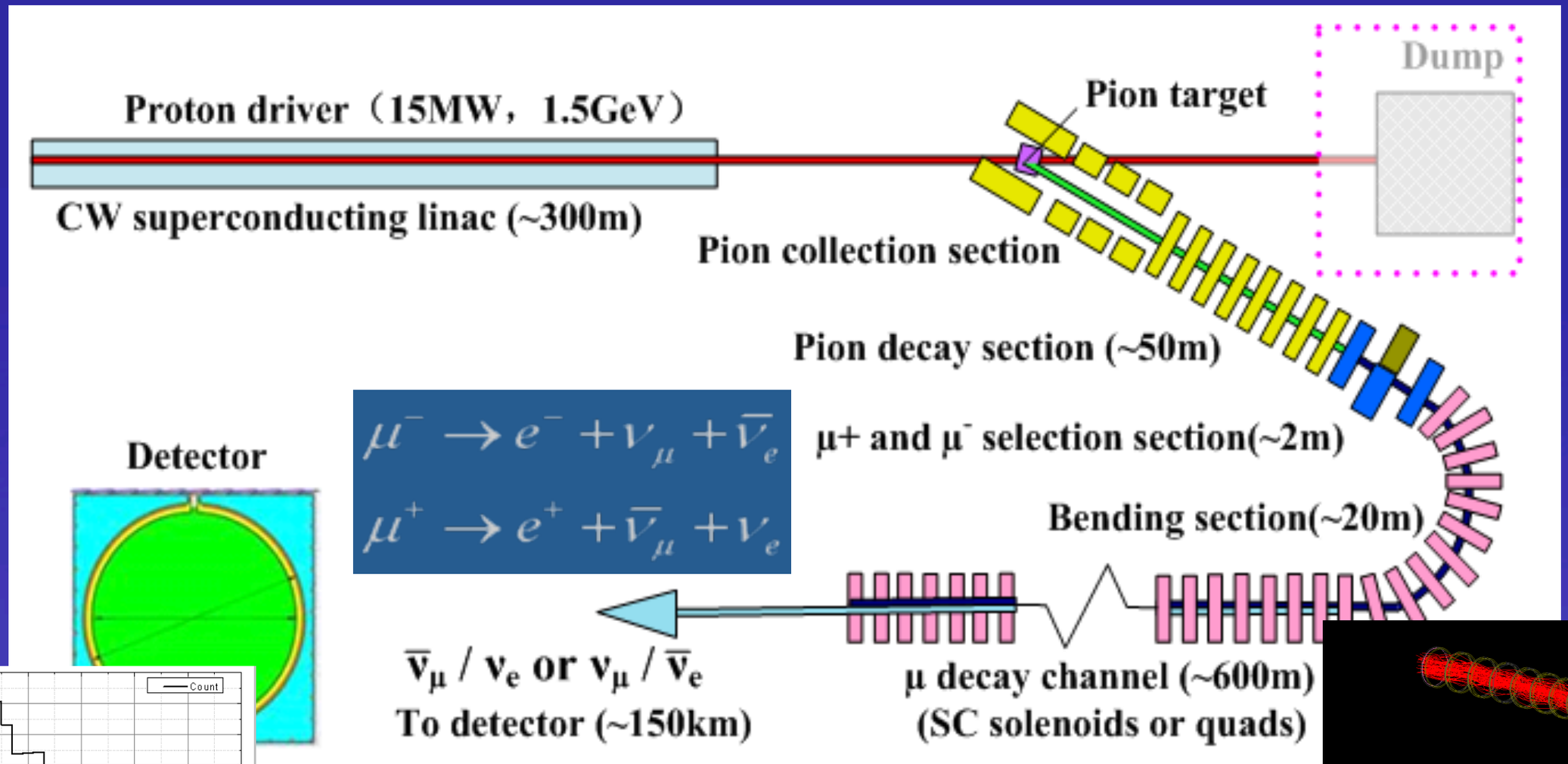


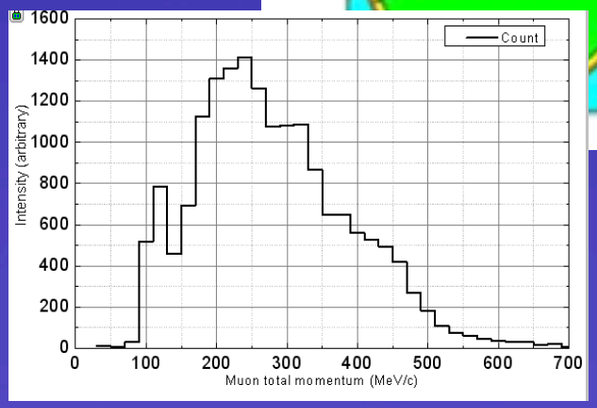


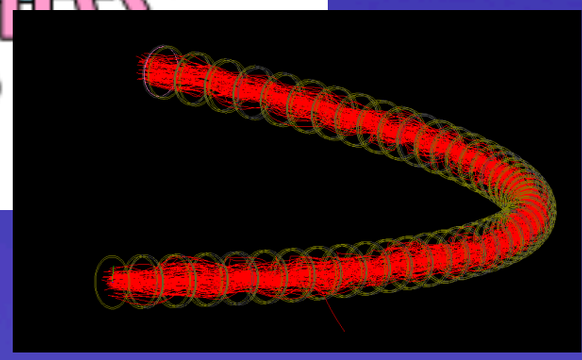
Accelerator based Neutrino Experiments in Asia

1. **China**
    1. MOMENT
        1. a muon-decay medium baseline neutrino beam
    2. RENO50
        1. Can detect the J-PARC neutrino beam.
3. **Japan**
    1. T2K (on-going)
        1. J-PARC to Super-K
    2. Hyper-K and future projects
        1. 1 Mton Water Cherenkov Detector at Kamioka w/ J-PARC
        2. Accelerator R&D, and Advanced detector R&D

MOMENT: A muon-decay medium baseline neutrino beam facility

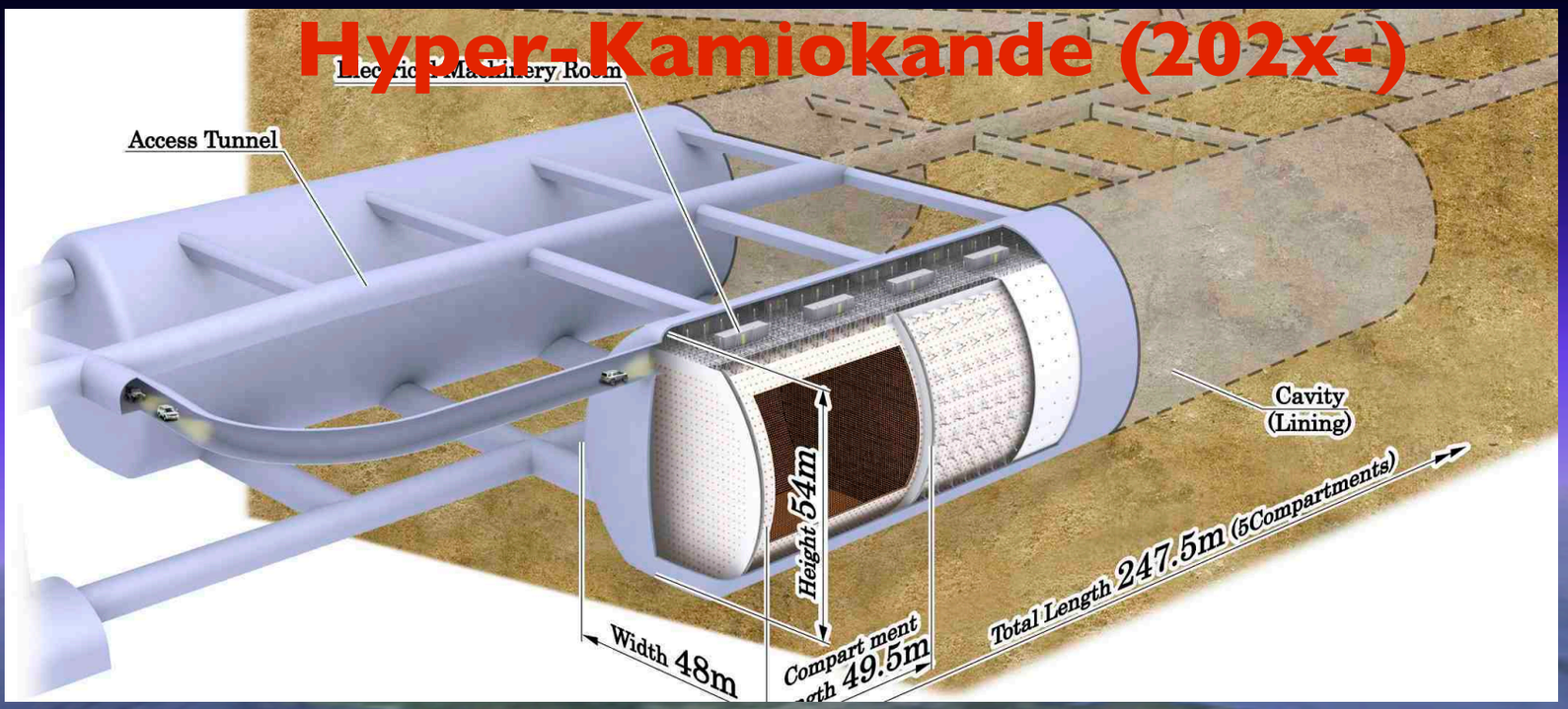




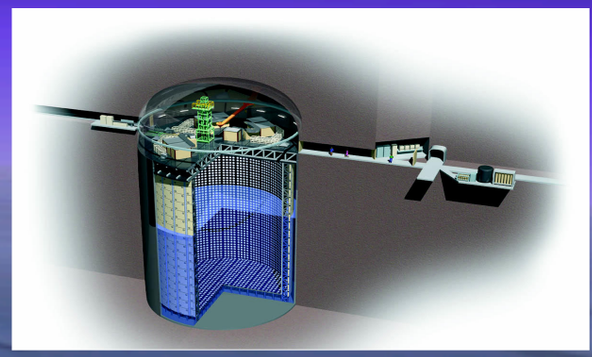


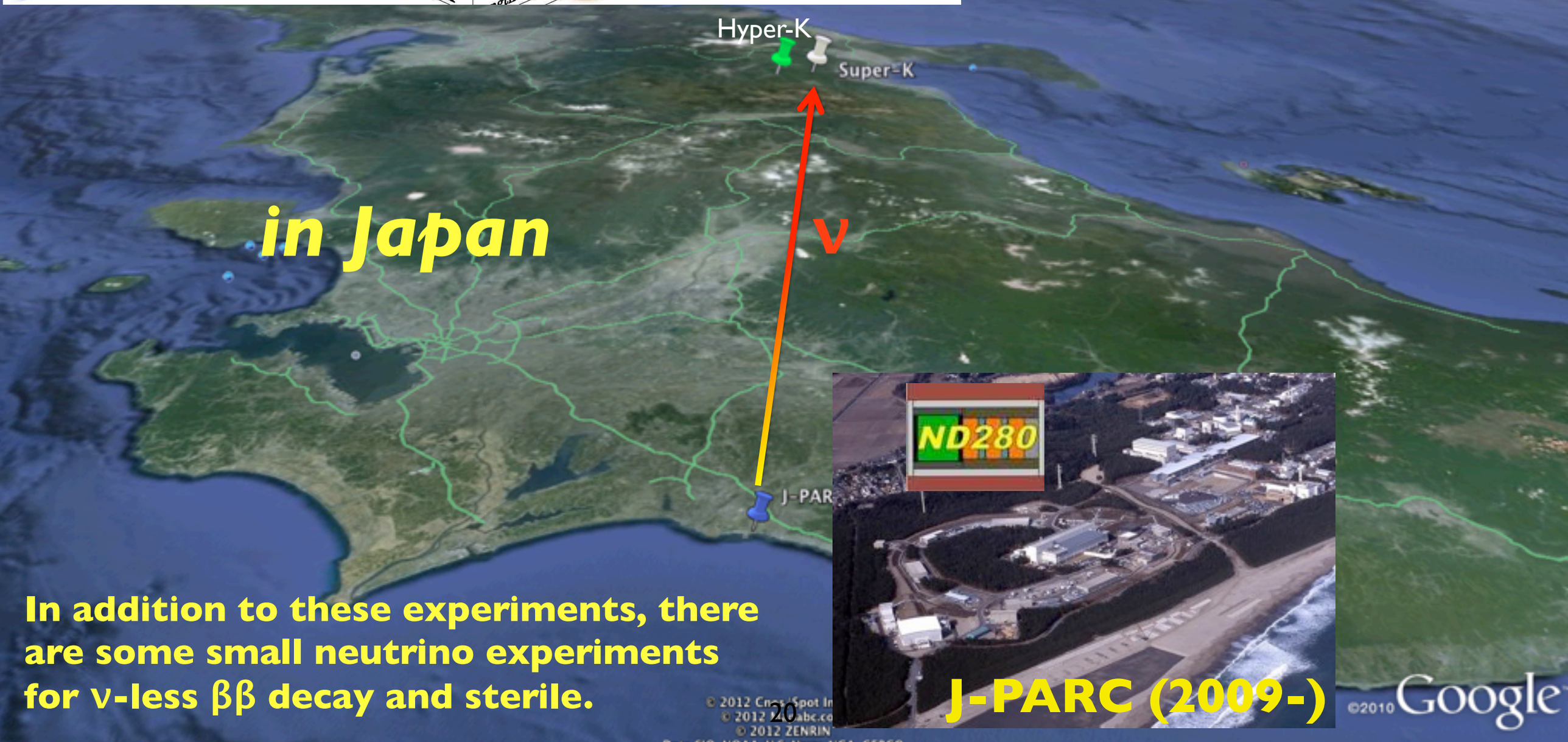
- MOMENT is still a concept.
  - Design studies are on-gong.
  - May be the first Neutrino Factory.

Hyper-Kamiokande (202x-)



Super-Kamiokande (1996-)





In addition to these experiments, there are some small neutrino experiments for ν-less ββ decay and sterile.

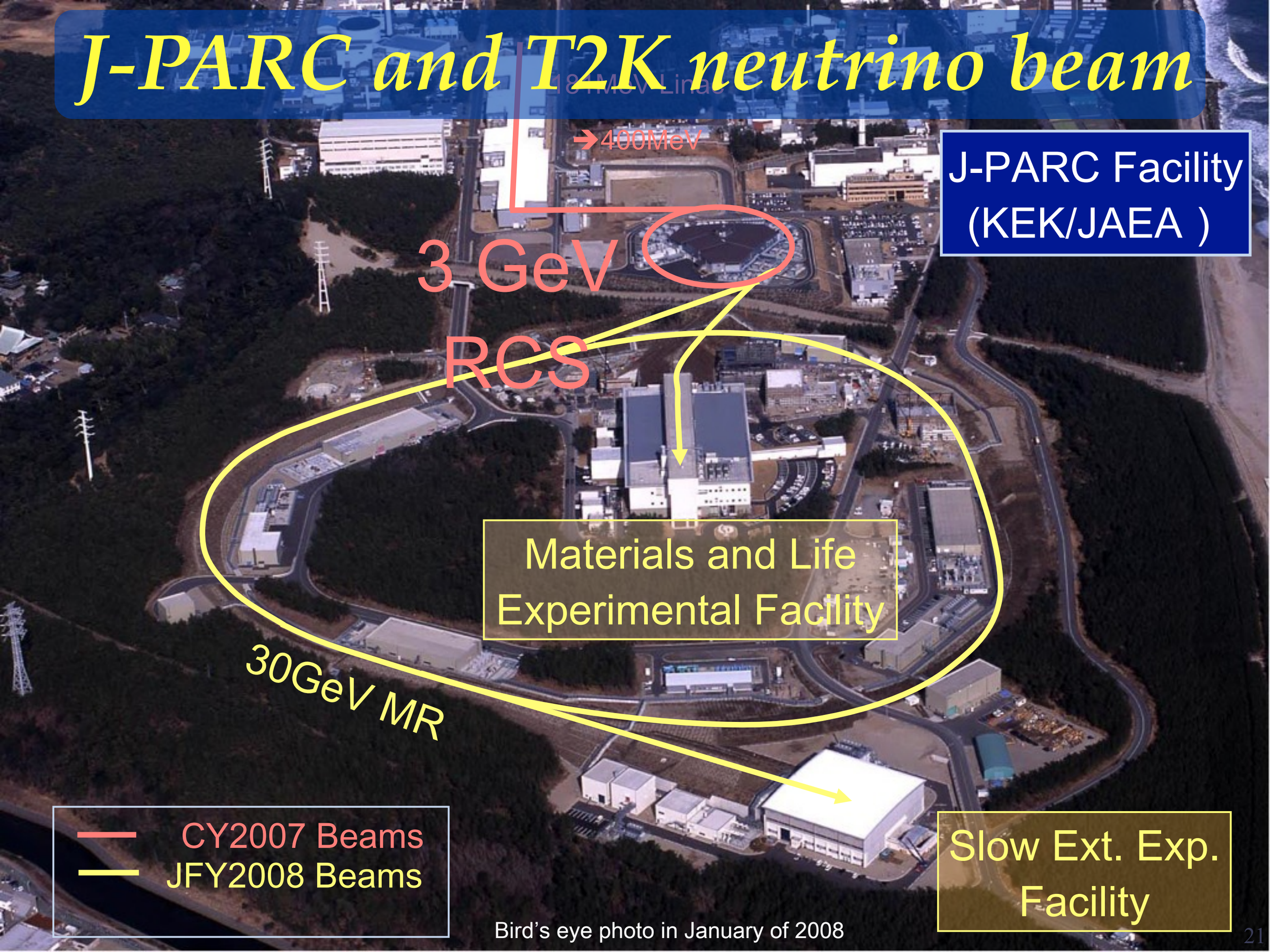
J-PARC and T2K neutrino beam

Bird's eye photo in January of 2008

J-PARC and T2K neutrino beam

Bird's eye photo in January of 2008

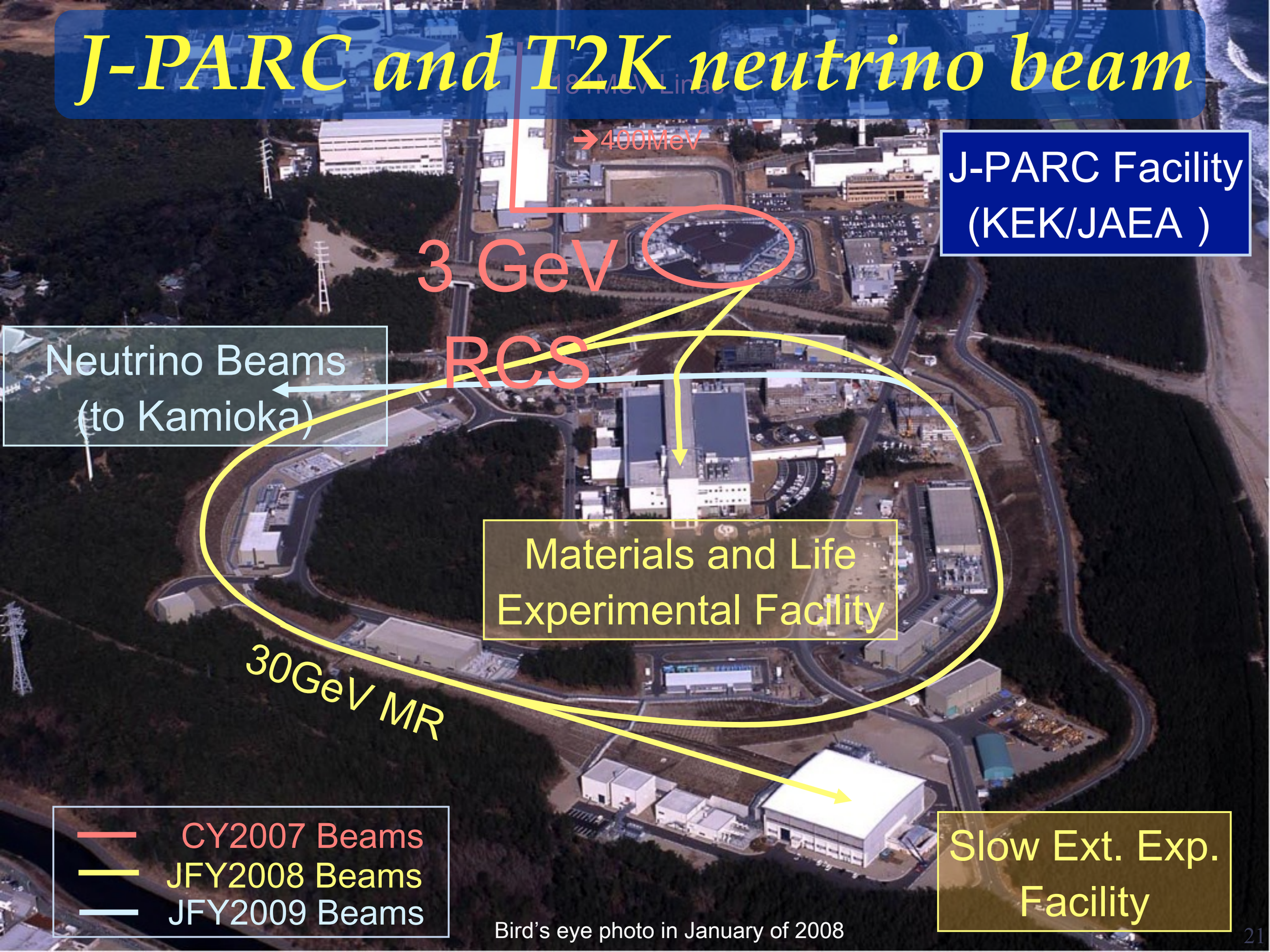
J-PARC and T2K neutrino beam



J-PARC Facility
(KEK/JAEA)

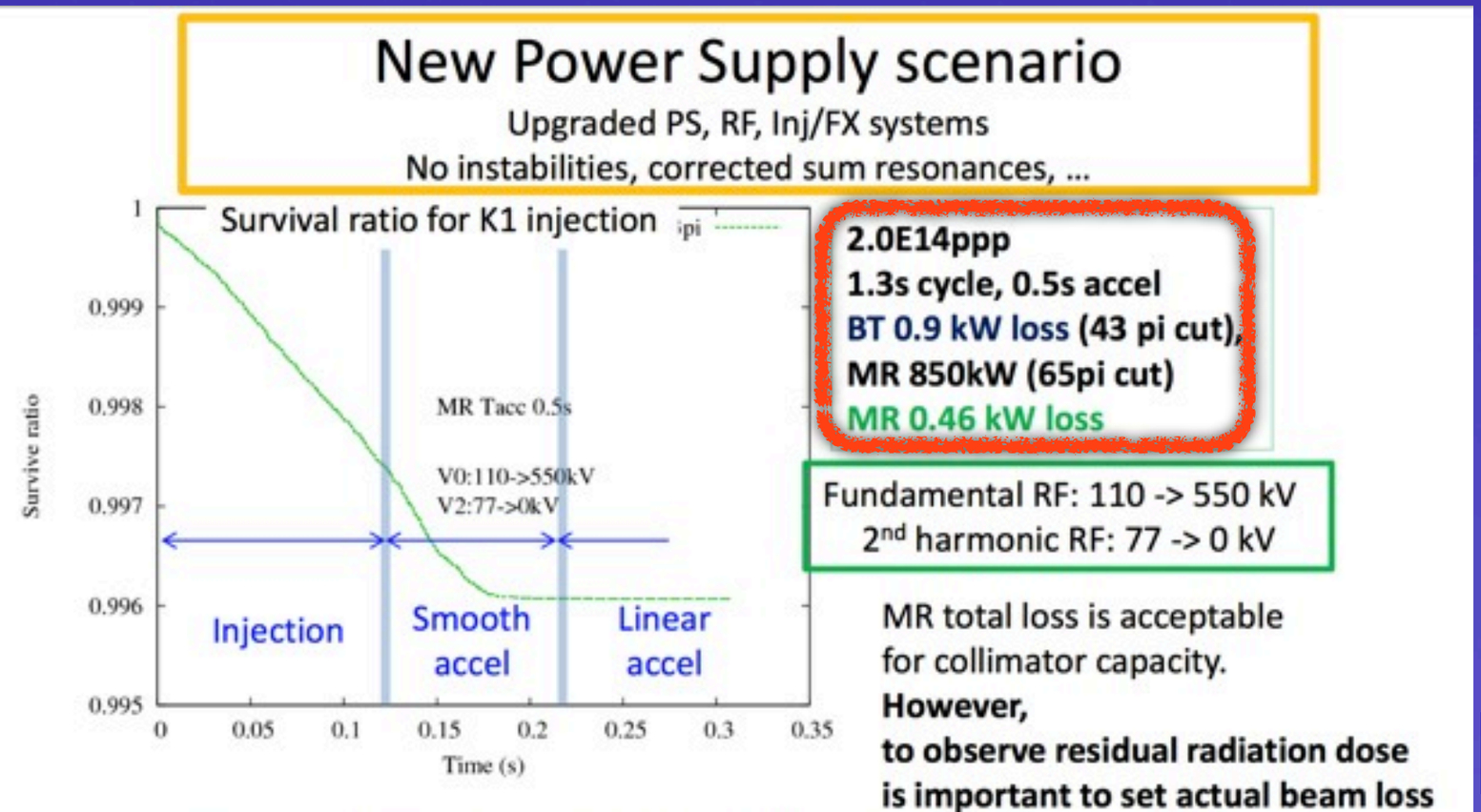
Bird's eye photo in January of 2008

J-PARC and T2K neutrino beam



J-PARC (High Power Proton Accelerator)

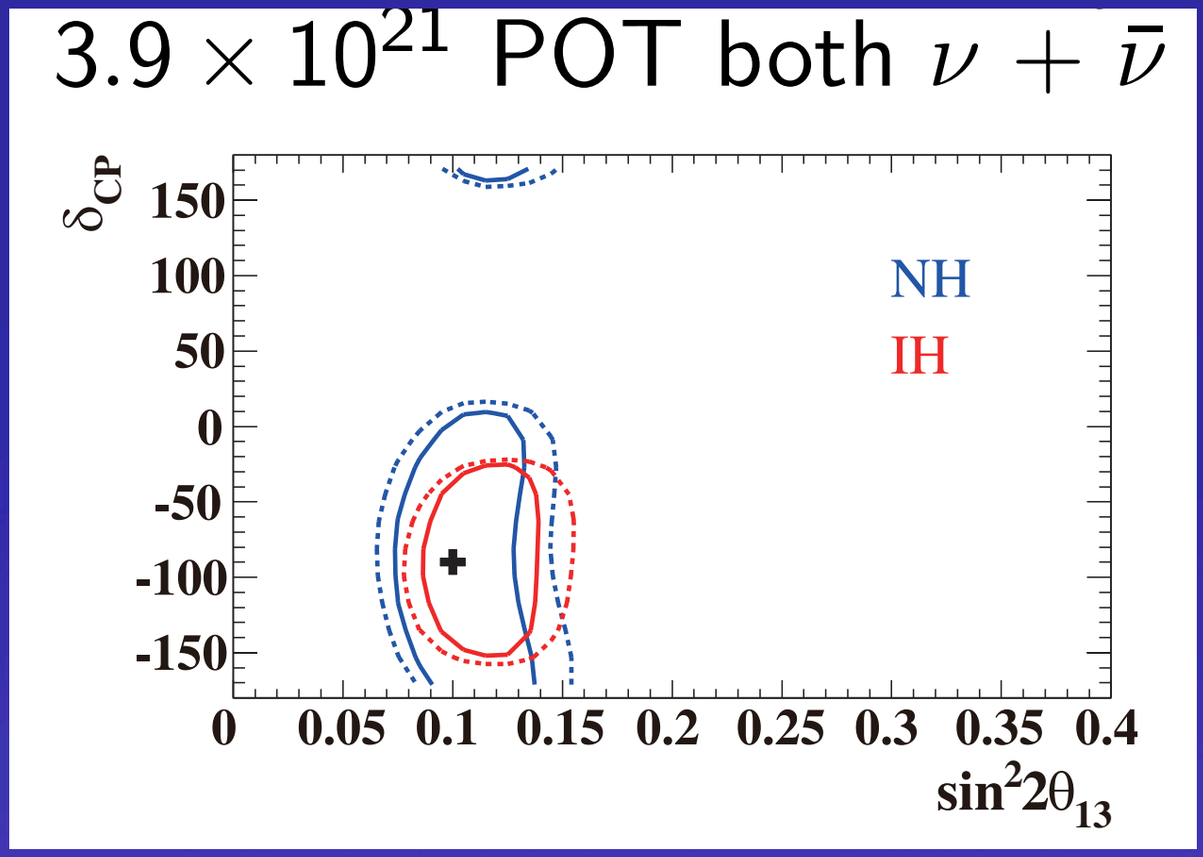
1. LINAC (400 MeV, 25Hz, 50mA peak current)
   1. 30 mA peak current now. -> upgrade in 2014
2. RCS (3 GeV, 25Hz, 1.0 MW)
   1. 600 kW operation demonstrated with 180 MeV injection.
   2. 300kW stable operation
3. MR (30 GeV, 1.3Hz, 0.75MW)
   1. 230 kW achieved with 1.2E14 protons/pulse
   2. In 2017, the magnet power supply and high gradient RF core upgrade are planned for 750 kW design.

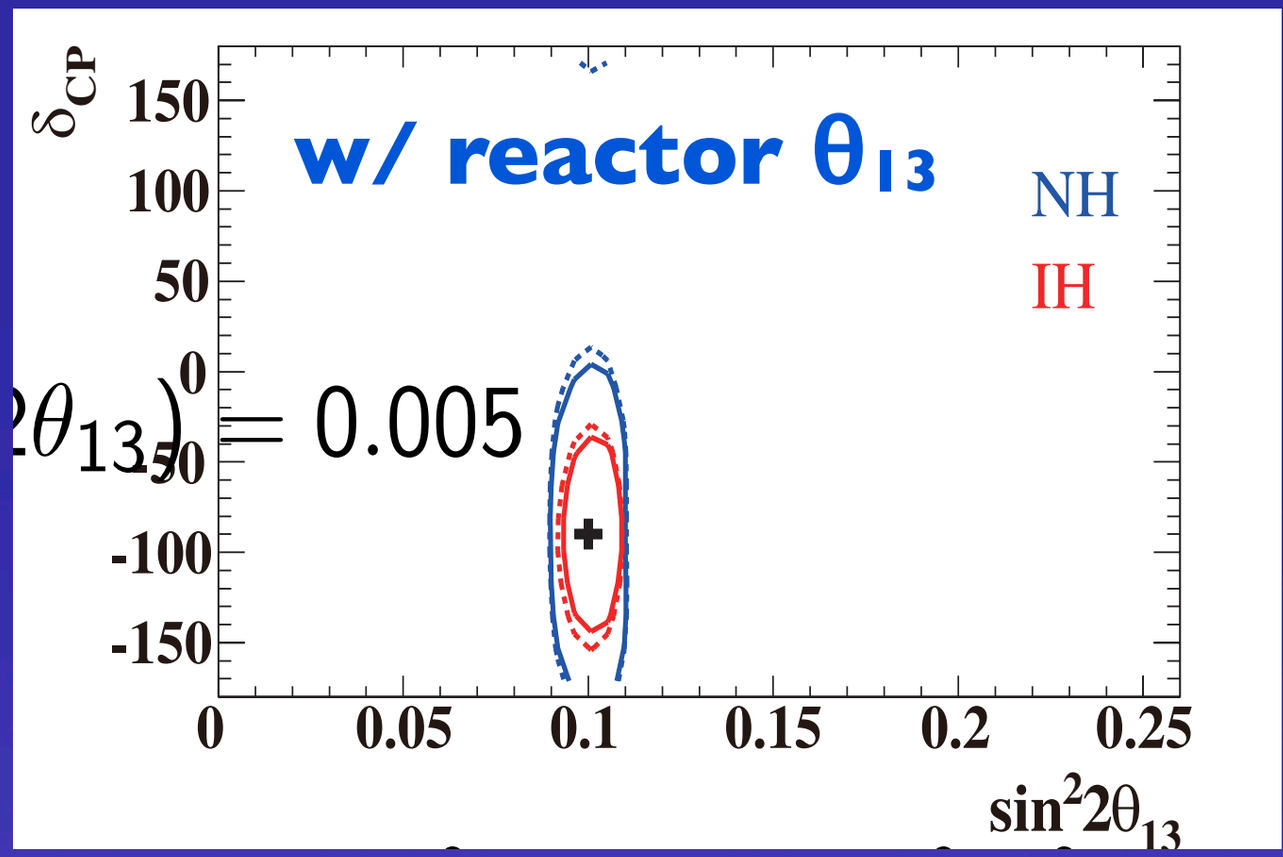


- **>750kW** can be reached in simulation with measurement inputs and realistic assumption.
- Seeking yet better operation point.

By Y.Sato, Feb.2014

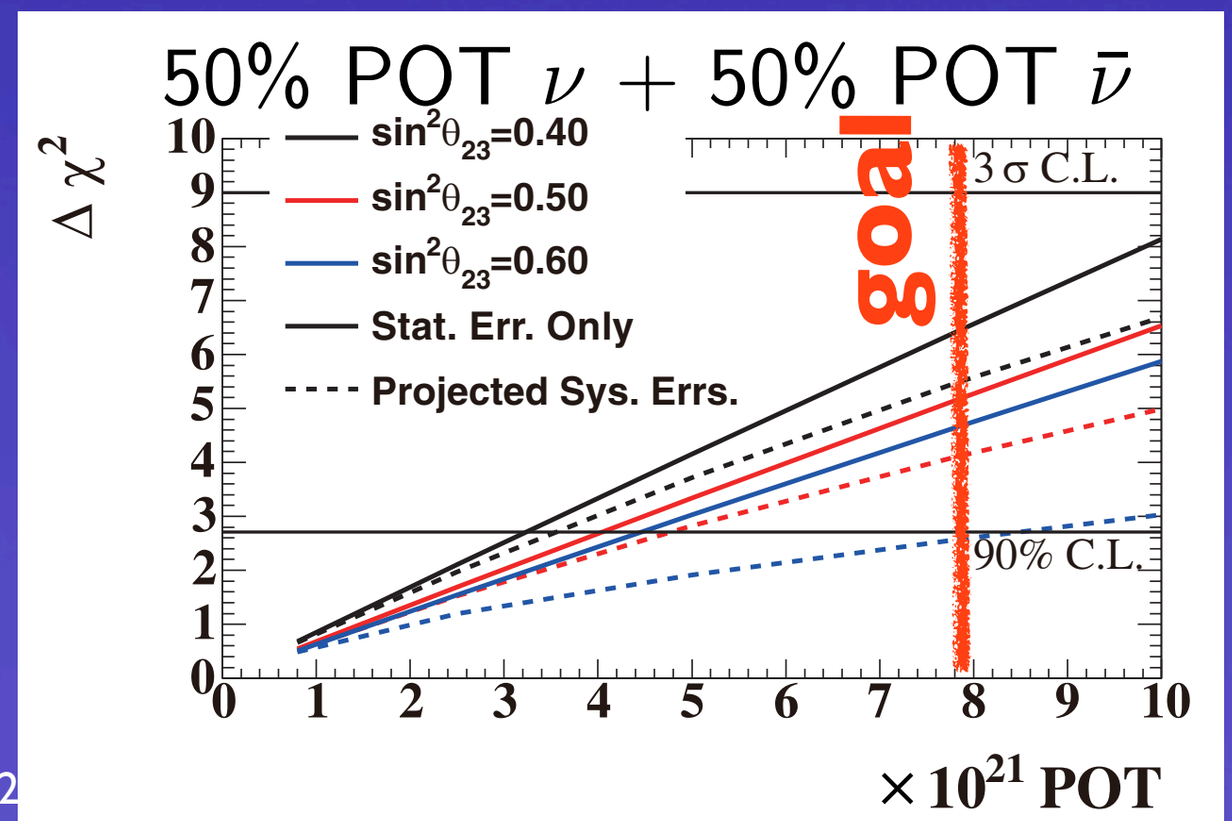
T2K future sensitivity for δ_{CP}



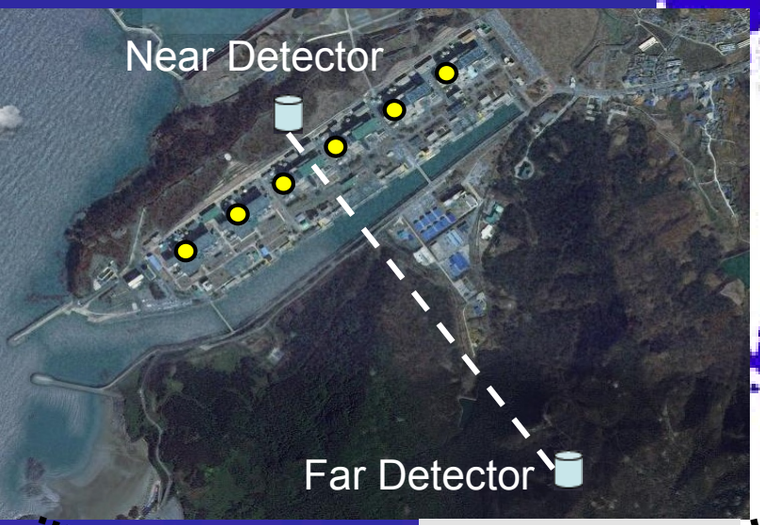


$\sin^2\theta_{13}$=0.1, δ_{CP}=-90°, $\sin^2\theta_{23}$=0.5, Δm^2_{32}=2.4E^{-3}eV^2

- Expect >10 times more data.
- In some cases, the CPV sensitivity will reach ~2σ level.



Neutrino beam in Korea



(NEAR Detector)

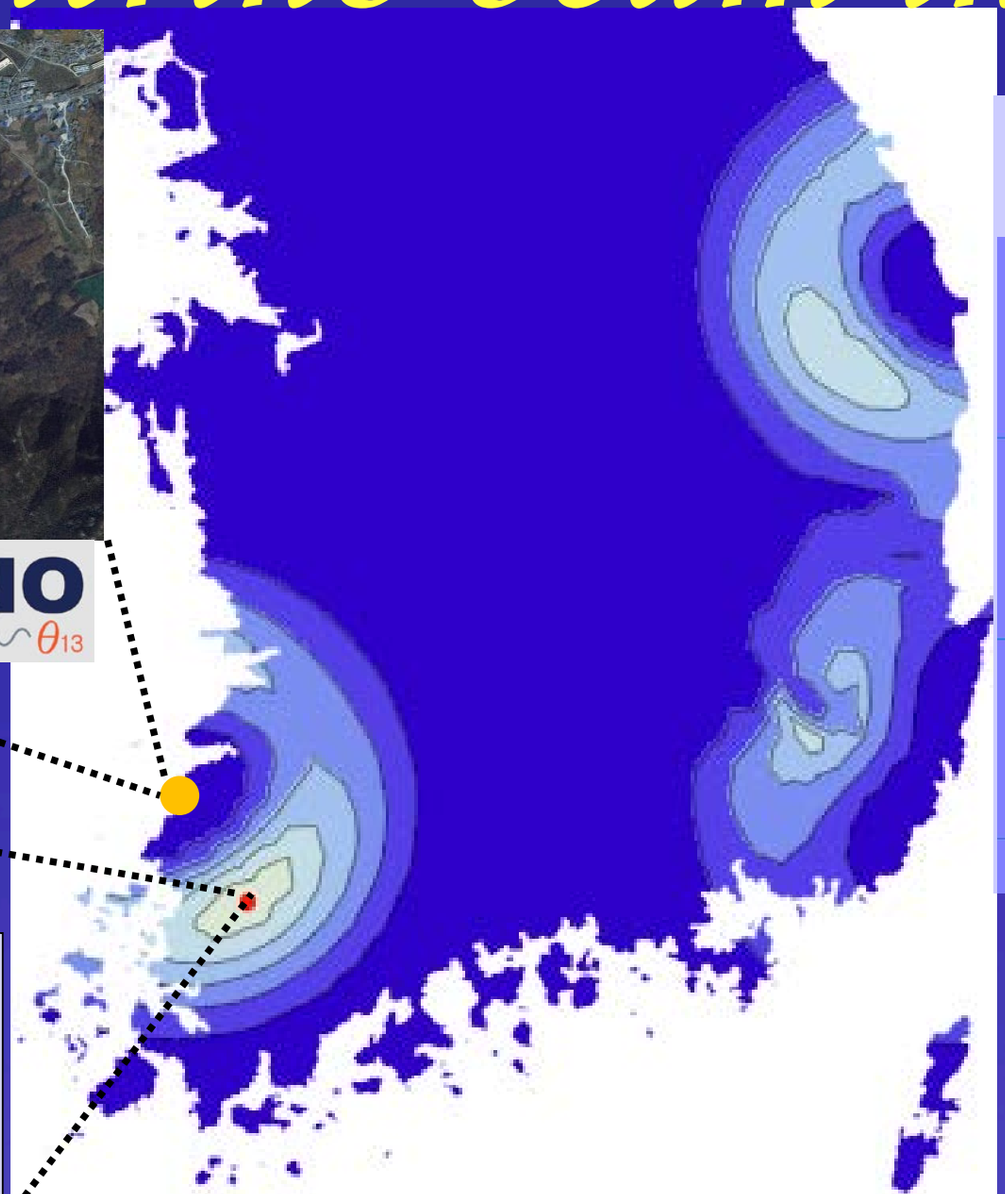
RENO $\nu \sim\sim\sim \theta_{13}$

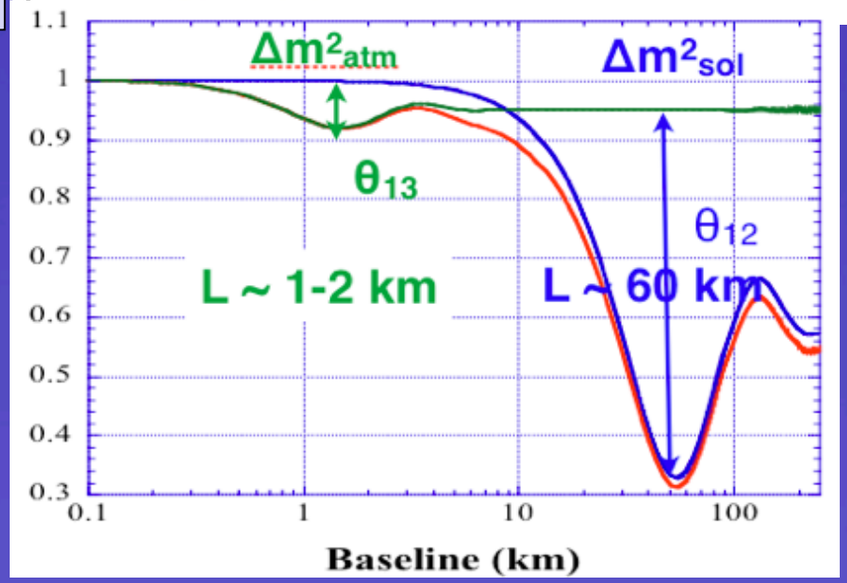
(FAR Detector)

RENO-50

10 kton LS Detector
~47 km from YG reactors

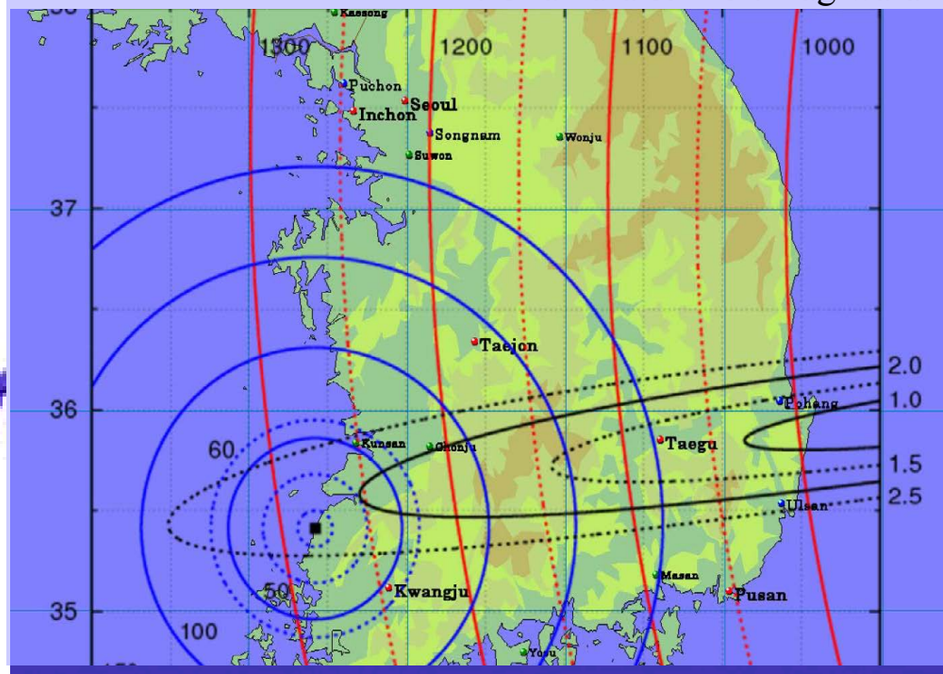
Mt. Guemseong (450 m)
~900 m.w.e. overburden





J-PARC neutrino beam

Dr. Okamura & Prof. Hagiwara



Soo-Bong Kim
@2nd J-PARC symposium, July 13, 2014

Toward Neutrino CPV with mass hierarchy

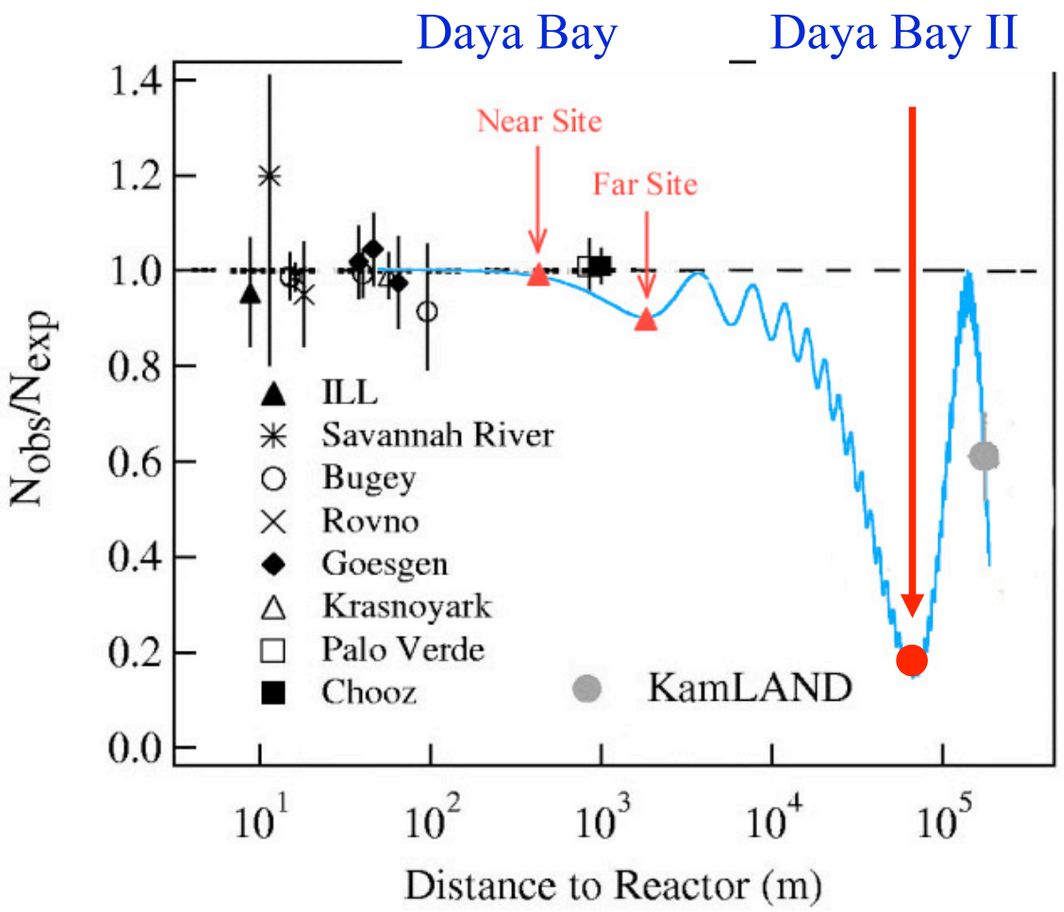
1. **Mass Hierarchy (many projects)**
    1. JUNO
    2. RENO50
    3. INO-ICAL
    4. Hyper-Kamiokande
2. **CP Violation (beam experiments)**
    1. Hyper-Kamiokande w/ J-PARC neutrino beam of ~1MW power.

Reactor neutrinos for mass hierarchy

JUNO Experiment and RENO50

JUNO (DYB-II) has been approved in China in Feb. 2013

Equivalent to CD1 of US DOE



- 20 kton LS detector
- 3%/√E resolution
- Rich physics
  - ⇨ Mass hierarchy
  - ⇨ Precision measurement of 4 oscillation parameters to <1%
  - ⇨ Supernovae neutrino
  - ⇨ Geoneutrino
  - ⇨ Sterile neutrino
  - ⇨ Atmospheric neutrinos
  - ⇨ Exotic searches

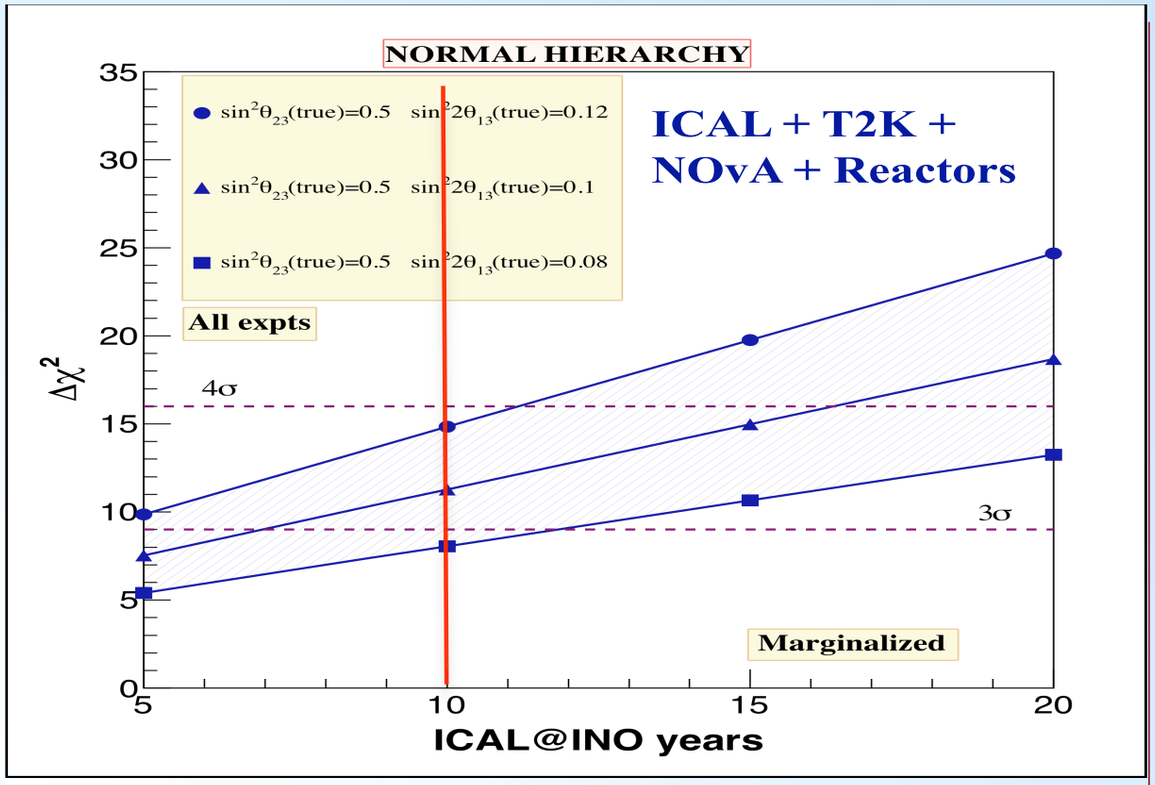
Talk by Y.F. Wang at ICFA seminar 2008...NuFact 2012; by J. Cao at Nutel 2009...NPB 2012 (ShenZhen);
Paper by L. Zhan, Y.F. Wang, J. Cao, L.J. Wen, PRD78:111103,2008; PRD79:073007,2009

by Jingyu Tang

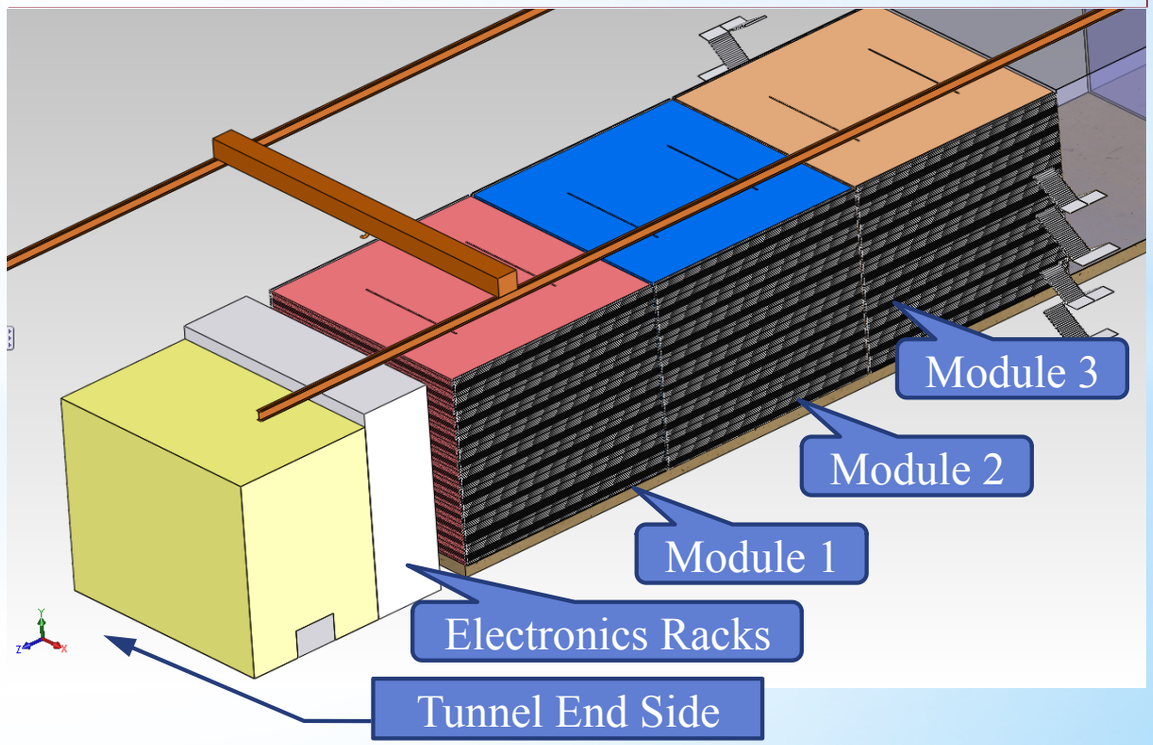
Atmospheric neutrinos for mass hierarchy

Approved projects under INO

- *Come up with an underground lab & surface facilities near Pottipuram village in Theni district of Tamil Nadu*
- *Build massive 50 kt magnetized Iron calorimeter (ICAL) detector to study properties of neutrinos*
- *Construction of INO centre at Madurai: Inter-Institutional Centre for High Energy Physics (IICHEP)*
- *Human Resource Development (INO Graduate Training Program)*
- *Completely in-house Detector R&D with substantial INO-Industry interface*
- *Time Frame for 1st module: 2018*

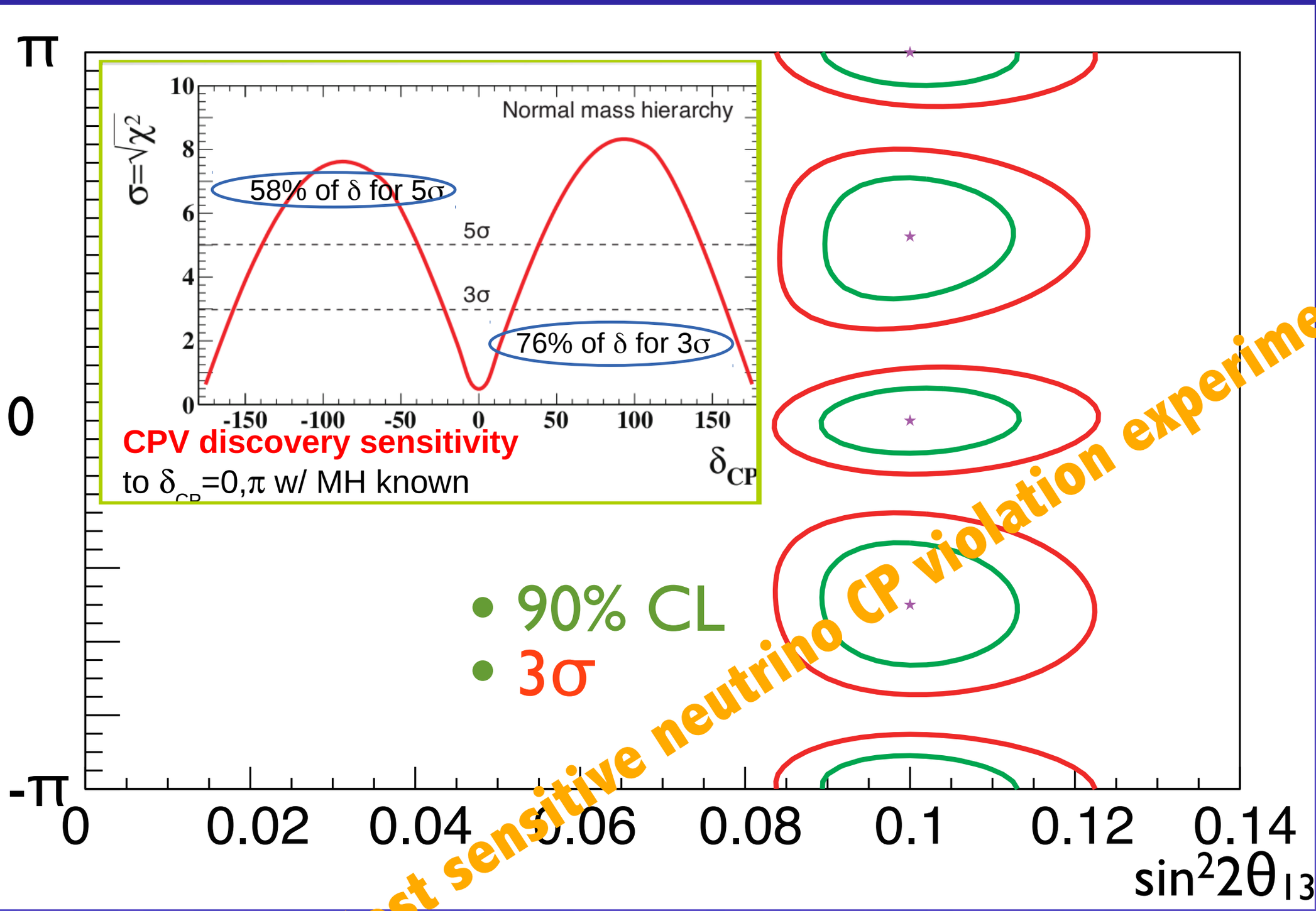


Ghosh, Thakore, Choubey, JHEP 1304 (2013) 009



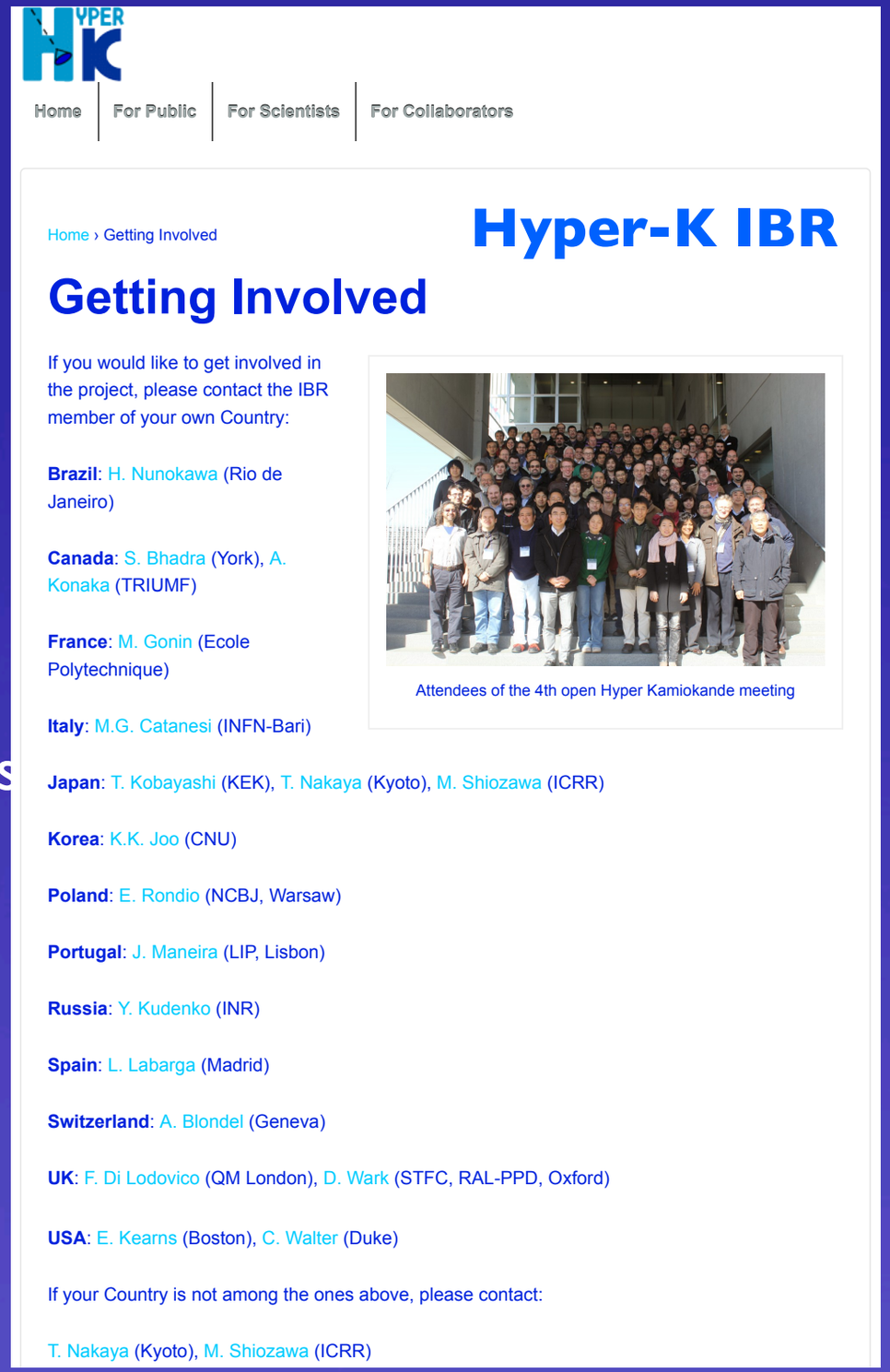
Hyper-K CP Sensitivity w/ J-PARC ν beam

(Mass Hierarchy will be determined by atmospheric ν measurements and also by other experiments.)



Hyper-K Status

- **2011**
  - The Hyper-K LOI: arXiv:1109.3262 [hep-ex]
- **2012**
  - The first open Hyper-K meeting (August 2012).
  - HEP and CRC communities endorse Hyper-K.
- **2013**
  - Budget for Hyper-K R&D is approved.
    - building One kton proto-type detector.
- **2014**
  - The Hyper-K working group
    - ~240 physicists from 67 institutes in 13 countries
  - Science Council of Japan announced "Japanese Master Plan of Large Research Projects".
    - http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-22-t188-1.pdf
    - Top 27 projects out of 192 are selected in all science area. The Hyper-K is one of the top projects to be pursued in Japan.
  - A full proposal is under preparation for negotiation with the funding agency with visible international contributions for the next MEXT roadmap.



Dream may come true

1. Determination of mass hierarchy
2. Discovery of Neutrino CP violation
3. Observation of Supernova explosion by neutrinos
4. Discovery of Proton Decay
5. Discovery of neutrino-less ββ decay
6. Finding a role of right-handed neutrinos
7. Prediction of the symmetry between quark and lepton.
8. Leptogenesis as the most probable scenario for matter dominant universe.
9. Evidence of dark matter annihilation to a neutrino pair.
10. Discovery of a sterile neutrino
11. any other topics????

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Summary

1. All neutrino experiments in Asia are important to be pursued.
   1. Many active R&D are on-going.
      1. Advanced detector technology.
      2. High power proton accelerators
      3. High quality and high power neutrino beam.
   2. Current status of future projects.
      1. China: A constructions of **JUNO** is ongoing. A concept of **MOMENT** is under studied.
      2. India: A constructions of **INO-ICAL** is ongoing.
      3. Japan: Funding for R&D of **Hyper-K** is approved. A full proposal is under preparation for negotiation with the funding agency.
      4. Korea: A proposal for R&D of **RENO50** is submitted. A full funding is under request.
2. Interesting results are expected from Asia for the next few decades.