

Directions for Neutrino Physics in Asia

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Outline

Summary of neutrino experiments (ongoing, planned, under discussion) in Japan.

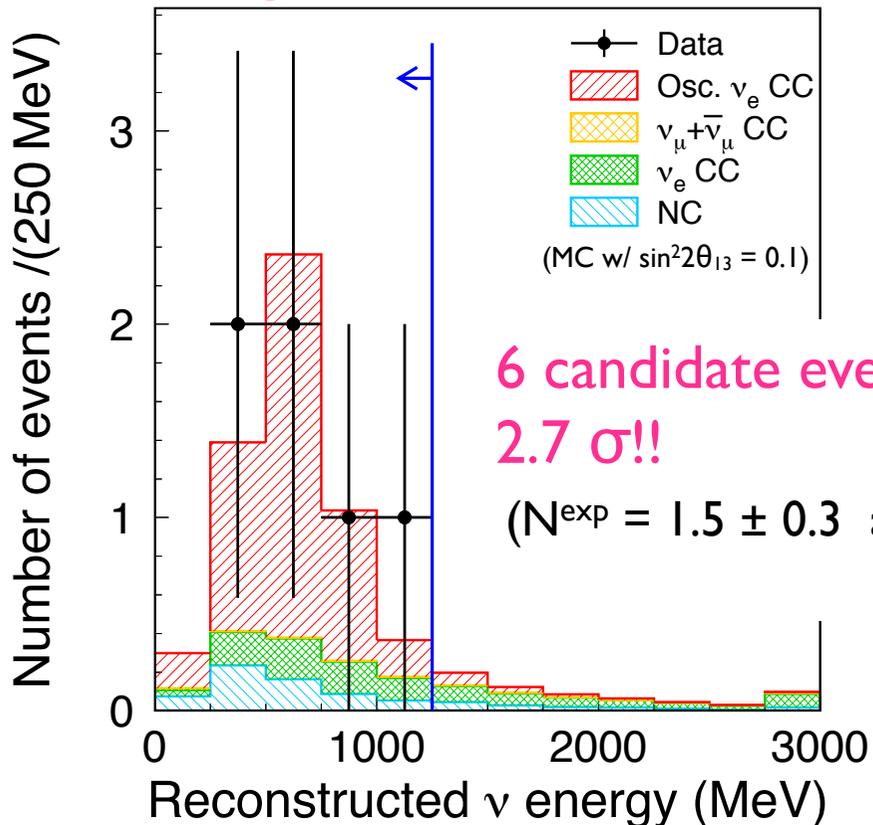
- Neutrino Oscillation experiments
 - Ongoing experiments: *Super-Kamiokande, T2K (J-PARC +SK)*
 - Next generation detectors: *Hyper-Kamiokande, Liquid Argon TPC*
- Double beta decay searches
 - *KamLAND-Zen, CANDLES, DCBA...*
- absolute ν mass by cosmological observation
 - *Subaru*, not covered by this talk...

Neutrino Oscillation Experiments

T2K (JPARC ν +Super-K)

T2K collaboration, PRL107,041801(2011)

Observed indication of $\nu_\mu \rightarrow \nu_e$,
2.7 σ significance of nonzero θ_{13}

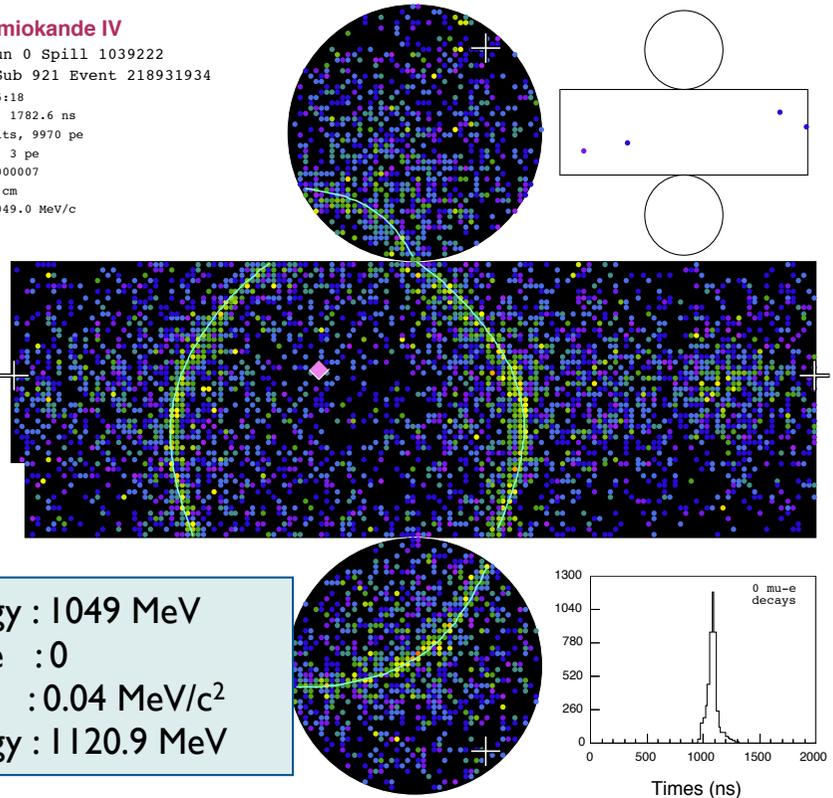


6 candidate events w/
2.7 σ !!
($N^{\text{exp}} = 1.5 \pm 0.3$ at $\sin^2 2\theta_{13} = 0$)

Super-Kamiokande IV
T2K Beam Run 0 Spill 1039222
Run 67969 Sub 921 Event 218931934
10-12-22:14:15:18
T2K beam dt = 1782.6 ns
Inner: 4804 hits, 9970 pe
Outer: 4 hits, 3 pe
Trigger: 0x80000007
D_wall: 244.2 cm
e-like, p = 1049.0 MeV/c

Charge (pe)

- >26.7
- 23.3-26.7
- 20.2-23.3
- 17.3-20.2
- 14.7-17.3
- 12.2-14.7
- 10.0-12.2
- 8.0-10.0
- 6.2-8.0
- 4.7-6.2
- 3.3-4.7
- 2.0-3.3



T2K's next step: establish ν_e appearance (in a few year?)

Next generation experiments aiming CP δ is urgent.

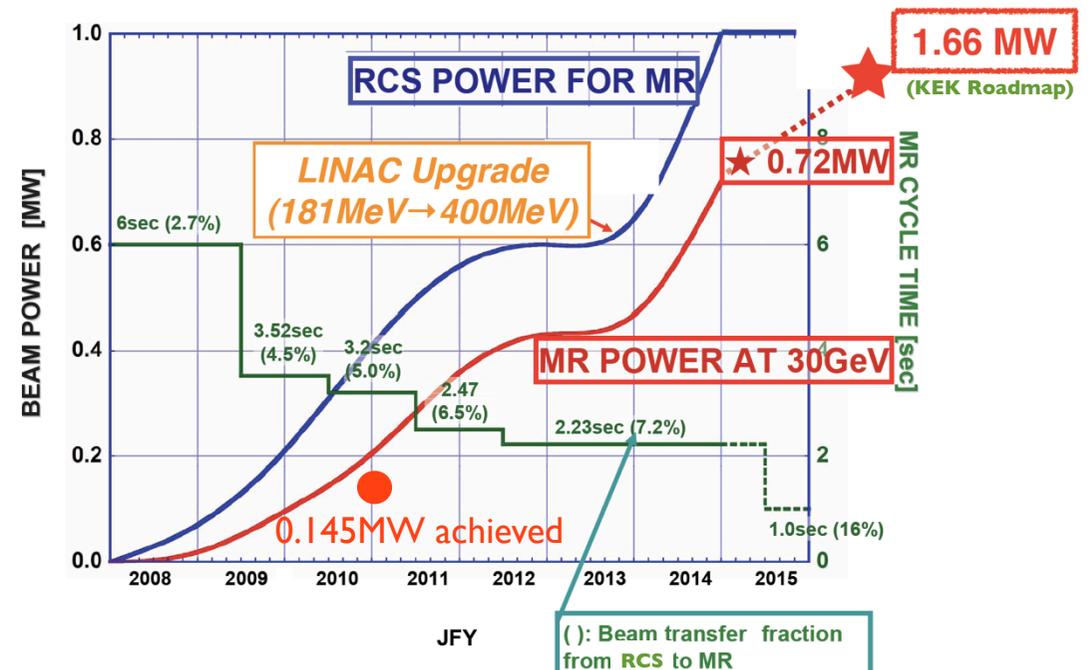
J-PARC



Efforts to increase beam power

2011 shutdown

- Replacement of injection kicker to MR
- Higher capacity of collimator for beam loss
- Adding more RF
- Tuning of MR power (rep rate 3sec to 2.2sec) further upgrade toward design power and beyond
- LINAC upgrade in 2013 (180 to 400MeV)
- new ion source (30mA to 50mA)
- R&D on high rep. rate MR power supply
- R&D on high gradient RF core



Letter of Intent:

The Hyper-Kamiokande Experiment

— Detector Design and Physics Potential —

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(Hyper-Kamiokande working group)

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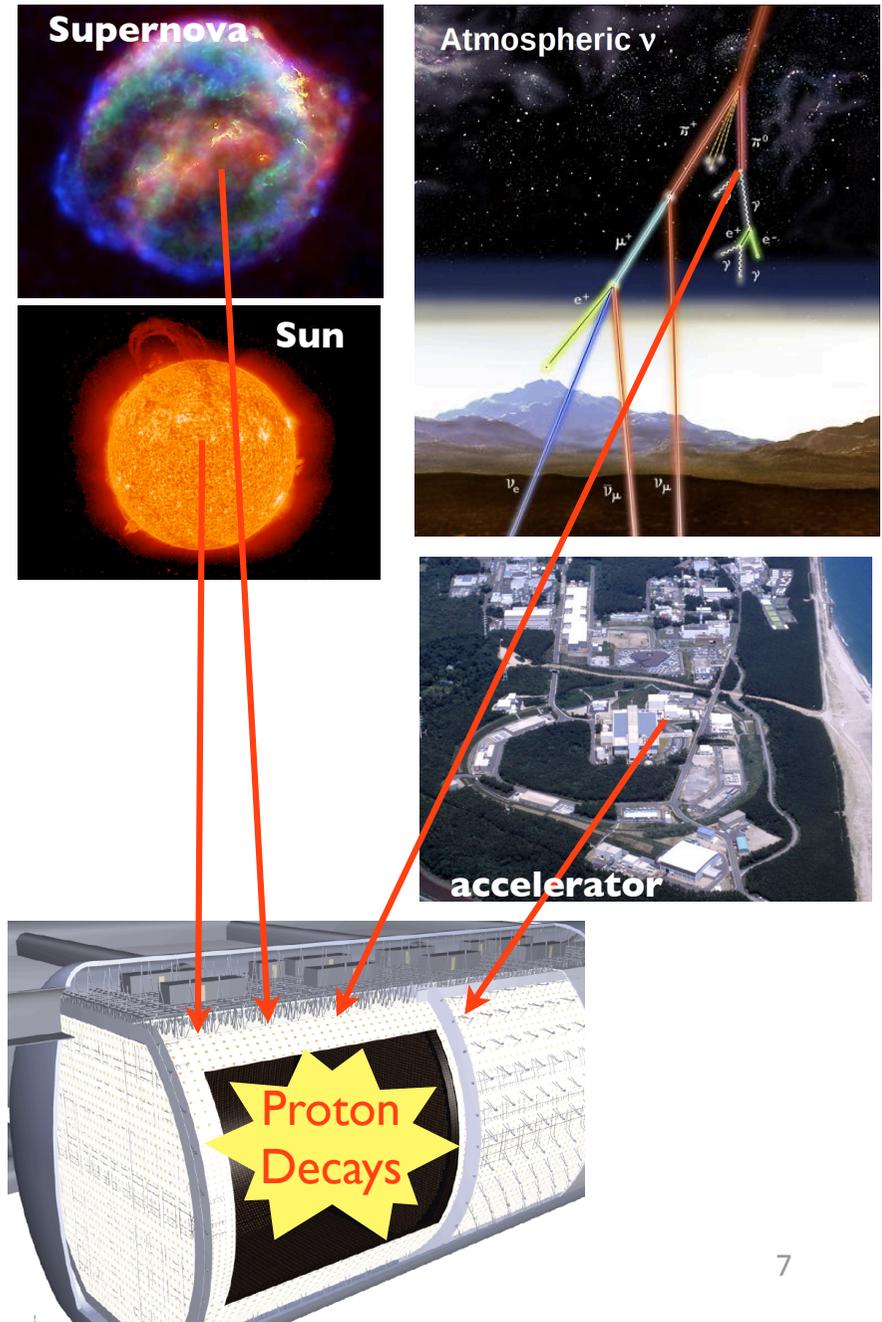
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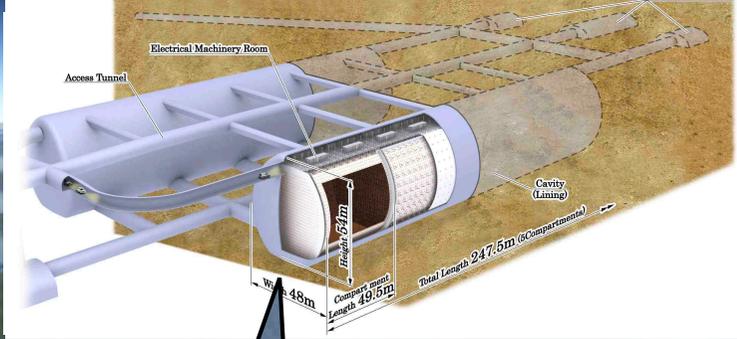
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Multi-purpose detector, Hyper-K

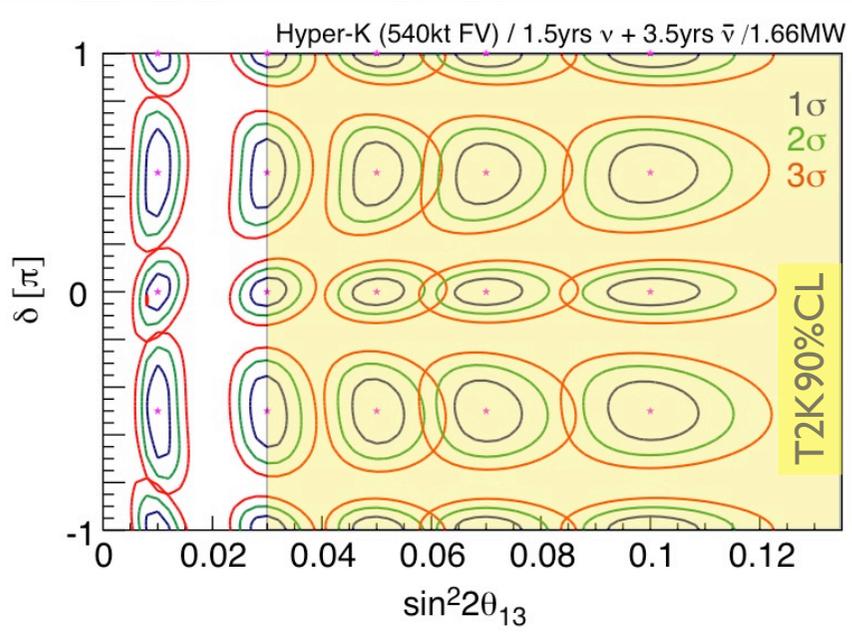
- Total (fiducial) volume is 1 (0.56) million ton
 - 25 × Super-K
- Explore full picture of neutrino oscillation parameters.
 - Discovery of leptonic CP violation (Dirac δ)
 - ν mass hierarchy determination ($\Delta m_{32}^2 > 0$ or < 0)
 - θ_{23} octant determination ($\theta_{23} < \pi/4$ or $> \pi/4$)
- Extend nucleon decay search sensitivity
 - $\tau_{\text{proton}} = 10^{34} \sim 10^{35}$ years
- Neutrinos from astrophysical objects
 - 200 ν 's / day from Sun
 - 250,000 (50) ν 's from Supernova @ Galactic-center (Andromeda)
 - 830 ν 's / 10 years Supernova relic ν





x25 Larger ν Target

Quest for CP Violation



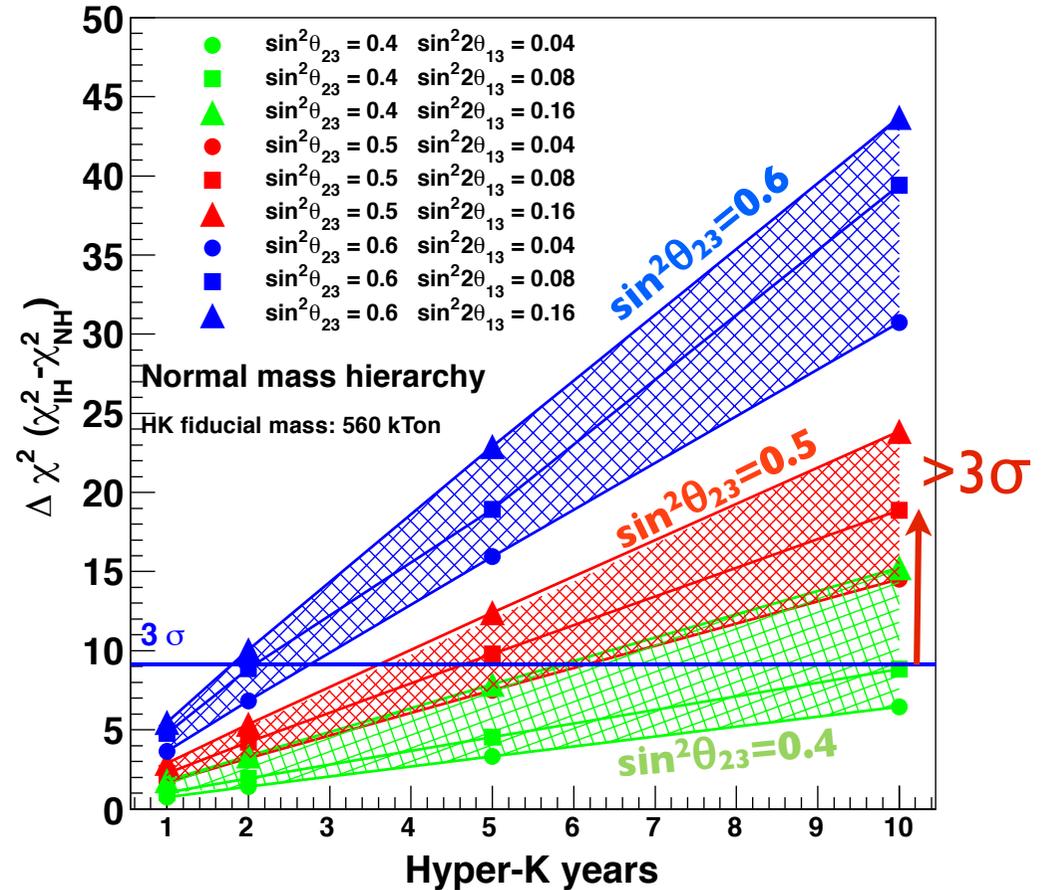
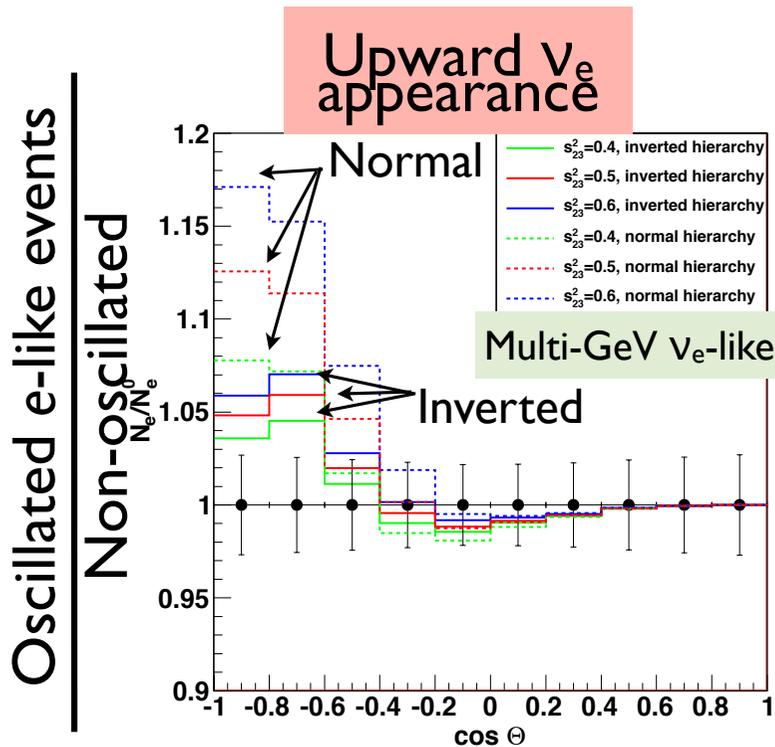
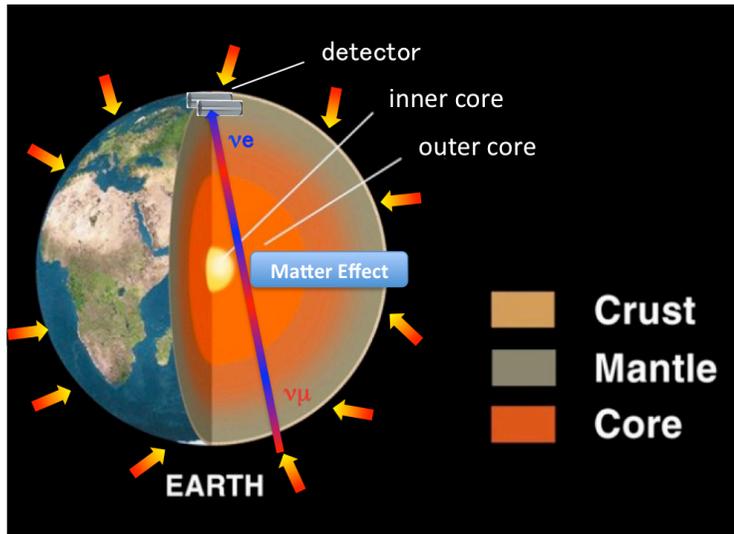
$\sim 0.6 \text{ GeV } \nu\mu$
295km

Higher Intensity
> 1.66MW (KEK roadmap)



Good sensitivity in whole T2K's θ_{13} allowed region!

Mass hierarchy discrimination power



► expect to discriminate normal from inverted hierarchy w/ 3σ significance by ~ 5 years data.

θ_{23} octant

$$\sin^2 2\theta_{23} = 0.96$$

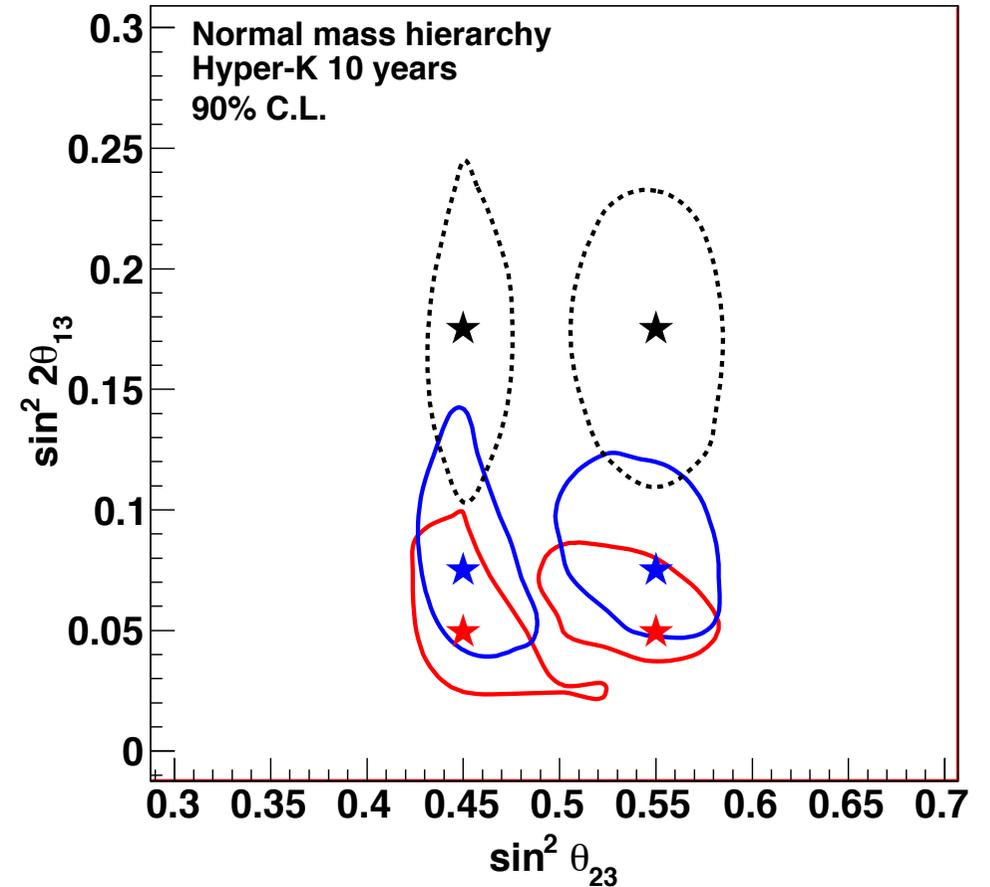
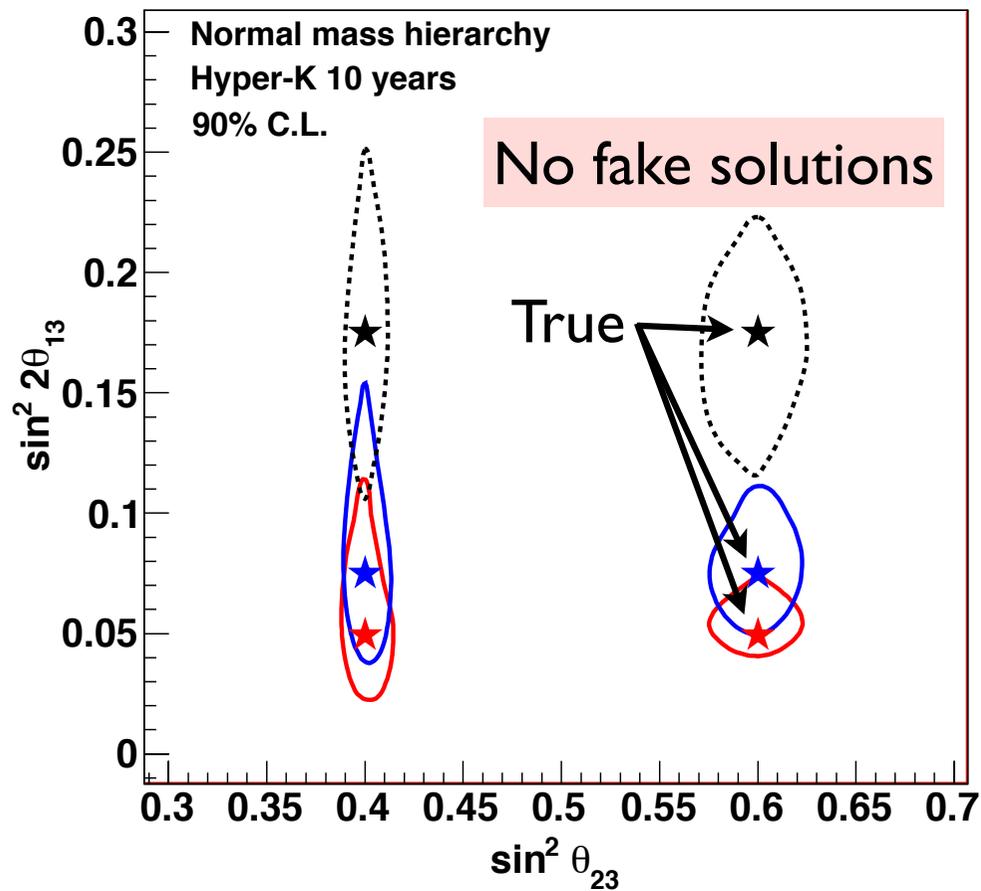
↓

$$\sin^2 \theta_{23} = 0.4 \text{ or } 0.6$$

$$\sin^2 2\theta_{23} = 0.99$$

↓

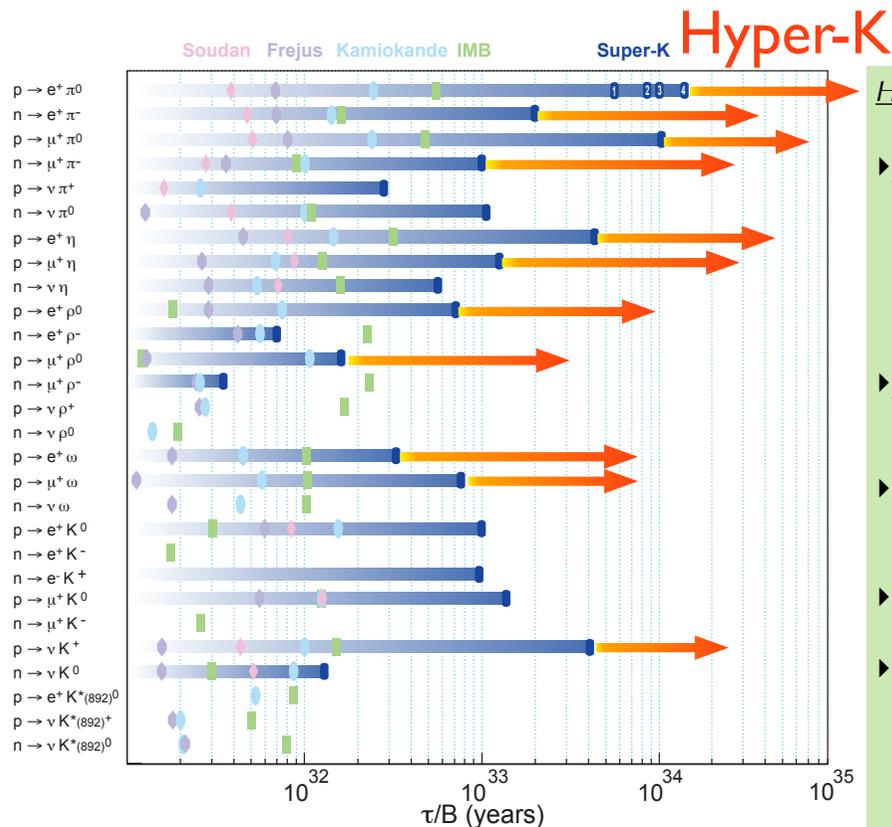
$$\sin^2 \theta_{23} = 0.45 \text{ or } 0.55$$



If $\sin^2 2\theta_{23} < 0.99$, θ_{23} octant can be determined.

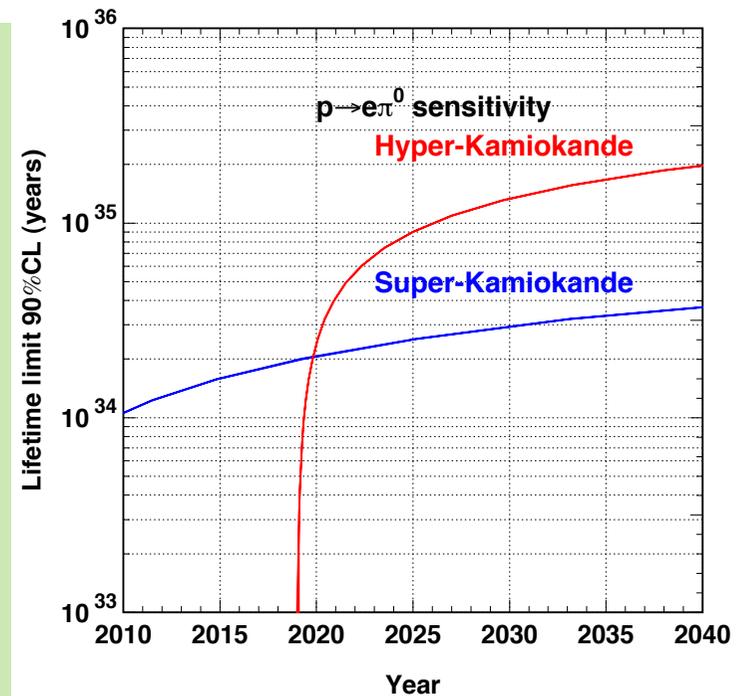
Searches for Nucleon Decays

- various nucleon decay modes (and models) can be tested.
- $>1.3 \times 10^{35}$ years for $p \rightarrow e^+ + \pi^0$, $>2.5 \times 10^{34}$ years for $p \rightarrow \nu + K^+$
- only known realistic option being reachable to such a sensitivity for $p \rightarrow e^+ + \pi^0$ (thanks to the large detector volume)



Hyper-K sensitivities

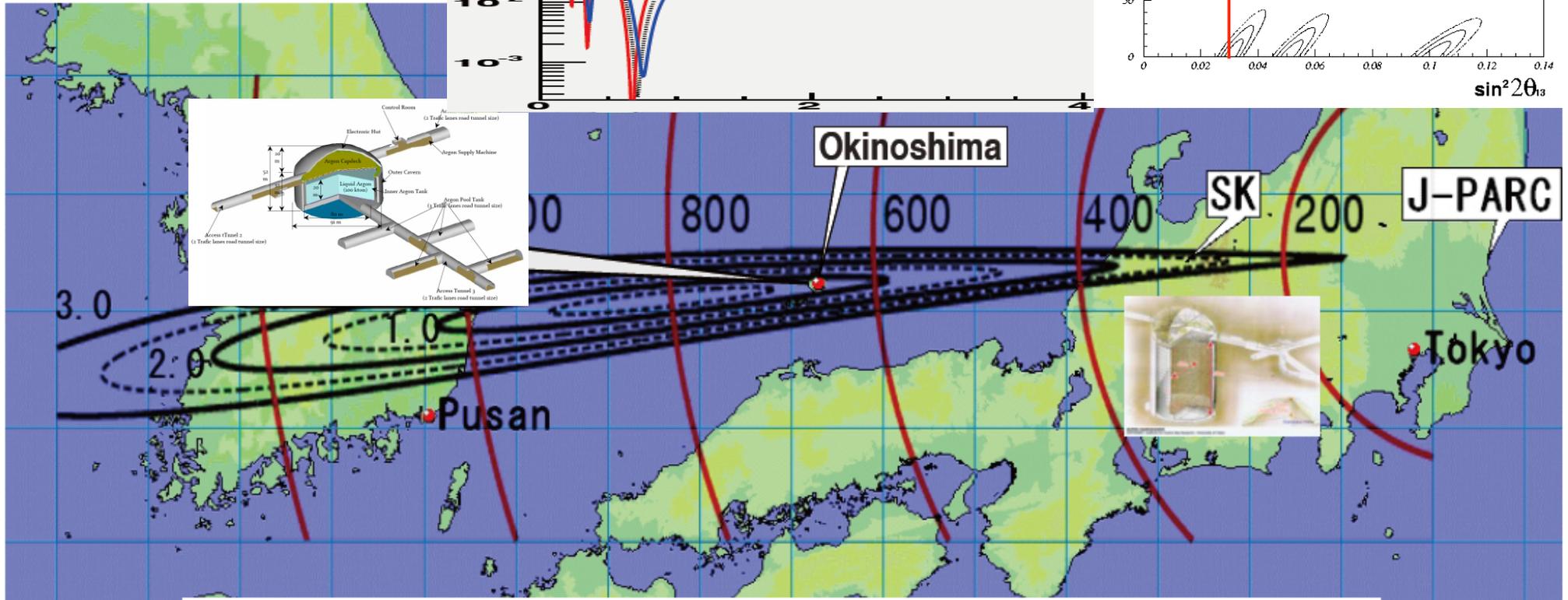
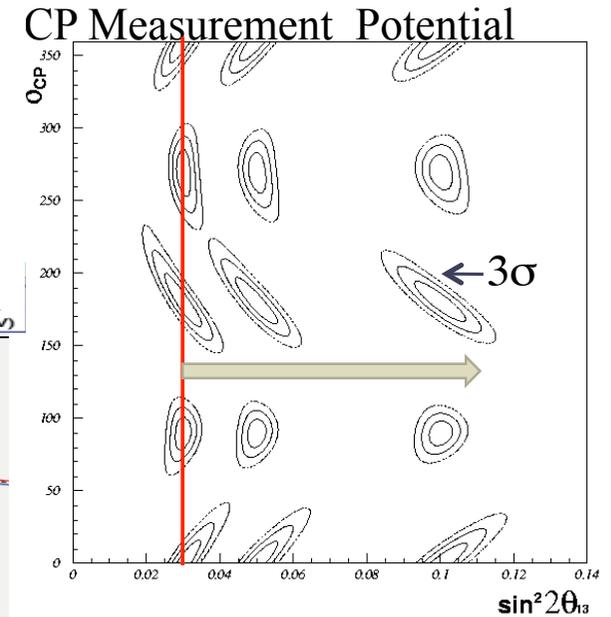
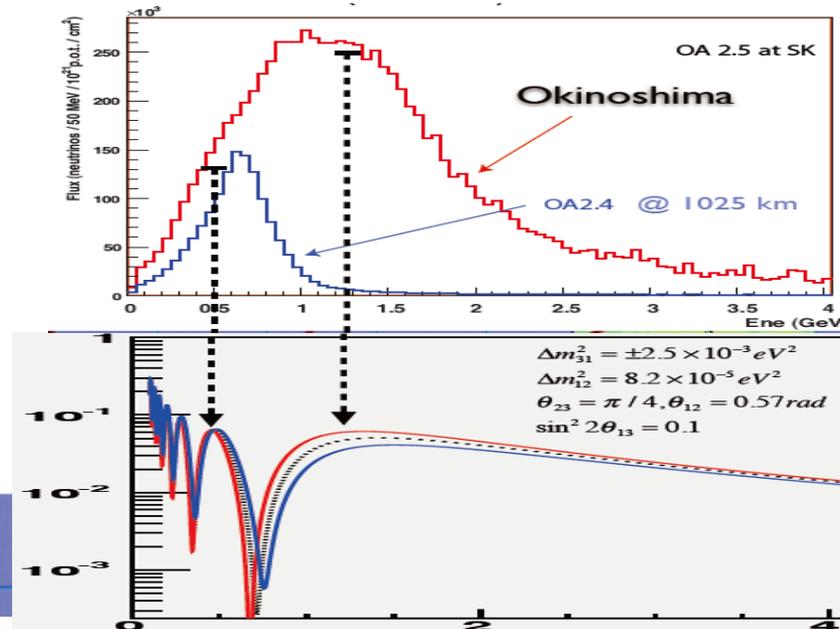
- ▶ $p \rightarrow e^+ + \pi^0$
 - ▶ $\tau_{\text{proton}}/\text{Br} > 1.3 \times 10^{35}$ years @90%CL
 - ▶ 5.6Mton×years (10 Hyper-K years)
- ▶ $p, n \rightarrow (e^+, \mu^+) + (\pi, \rho, \omega, \eta)$
 - ▶ $O(10^{34-35})$ years
- ▶ *SUSY favored* $p \rightarrow \nu + K^+$
 - ▶ 2.5×10^{34} years
- ▶ K^0 modes, $\nu\pi^0, \nu\pi^+$ possible
- ▶ Other various decay modes.
 - ▶ (B-L) violated modes
 - ▶ radiative decays $p \rightarrow e^+ \gamma, \mu^+ \gamma$
 - ▶ neutron-antineutron oscillation ($|\Delta B|=2$)
 - ▶ di-nucleon decays ($|\Delta B|=2$)
 - ▶ $pp \rightarrow XX\dots, nn \rightarrow XX\dots$



100kton Liquid Argon TPC

On-axis
 ($\theta=0.76^\circ$,
 $2.5^\circ@SK$)
 $L=658\text{km}$

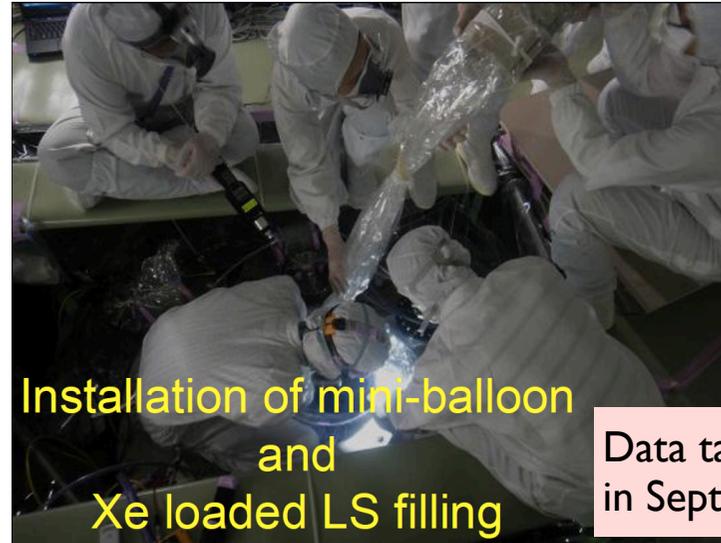
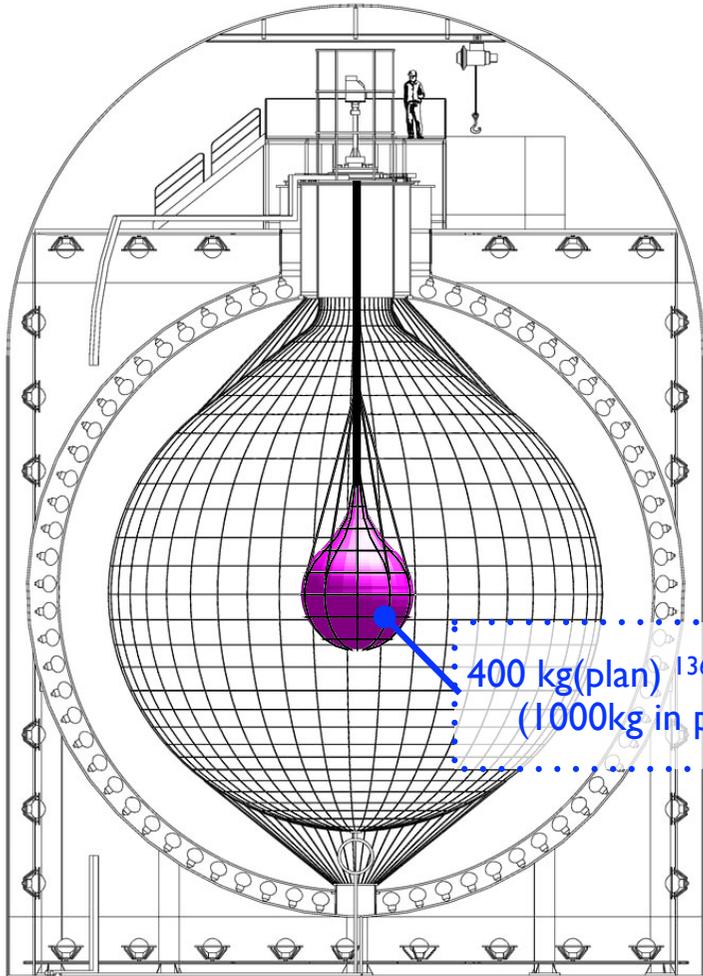
P32 proposal (Lar TPC R&D)
 Recommended by J-PARC PAC
 (Jan 2010), arXiv:0804.2111



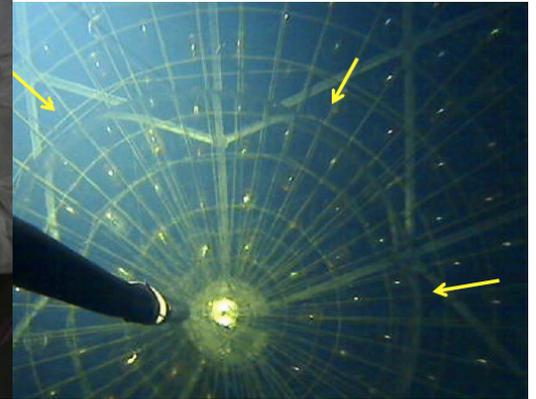
→ Extract δ_{CP} from fit of 1st & 2nd maximum

Double Beta Decay Experiments

KamLAND-Zen $0\nu 2\beta$



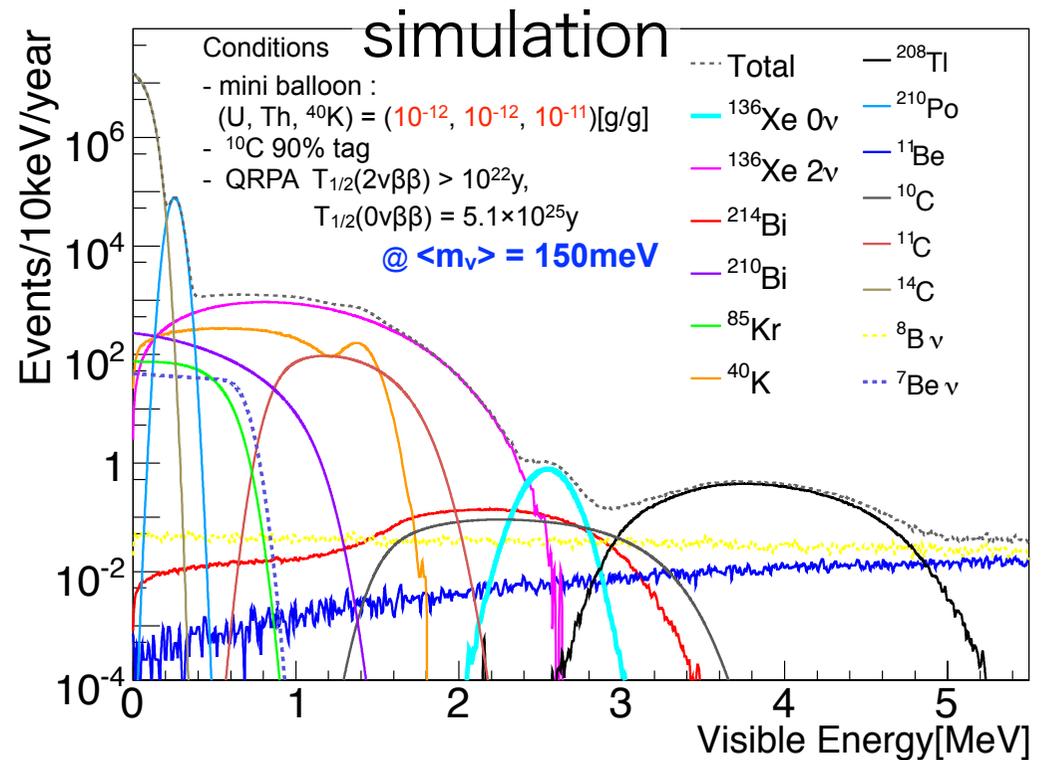
Installation of mini-balloon and Xe loaded LS filling



Data taking started w/ 330kg ^{136}Xe in September 2011 !

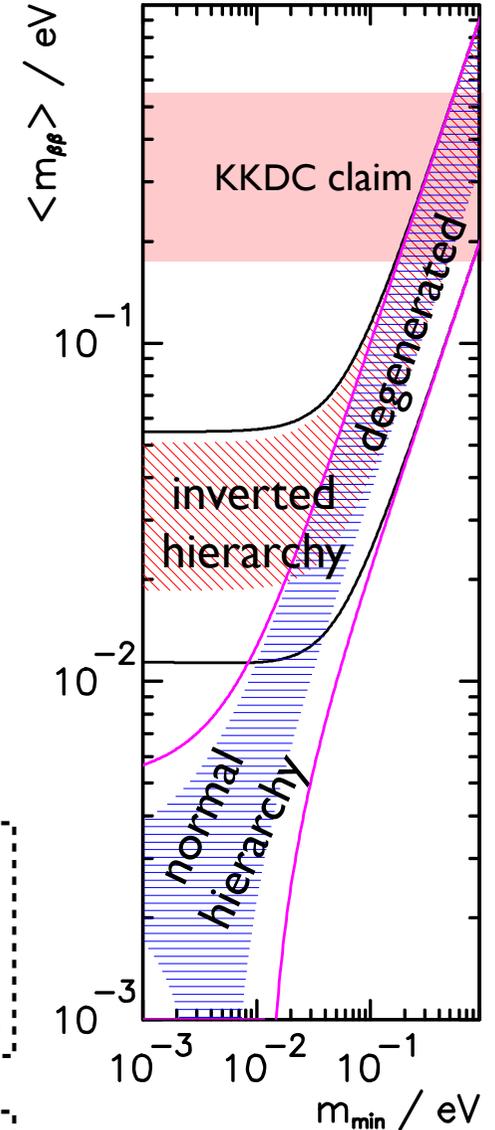
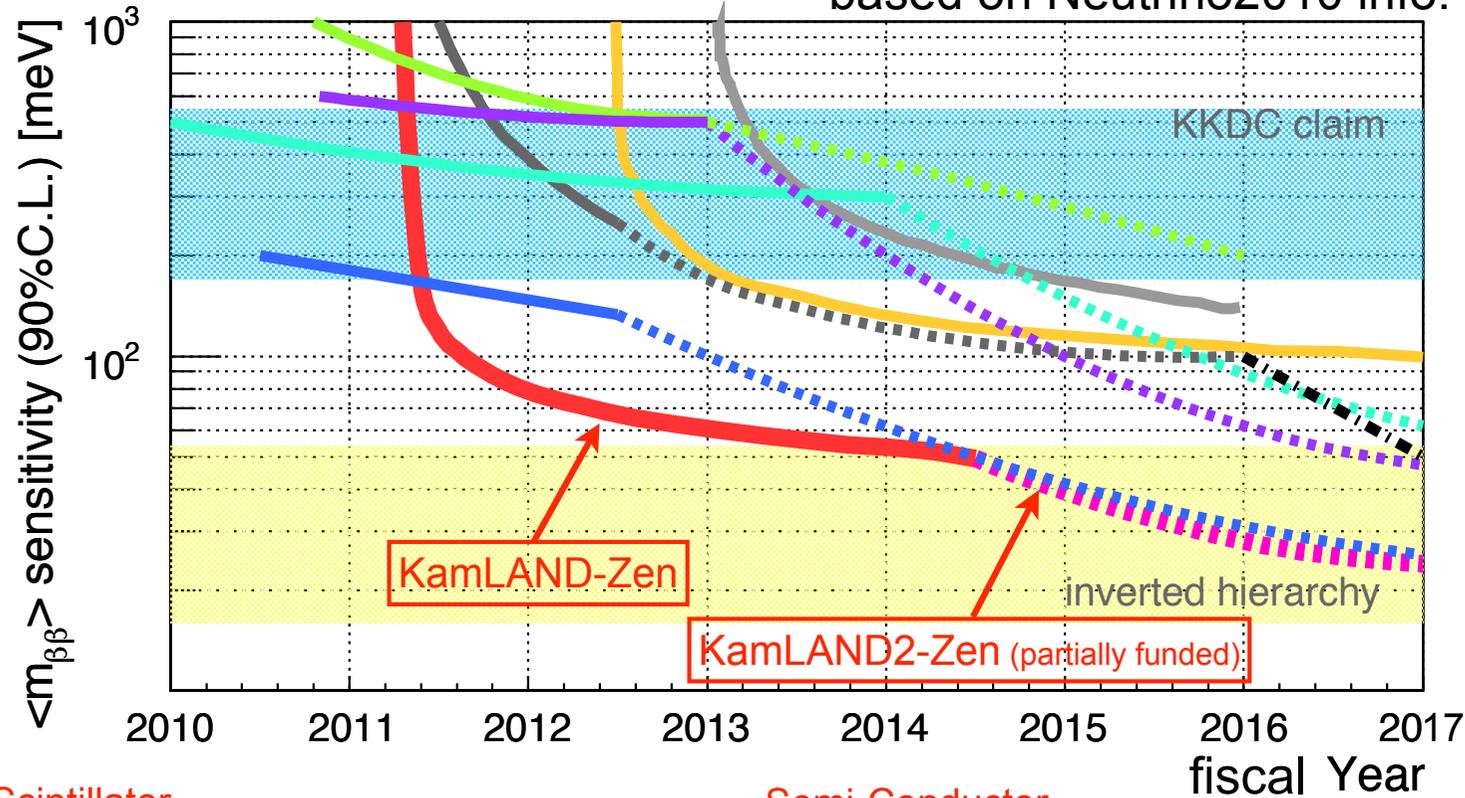
400 kg(plan) ^{136}Xe loaded
(1000kg in phase II)

- 1st phase ~ 60 meV in 5 years
400kg (plan) ^{136}Xe
- high scalability (2nd phase)
1000 kg ^{136}Xe , improvement of energy resolution
with light concentrators and brighter LS,
maybe higher concentration with pressurized Xenon ~ 20 meV in 5 years



Expected sensitivity of KamLAND-Zen

based on Neutrino2010 info.



Scintillator

- █ KamLAND (^{136}Xe , 400kg)
- ▤▤▤▤▤▤ KamLAND (^{136}Xe , 1000kg) light concentrator
brighter LS
(pressurized Xenon)
- █ SNO+ (^{150}Nd), 56kg
- █ CANDLES III (^{48}Ca 300g)
- ▤▤▤▤▤▤ CANDLES IV (^{48}Ca 3kg)

Tracking

- █ NEMO-3 (^{100}Mo 7kg)
- ▤▤▤▤▤▤ SuperNEMO (^{150}Nd or ^{82}Se 100-200)

Semi-Conductor

- █ MAJORANA (^{76}Ge), 30-60kg
- ▤▤▤▤▤▤ GERDA phaseI (^{76}Ge :17.66kg)
- ▤▤▤▤▤▤ GERDA phaseII (^{76}Ge :37.5kg)
- █▤▤▤▤▤▤ GERDA phaseIII + MAJORANA (^{76}Ge :~80kg)

Bolometer

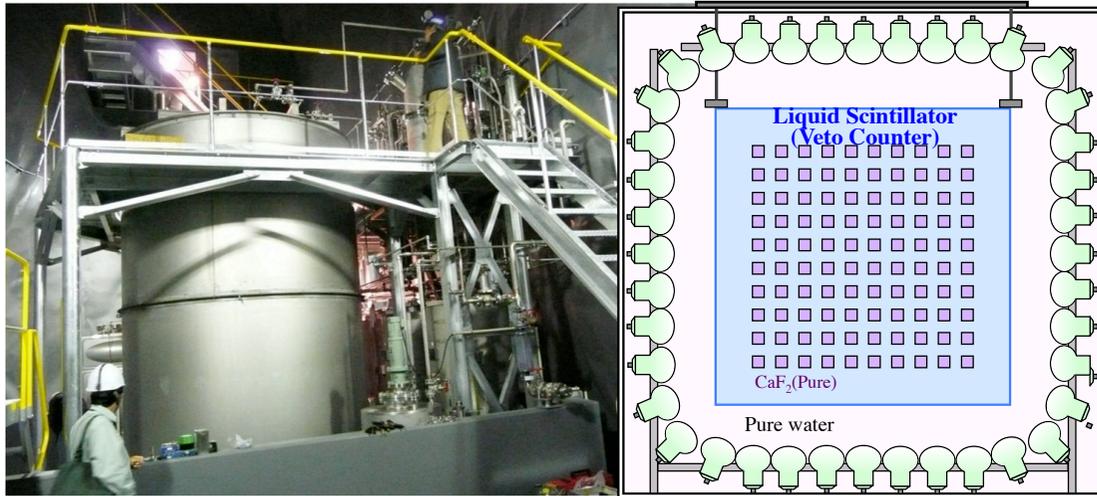
- █ CUORE-0 (^{130}Te ~10kg)
- ▤▤▤▤▤▤ CUORE (^{130}Te 204kg)

Liquid TPC

- █ EXO-200 (^{136}Xe 200kg)
- ▤▤▤▤▤▤ EXO (^{136}Xe 1t)

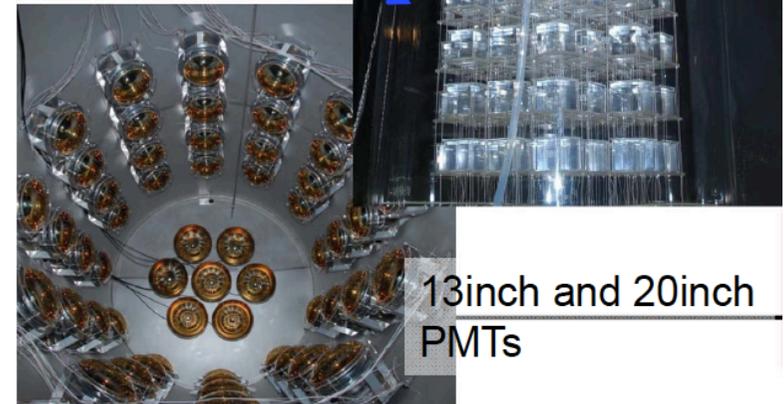
CANDLES (Osaka Univ.)

Phase-III commissioning started



Main detector
CaF₂ Scintillators
(305kg)

Liquid Scintillator
Tank(2m³)

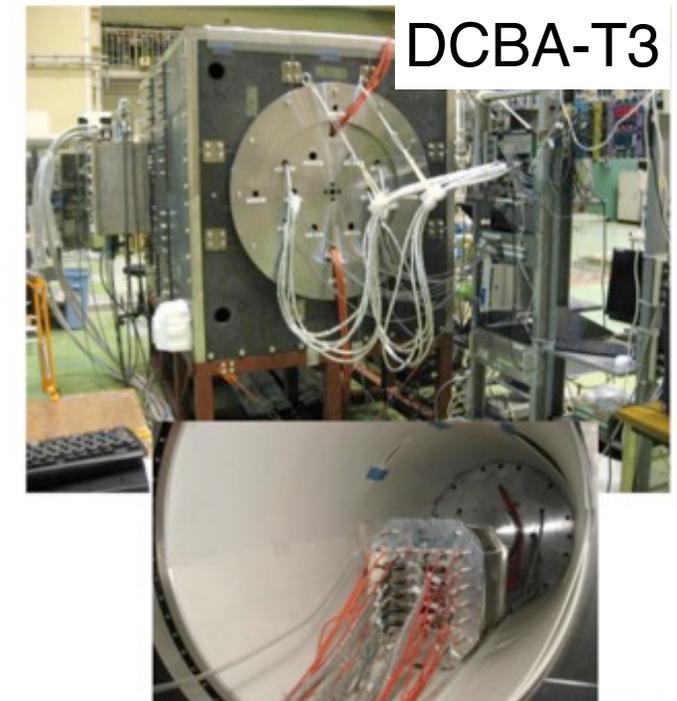
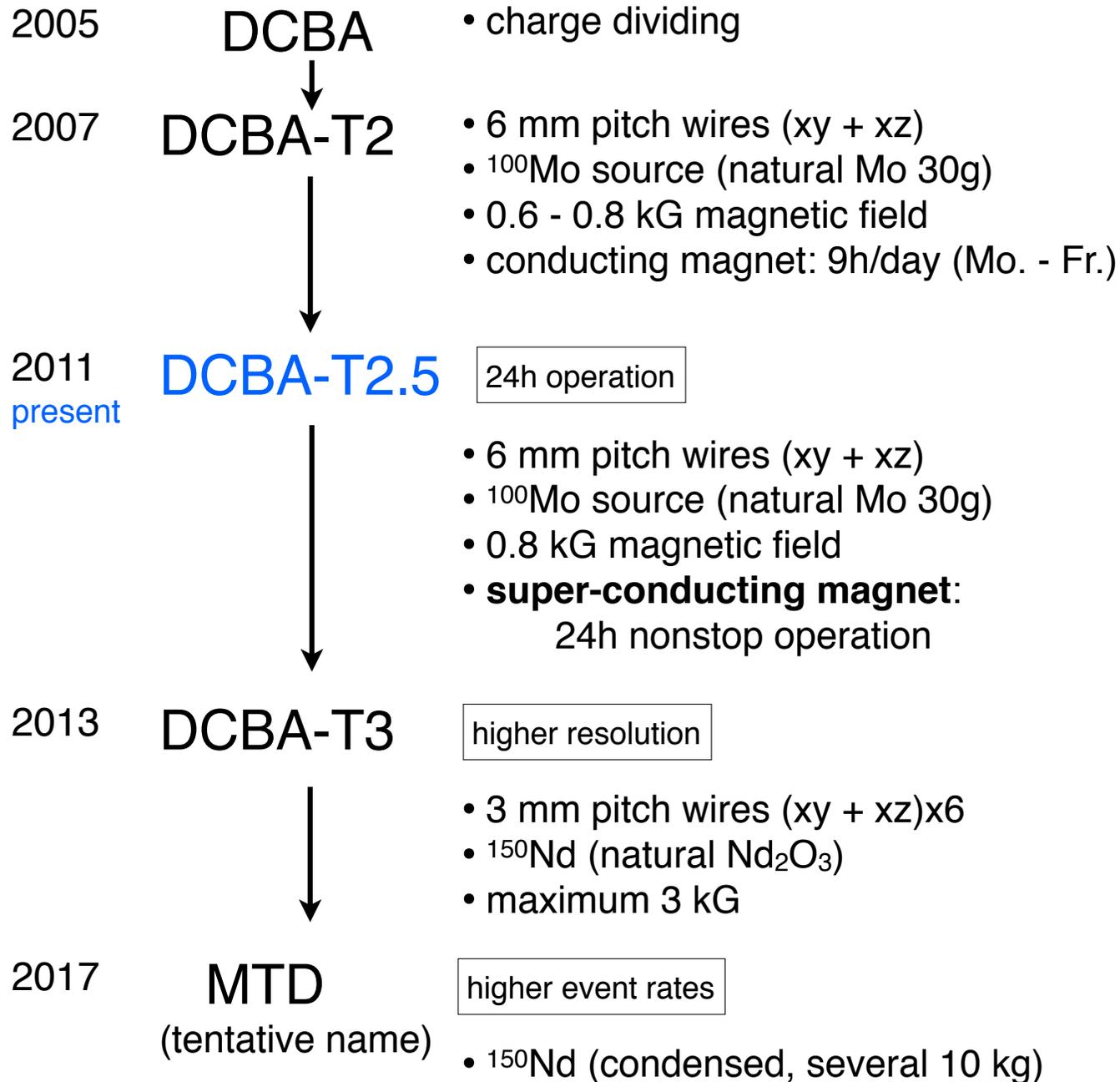


- ◆ 0ν2β search w/ CaF₂ crystal
- ◆ low BG
 - ◆ ⁴⁸Ca, high Q=4.27MeV
 - ◆ water and LS active shields
 - ◆ pulse shape discrimination
- ◆ phase-III (305kg) running
 - ◆ m_{ββ}~0.5eV
- ◆ next CANDLES (2ton⁴⁸Ca), goal m_{ββ}~50mV

⁴⁸Ca: 0.2% natural abundance
could be enriched by crown ether.
0.26% has been achieved.



DCBA experiment (KEK)



DCBA-T2-detector
in T3 (=T2.5)

Summary

- Next generation nucleon decay and neutrino detectors will cover rich physics topics.
 - discovery reach for leptonic CP violation.
 - good chance to discriminate hierarchy and θ_{23} octant.
 - ~ 10 times better sensitivity for nucleon decays.
 - various astrophysical objects.
 - based on well proven technology (water Cherenkov) or Liq.Argon technology w/ better resolution.
- Double beta decay searches
 - KamLAND-zen, CANDLES, DCBA
 - explore inverted hierarchy region in 5~10 years