

Experiments at Kamioka Underground

(Past, Present and Future)

Two Research Laboratories now in the Kamioka underground:

Kamioka Observatory, ICRR (University of Tokyo)

Super-K & others

Neutrino Science Center (Tohoku University)

KamLAND



Yoichiro SUZUKI

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The University of Tokyo

and

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The University of Tokyo

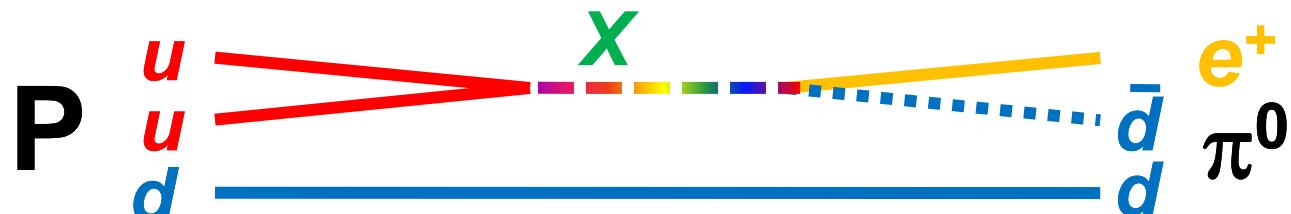
Pre-history

In the beginning was Proton Decay

1974: Grand Unified Theories
SU(5) and
other models later

leptons-quarks \leftrightarrow single irreducible representation

→ Proton decay : $\tau_p(e^+\pi^0) \sim 10^{29 \pm 1.7} \text{ yr}$



Creation of the Large Water Cherenkov Detectors

People were aware that

**Large Water Cherenkov Detectors can look
for Proton Decay**

(1000 tons Water → $\sim 3 \times 10^{32}$ protons)

Real experimental search → in early 1980s

IMB in USA (7000tons, 1982~)

Kamiokande in Japan

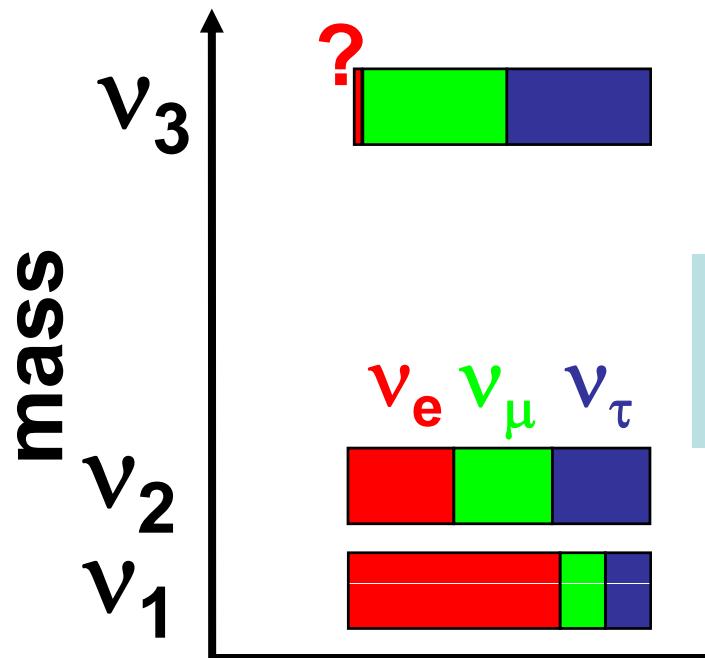


Brief history

1981-1983	Kamiokande Construction
1984	Kamiokande started
1985 →	Non observation of proton decay (KM) proton lifetime exceeds 10^{31} yr → SD(5)
1987 →	Neutrino burst from SN1987A (KM)
1988 →	Confirmation of solar neutrino problem (KM)
1988 →	Atmospheric Neutrino Anomaly (KM)
1991-1996	Super-Kamiokande Construction
1996	Super-Kamiokande started
1998 →	Discovery Atmospheric Neutrino Oscillation (SK)
1999	K2K started
1999-2002	KamLAND construction
2001 →	Discovery Solar Neutrino Oscillation w/ SNO (SK)
2002	KamLAND started
2003 →	Discovery of reactor neutrino disappearance (KL)
2004 →	Confirmation of Atmospheric ν oscillation (K2K/SK)
2005 →	Observation of Geo-neutrinos (KL)

Neutrino Mass and Mixing

Case for normal hierarchy



mixing:

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

flavor eigenstates mass eigenstates

Atmospheric ν
Long baseline
(θ₂₃: maximal?)

CHOOZ
(θ₁₃: small;
upper limit)

Solar ν
Reactor
(θ₁₂: large)

$$U_{\alpha i} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\approx \begin{pmatrix} c_{12} & s_{12} & s_{13}e^{-i\delta} \\ -c_{23}s_{12} & c_{23}c_{12} & s_{23} \\ s_{23}s_{12} & -s_{23}c_{12} & c_{23} \end{pmatrix} \text{ for } \begin{cases} s_{13} = \sin\theta_{13} : \text{small} \\ c_{13} = \cos\theta_{13} \rightarrow 1 \end{cases}$$

Experimental Observation

Δm₂₃ >> Δm₁₂
Atm-ν ($\nu_\mu \rightarrow \nu_\tau$): θ_{atm} maximal?
Sol- ν ($\nu_e \rightarrow \nu_x$): θ_{sol} large
reactor($\nu_e \rightarrow \nu_x$): θ₁₃ small
(short distance)

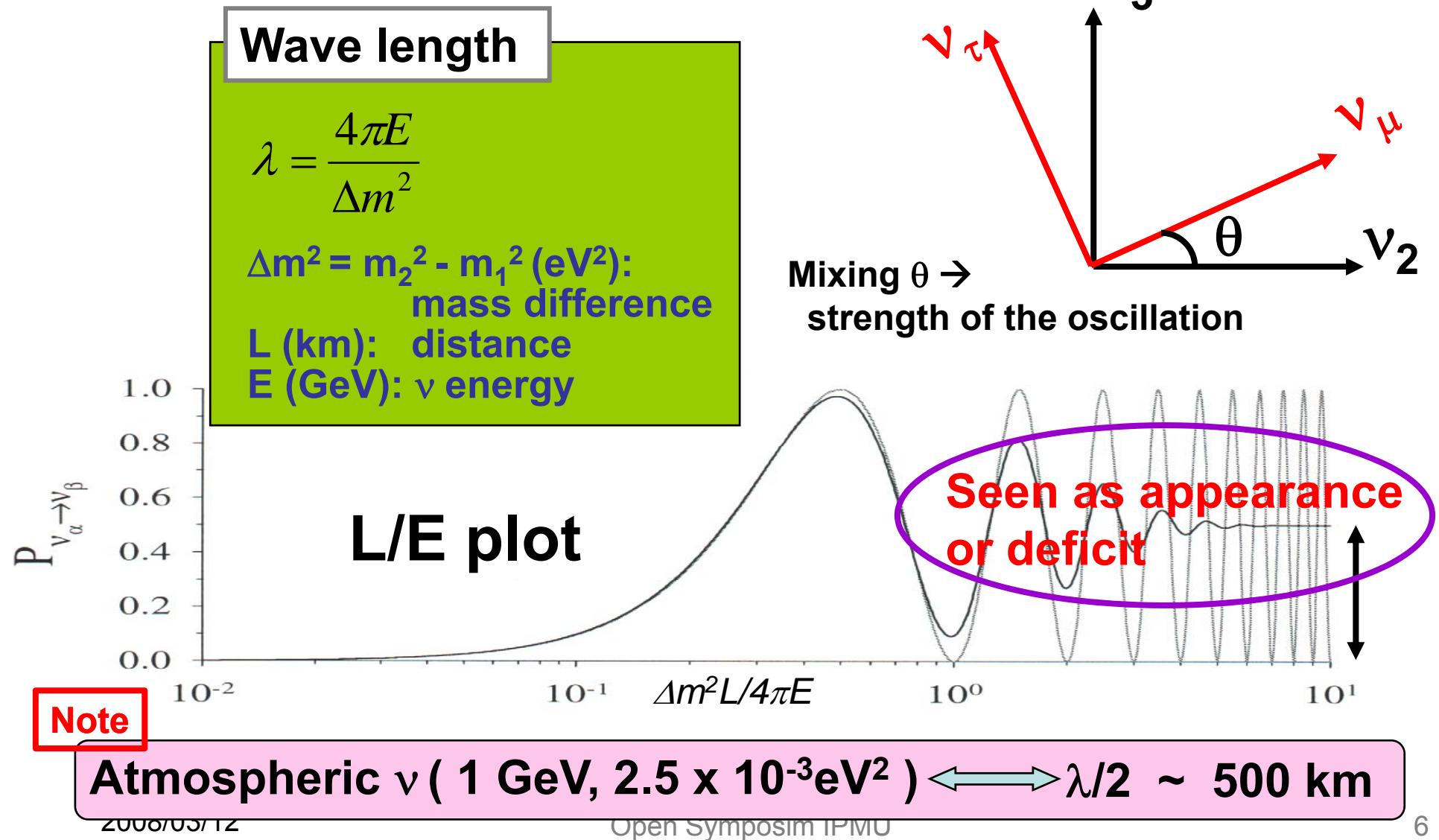


approximately

θ_{atm} ~ θ₂₃, θ_{sol} ~ θ₁₂

Neutrino oscillations for two neutrino case

$$P(\nu_\mu \rightarrow \nu_\tau) = \left| \langle \nu_\tau(t) | \nu_\mu(0) \rangle \right|^2 = \sin^2 2\theta_{23} \sin^2 \left(1.27 \frac{L}{E} \Delta m_{23}^2 \right)$$

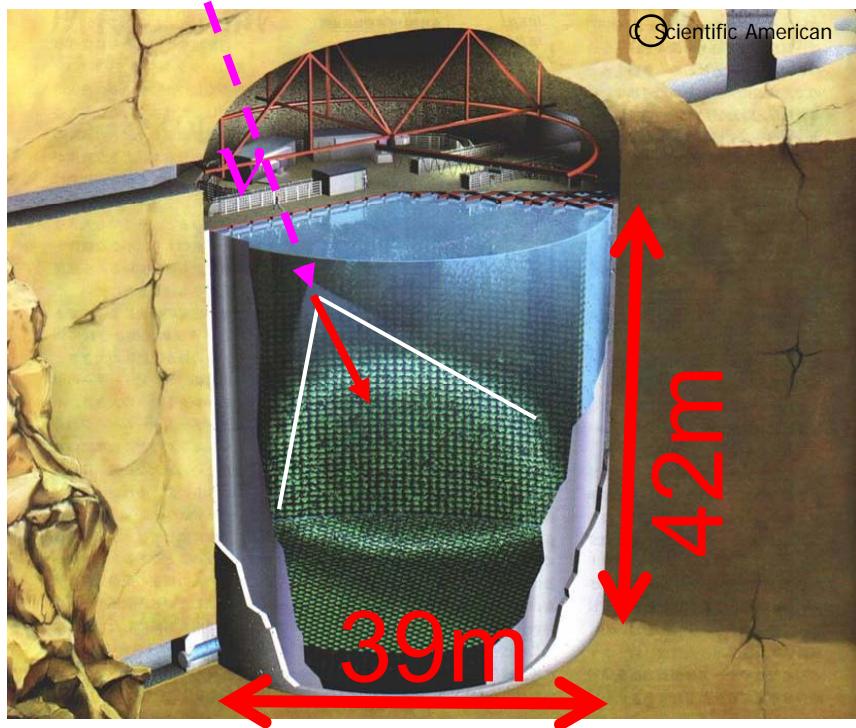


Art McDonald has discussed solar neutrinos,
including SK and KL results, therefore
I will present

- 1) a brief summary of atmospheric ν & K2K,
- 2) future activities in Kamioka underground,
and
- 3) ‘beyond underground’?

Super-Kamiokande

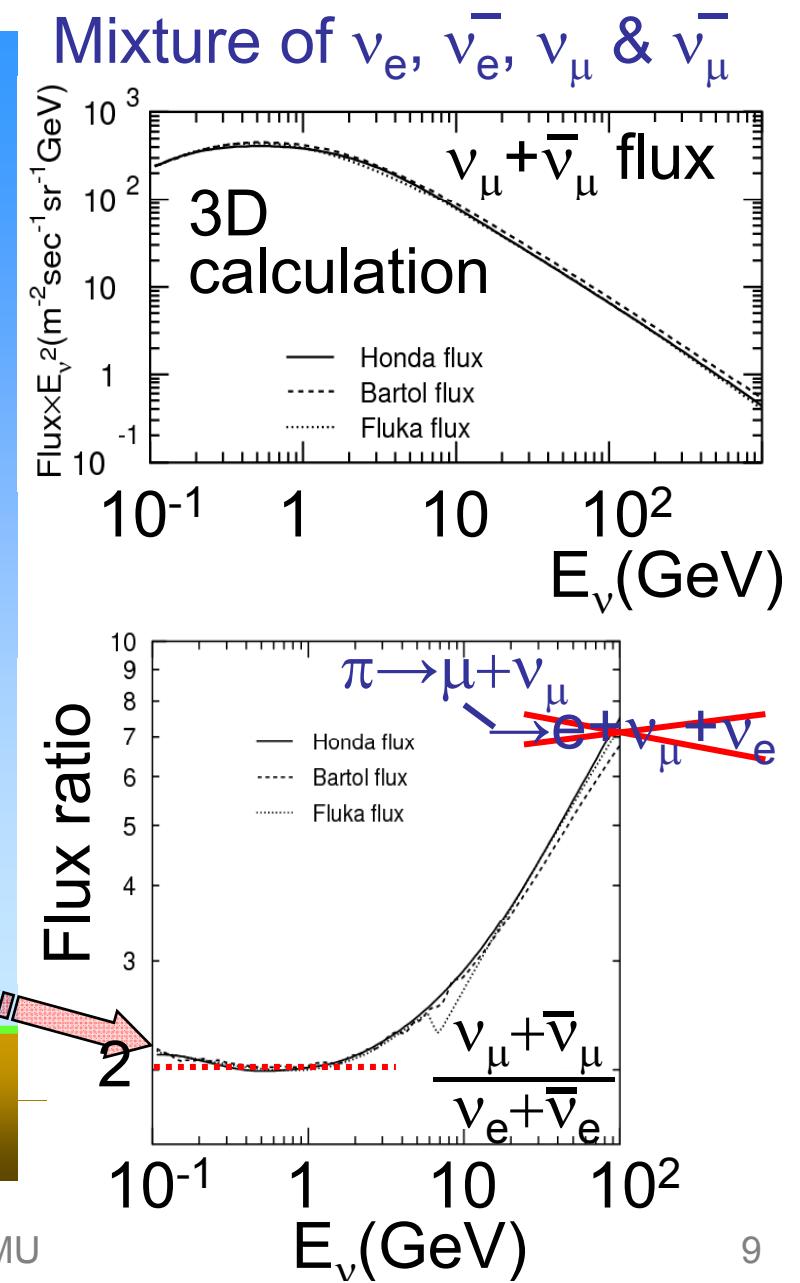
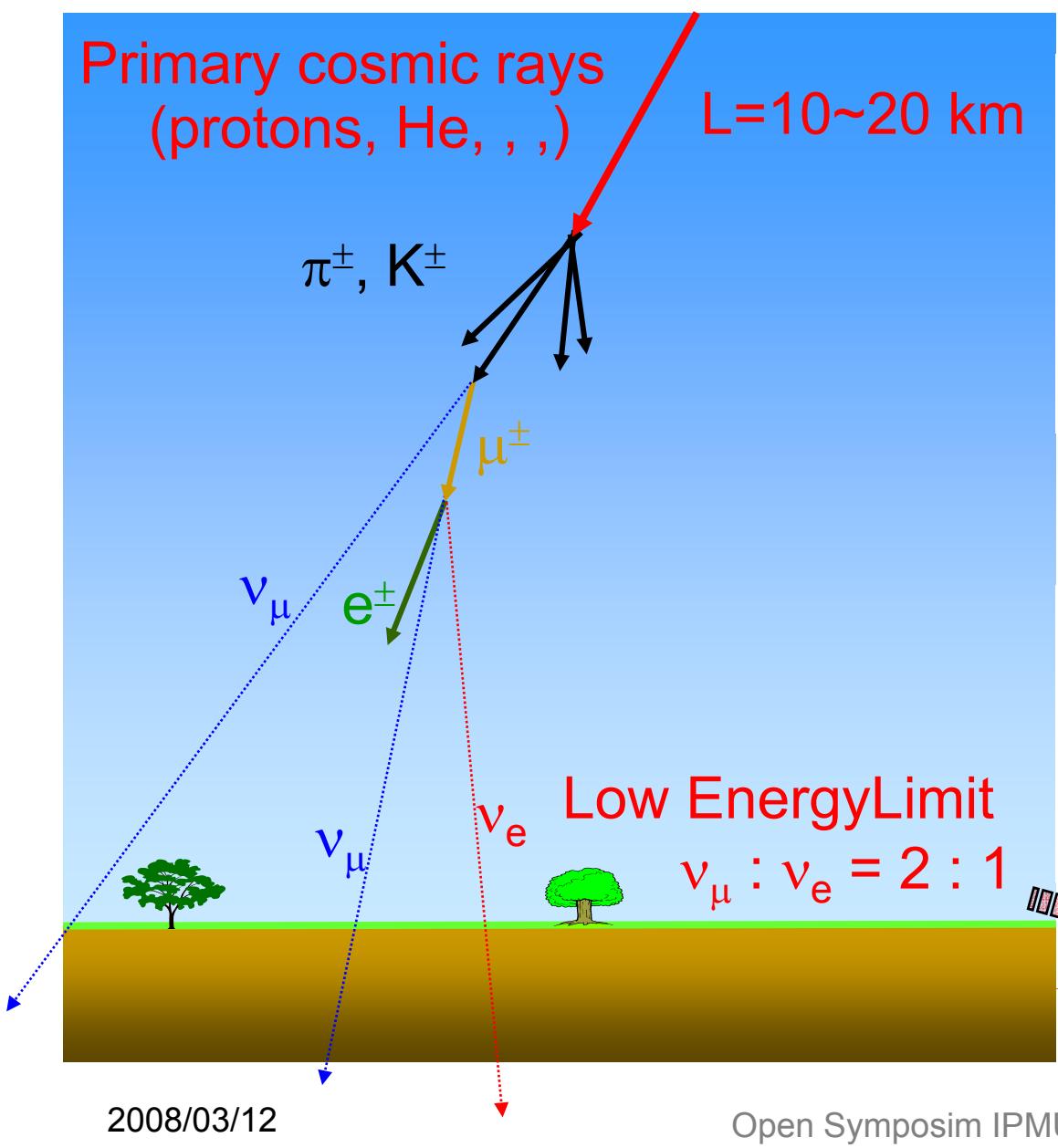
50 kt of Imaging Water Cherenkov Detector



- Inner: 32,000 tons
(Outer Vol: ~2.5 m thick)
- Fid. Vol: 22.5 kt \leftarrow 1kt(KM)
- 11,146 PMTs (ID)
 - 50 cm in diameter
 - 40% coverage \leftarrow 20%(KM)
- 1,885 PMTs (OD)
 - 20 cm in diameter
- 1,000 m underground

***45 times more solar neutrino data \leftarrow KM
with lower energy threshold (5 MeV \leftarrow 7 MeV)***
***20 times more atmospheric neutrino data
w/ better resolution***

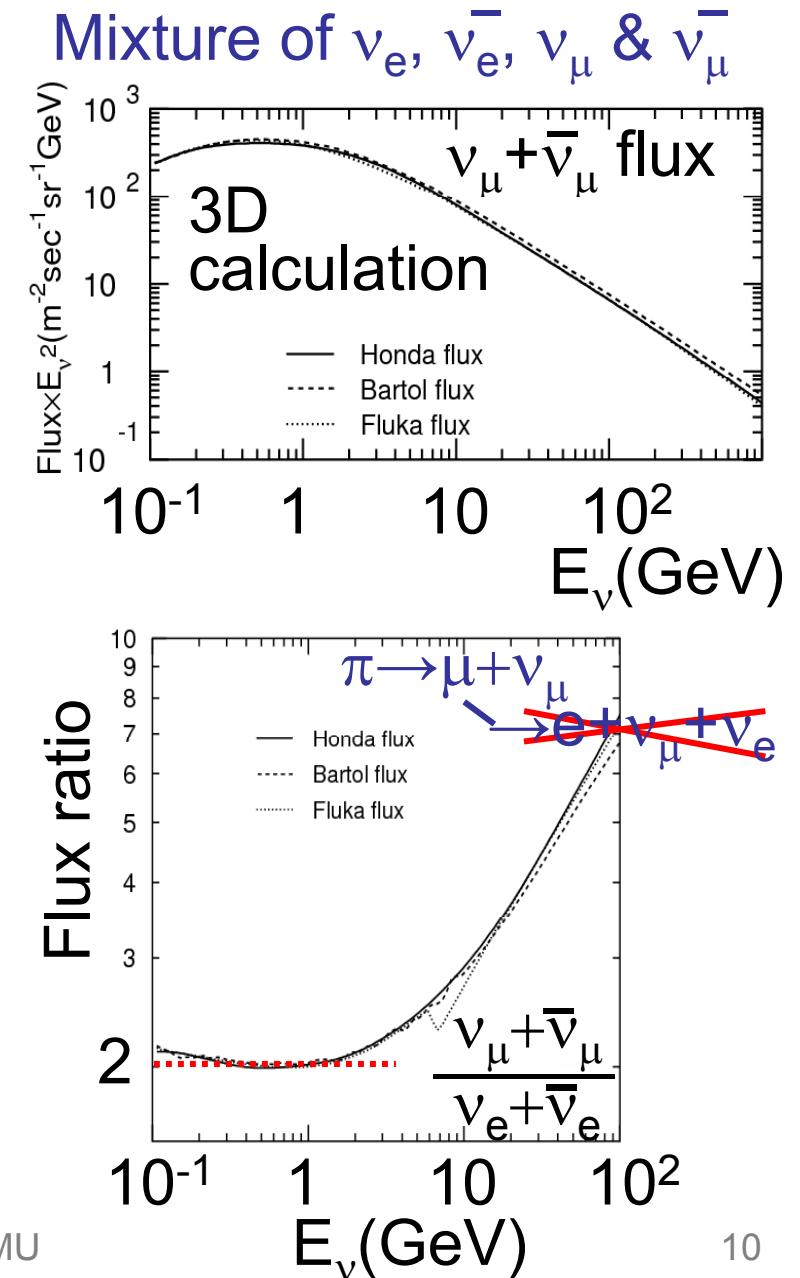
Atmospheric Neutrinos



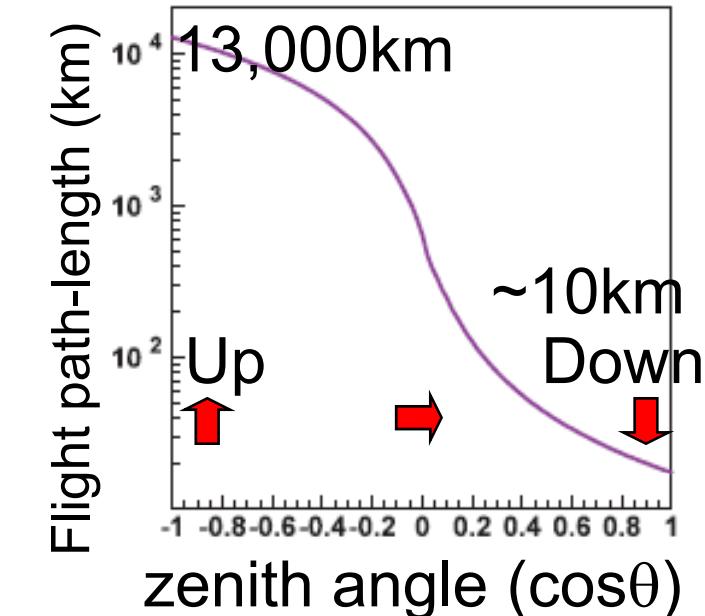
Atmospheric Neutrinos

The atmospheric neutrino flux calculation

- Many improvements for the last ~10 years
 - Primary flux (AMS, BESS,,,,)
 - hadronic interactions
 - 3D calculation
 - and so on
- Uncertainty of absolute ν -Flux
 - 10% @ <10GeV
 - Uncertainty in primary proton flux: $E_{\text{proton}}^{-2.71}$ ($\delta\alpha \sim 0.05$: @ $E_{\text{pr}} > 100\text{GeV}$)
- Uncertainty in R (flux)
 - 3% @ <5GeV
 - 15% @ 100GeV



Atmospheric Neutrino Events in Super-K



Wide range of path-length (3 orders)
 $L: \sim 10 \sim 13,000 \text{ km}$
 Wide range of the energy (5 orders)
 $E: \sim 0.1 \sim 10,000 \text{ GeV}$

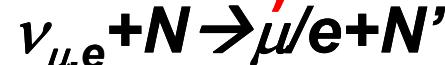


Partially Contained (PC)
 $\langle E_\nu \rangle \sim 10 \text{ GeV}$



Fully Contained (FC)

$\langle E_\nu \rangle \sim 1 \text{ GeV}$



Upward

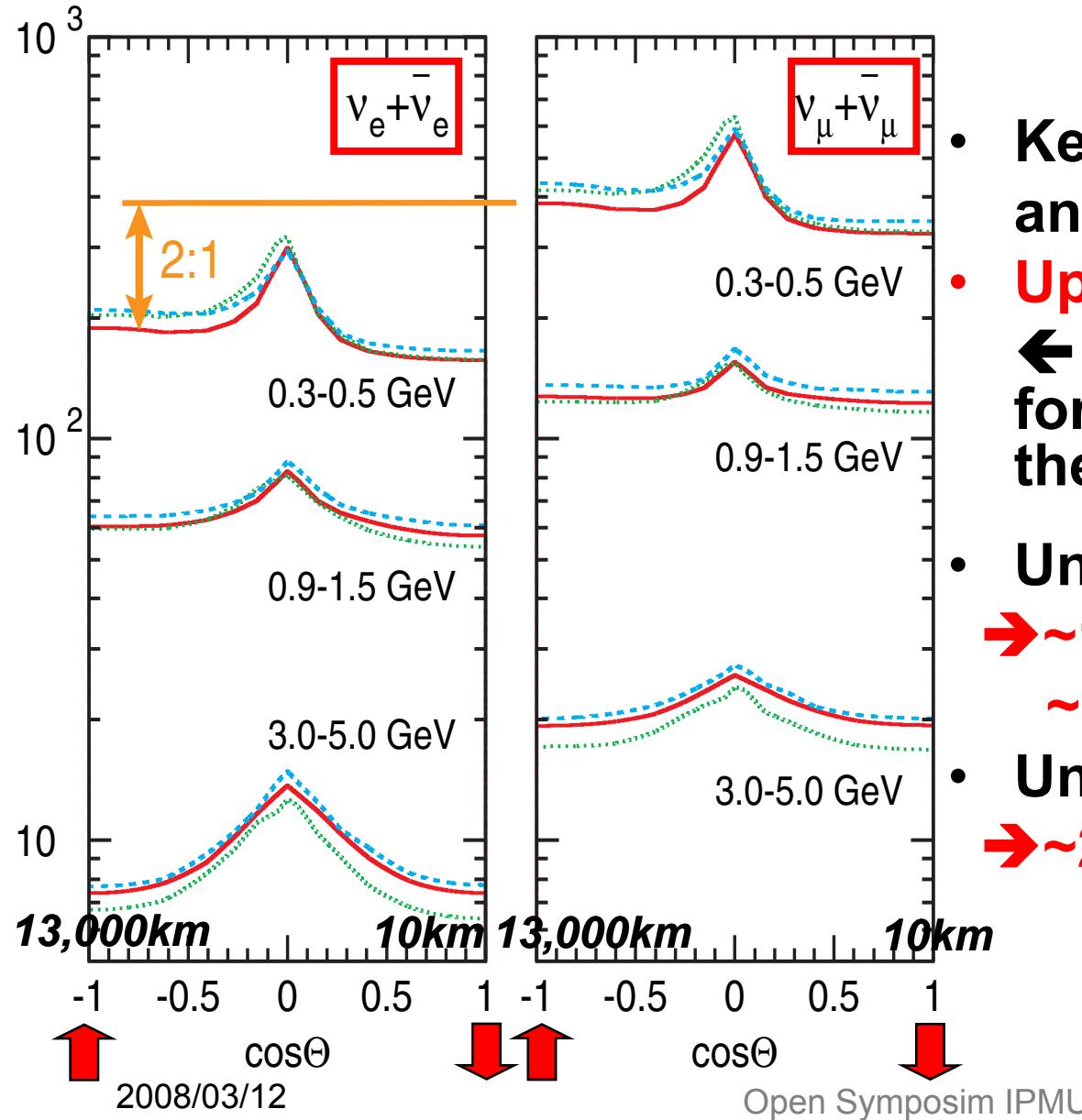
Through-going μ ($\langle E_\nu \rangle \sim 100 \text{ GeV}$)



Upward Stopping μ
 $\langle E_\nu \rangle \sim 10 \text{ GeV}$



Zenith angle distribution

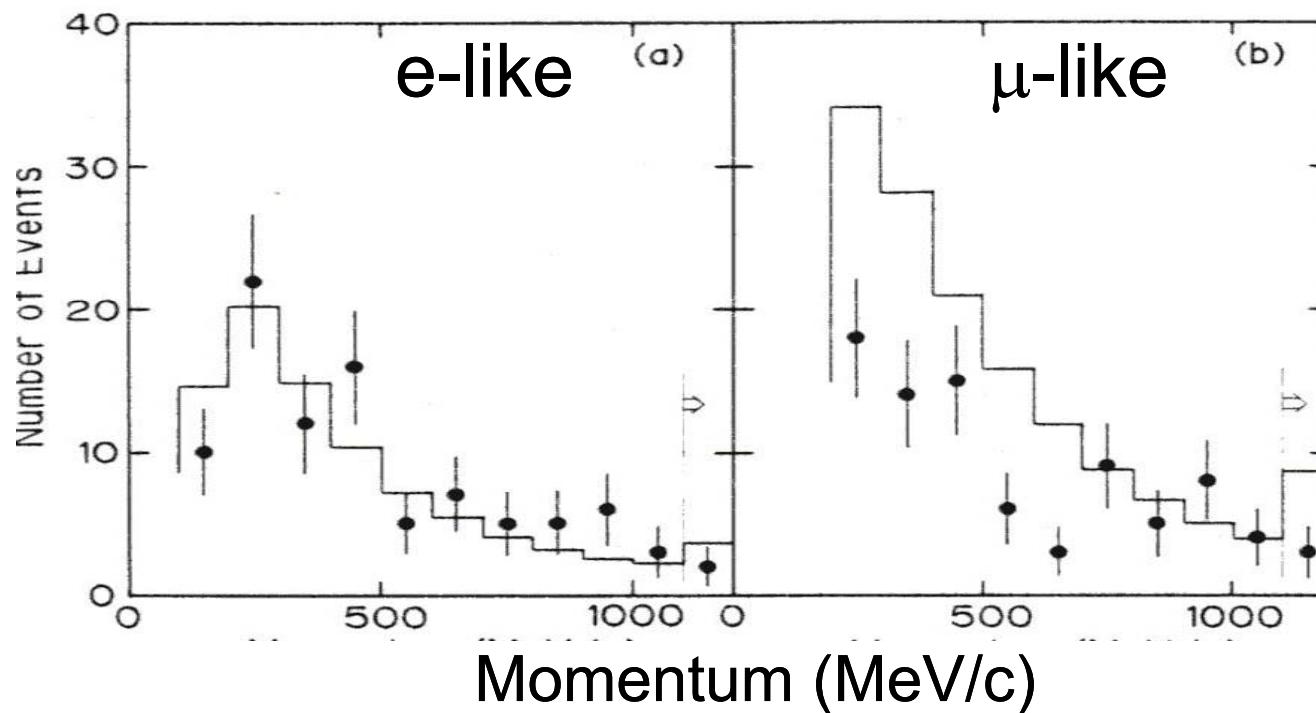


- Key to the oscillation analysis
- Up-Down Symmetry ← uniformity of Pr. CR for the energy above the geomagnetic cut off
- Uncertainty in Up/Down → ~1~2% $E_\nu < 1\text{GeV}$
~1% in a few GeV region
- Uncer. of Hol./Ver. (up- μ) → ~2% (from π/K ratio)

Historical Remarks

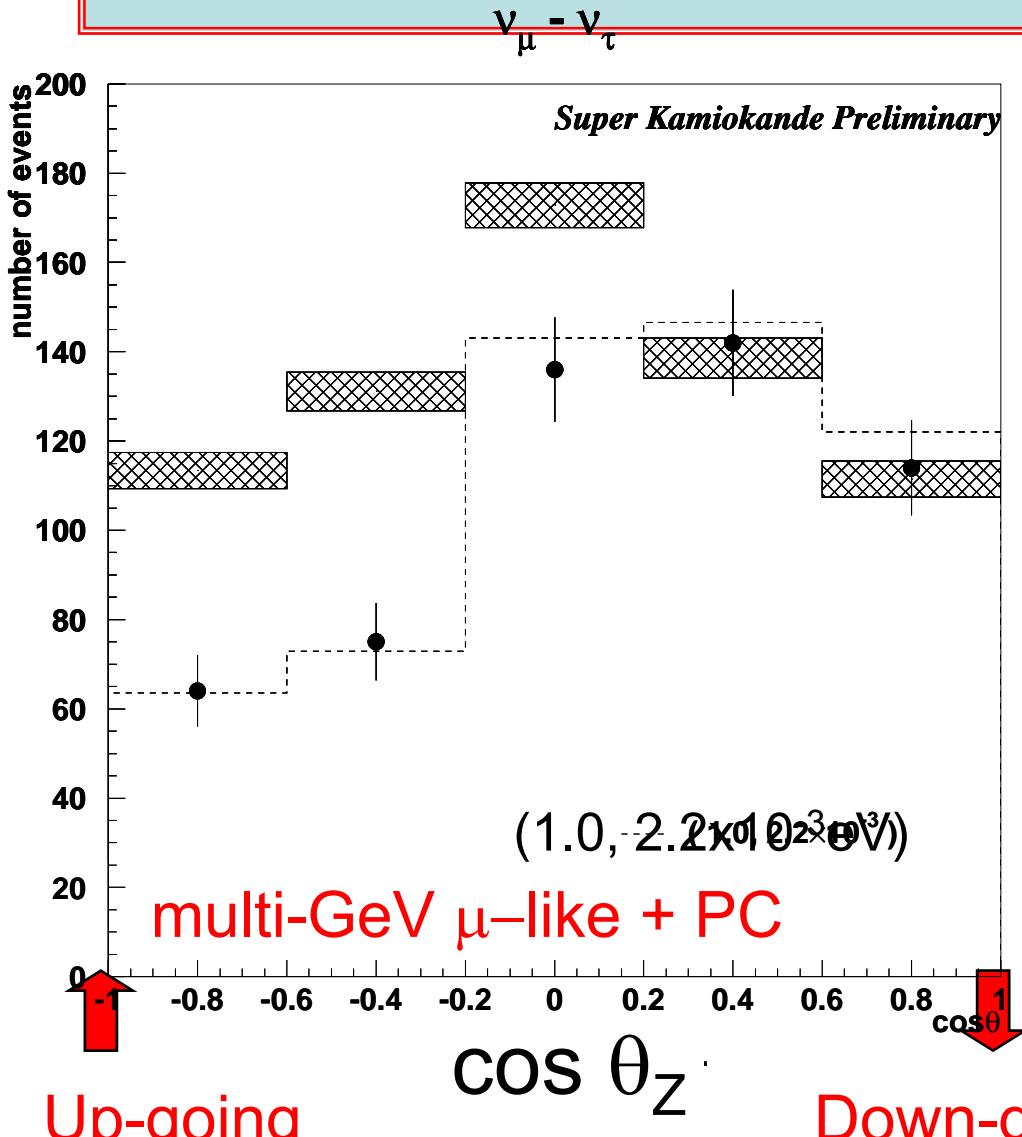
In 1988, Kamiokande saw few μ

$$(\text{Obs./MC})\mu\text{-like} = 0.59 \pm 7\% \text{ (stat.)}$$



- **Problems:**
 - Large uncertainty of the flux calculation
 - Theorists did not believe large mixing

Discovery of Atmospheric Neutrino Oscillation by Super-Kamiokande

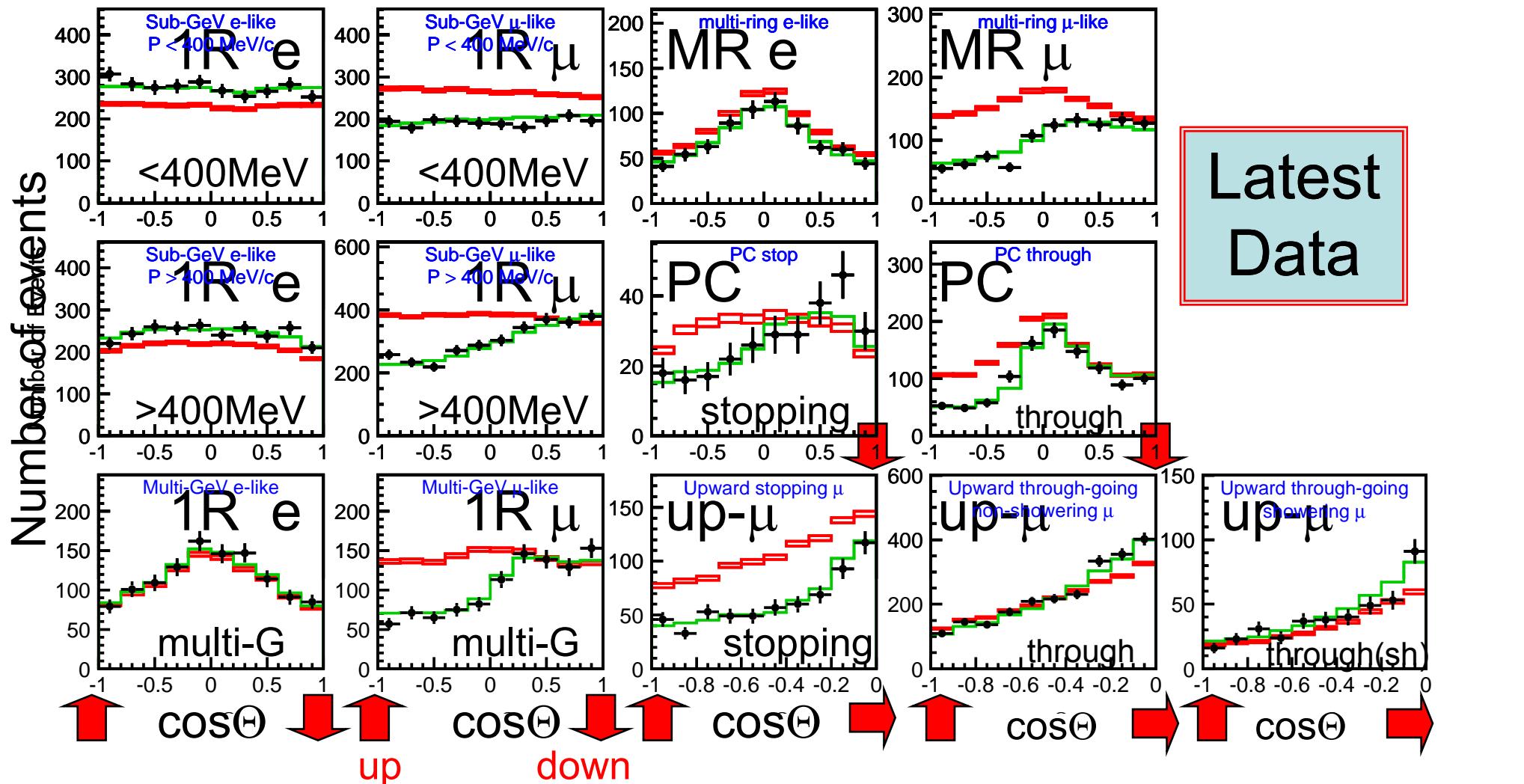


In 1998 (10 yrs later)
SK provided

- definitive evidence in zenith angle distributions
- independent of the absolute value of flux calculations

Theorists did believe the results

Zenith angle Distribution (SK-I + SK-II)



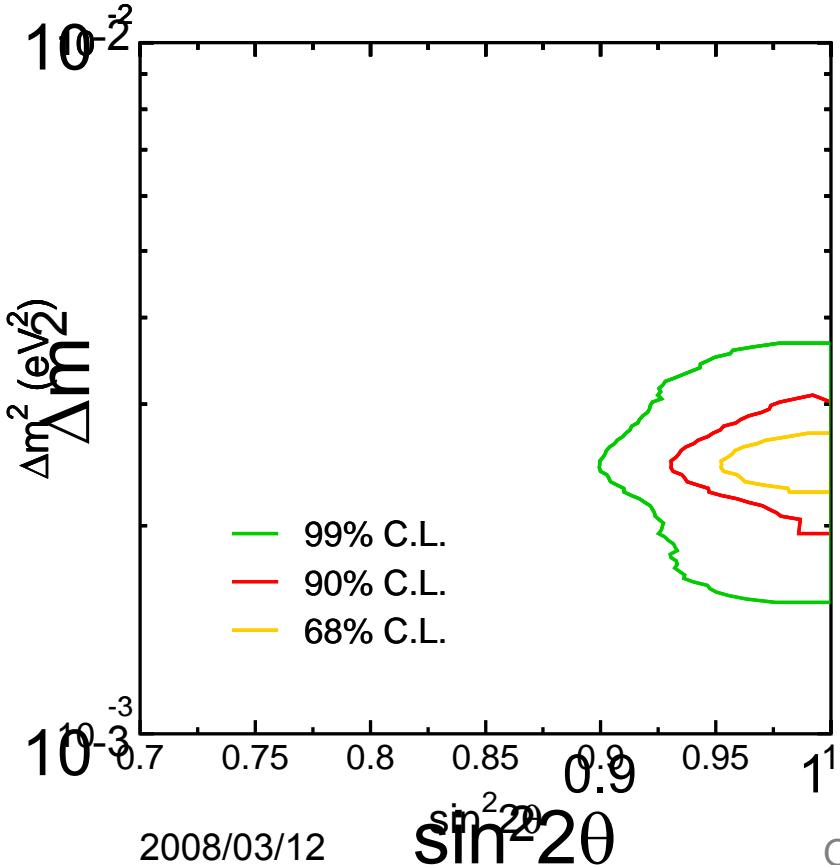
Oscillation Parameters (SK-I + SK-II)

Assume 2 neutrino oscillation: $\nu_\mu \rightarrow \nu_\tau$

of bins

$$\chi^2 \equiv \sum \left(2(N_i^{\text{exp}} - N_i^{\text{obs}}) + 2N_i^{\text{obs}} \ln \frac{N_i^{\text{obs}}}{N_i^{\text{exp}}} \right) + \sum_{j=1} \left(\frac{\varepsilon_j}{\sigma_j} \right)^2$$

$$N_i^{\text{exp}} = N_i^0 \cdot P(\nu_\alpha \rightarrow \nu_\beta) \cdot (1 + \sum_{j=1} f_j^i \cdot \varepsilon_j)$$



Best fit (Physical Region)

$$\sin^2 2\theta = 1.00$$

$$\Delta m^2 = 2.5 \times 10^{-3} \text{ eV}^2$$

$$\chi^2_{\text{min}} = 839.6 / 755 \text{ dof}$$

$$\Delta \chi^2 = 555.8 \text{ (for no osc.)}$$

1.9 × 10⁻³ eV² < Δm² < 3.1 × 10⁻³ eV²
 $\sin^2 2\theta > 0.93$ (@90% C.L.)

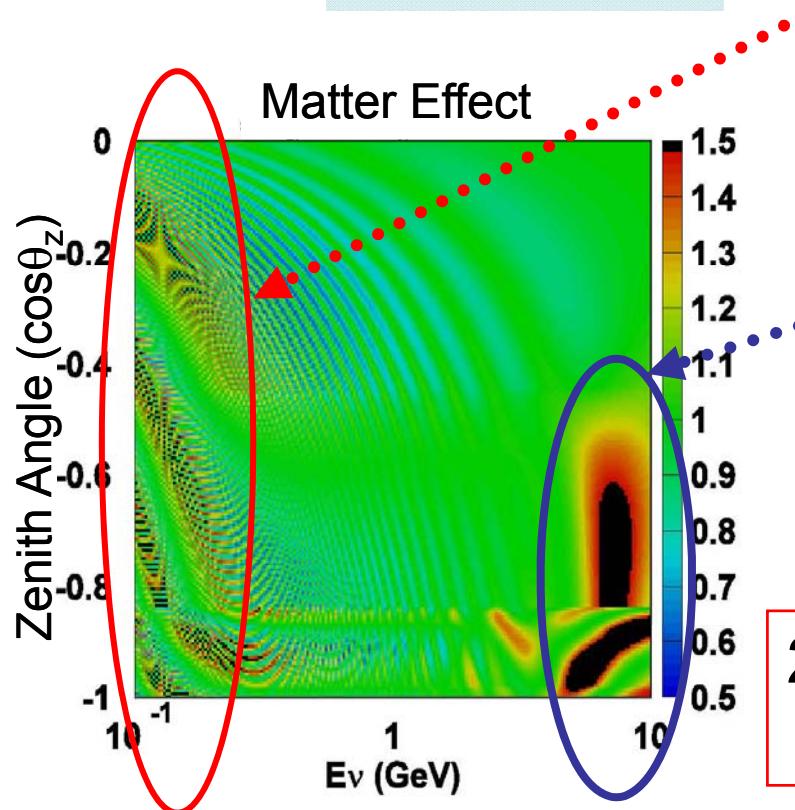
Other effect expected from the neutrino oscillation

- *Evidence for τ appearance ($\nu_\mu \rightarrow \nu_\tau$)? Yes*
- *Oscillation pattern? Yes*
- *Subdominant effects? Not yet!*
 - Effect of Δm_{12} , θ_{12} (Solar term)
 - Octant of θ_{23} (θ_{23} is maximal?)
 - Effect of θ_{13} (θ_{13} can be seen in atm- ν)
 - Effect of CPV
 - Mass hierarchy

3 flavor oscillation and ν_e -appearance

$$\frac{\Psi(\nu_e)}{\Psi_0(\nu_e)} - 1 \cong P_2(r \cdot c_{23}^2 - 1) - r \cdot \tilde{s}_{13} \cdot \tilde{c}_{13}^2 \cdot \sin 2\vartheta_{23} (\cos \delta_{CP} \cdot R_2 - \sin \delta_{CP} \cdot I_2) + 2\tilde{s}_{13}^2 (r \cdot s_{23}^2 - 1)$$

$P_2 = |A_{e\mu}|^2 : \nu_e \rightarrow \nu_{\mu,\tau}$ in matter
 $R_2 = \text{Re}(A_{ee}^* A_{e\mu})$
 $I_2 = \text{Im}(A_{ee}^* A_{e\mu})$
 $r : \mu/e$ flux ratio
 $\sim : \text{mixing angle in matter}$



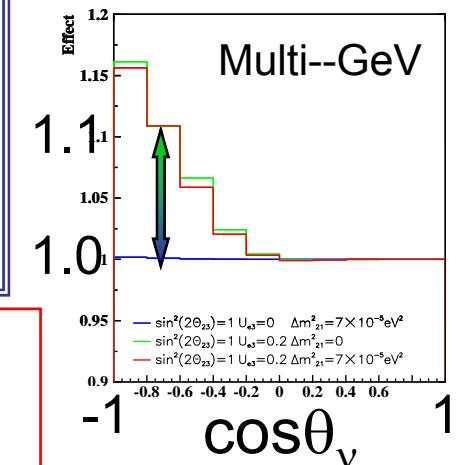
1st term: solar term (θ_{12} , Δm_{12})

mostly in low energy
cancellation effect ($c_{23}^2=0.5, r=\nu_\mu/\nu_e=2$)
1~2% effect

~ 0 for $\cos^2 \theta_{23} = 0.5$
 < 0 for $\cos^2 \theta_{23} < 0.5$
 > 0 for $\cos^2 \theta_{23} > 0.5$

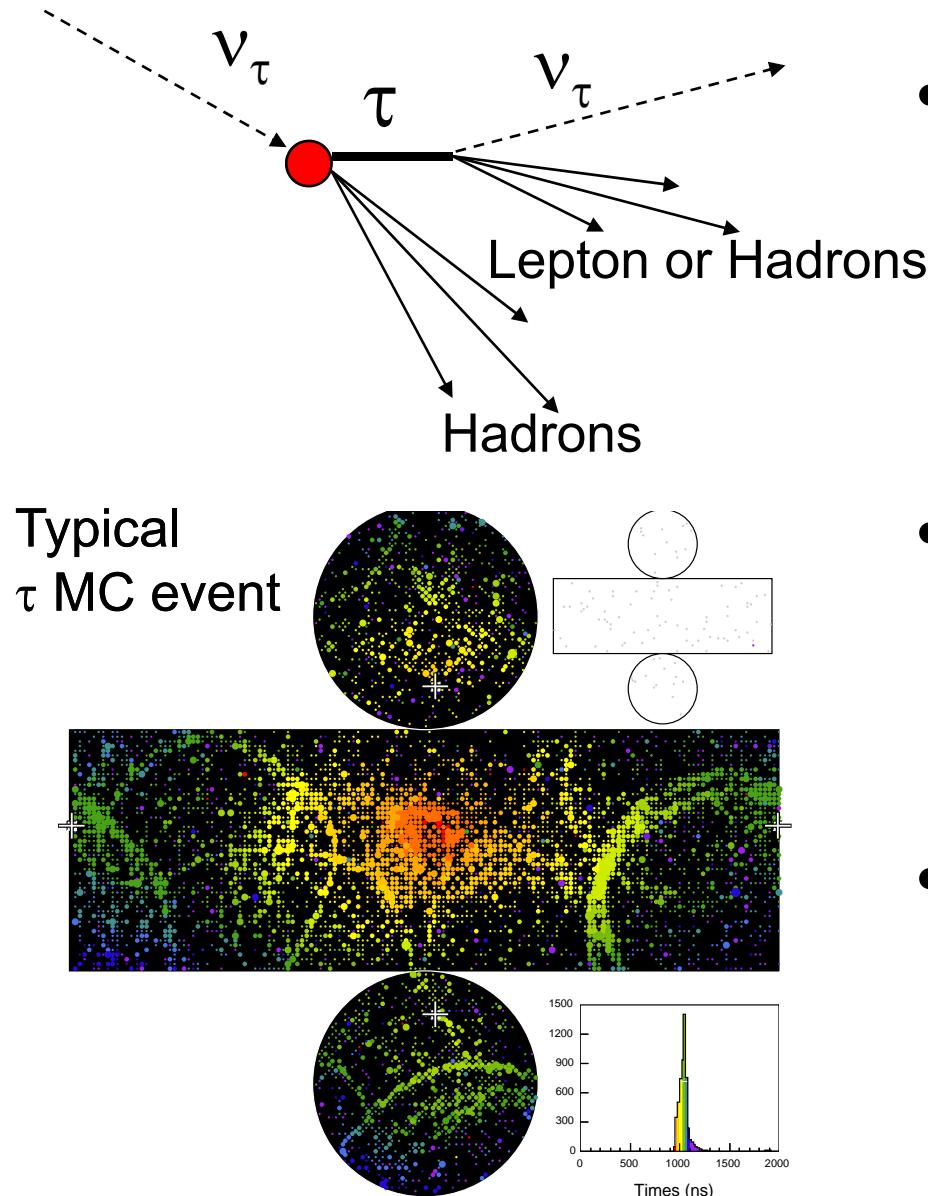
3rd term: θ_{13} term
> a few GeV
in multi-GeV
10~15% effect

2nd term: Interference
CP-phase



No positive evidence yet!

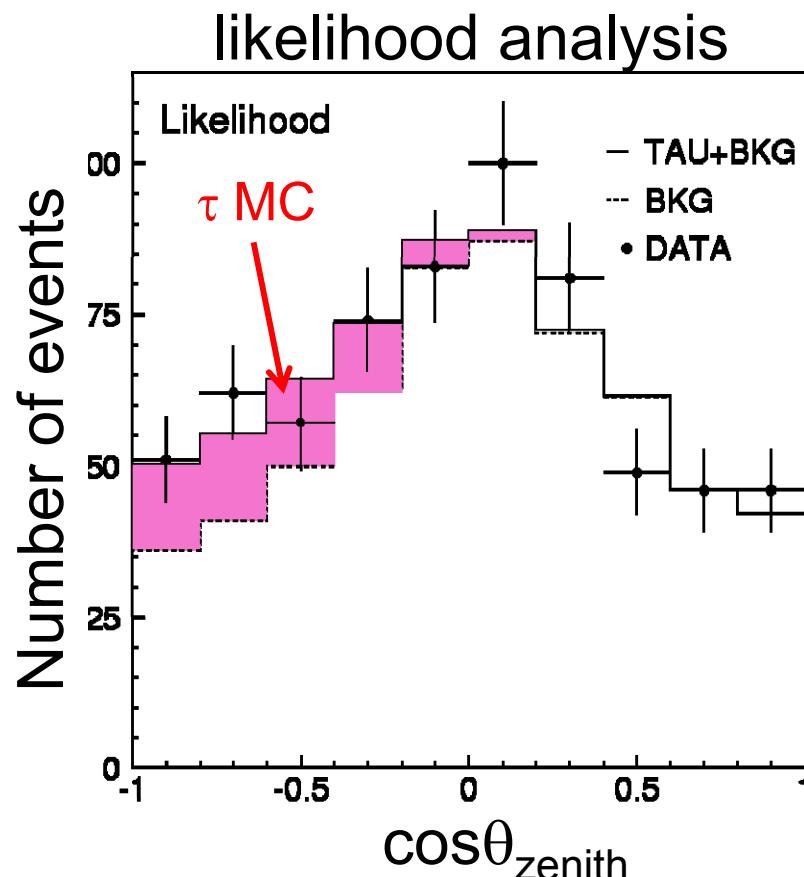
Search for τ appearance in atmospheric ν



- τ events cannot be identified by event-by-event basis
 - ← Many Hadrons
 - ← Complicated events
- Make statistical analysis
 - ← using characteristics of τ production
- But not easy
 - $E_{\text{th}} > 3.5 \text{ GeV}$
 - Low rate
 - $\sim 1 \text{ CC } \nu_\tau \text{ FC ev /kt/yr}$
 - BG: $\sim 130 \text{ ev /kt/yr}$

Zenith angle dist. and results

→ Select τ -like events using
(for 6 distribution) 1) likelihood analysis or
2) neural network meth.



Fitted # of τ events
(corr. for 43% efficiency) $138 \pm 48(\text{stat.})$
 $+14.8 / -31.6$

Expected # of τ events $78.4 \pm 26(\text{syst.})$

Tau appearance
 2.4σ

L/E analysis

- Can observe oscillation pattern in L/E plot $\leftarrow \lambda \sim E$
 - direct oscillatory evidence
 - distinguish other exotic hypotheses
 - strong constraint on Δm^2

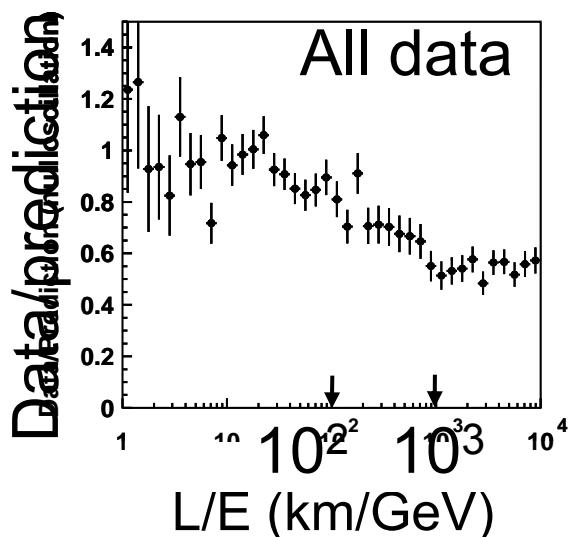
($\lambda/E = 4\pi/\Delta m^2$: Position of Dip)

Difficult to see the pattern
for all the data



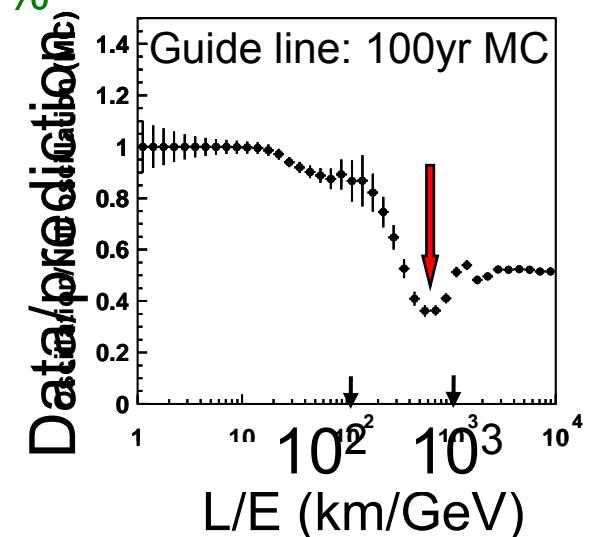
~1 /5 of total data

Select events : $\Delta(E/L) < 70\%$

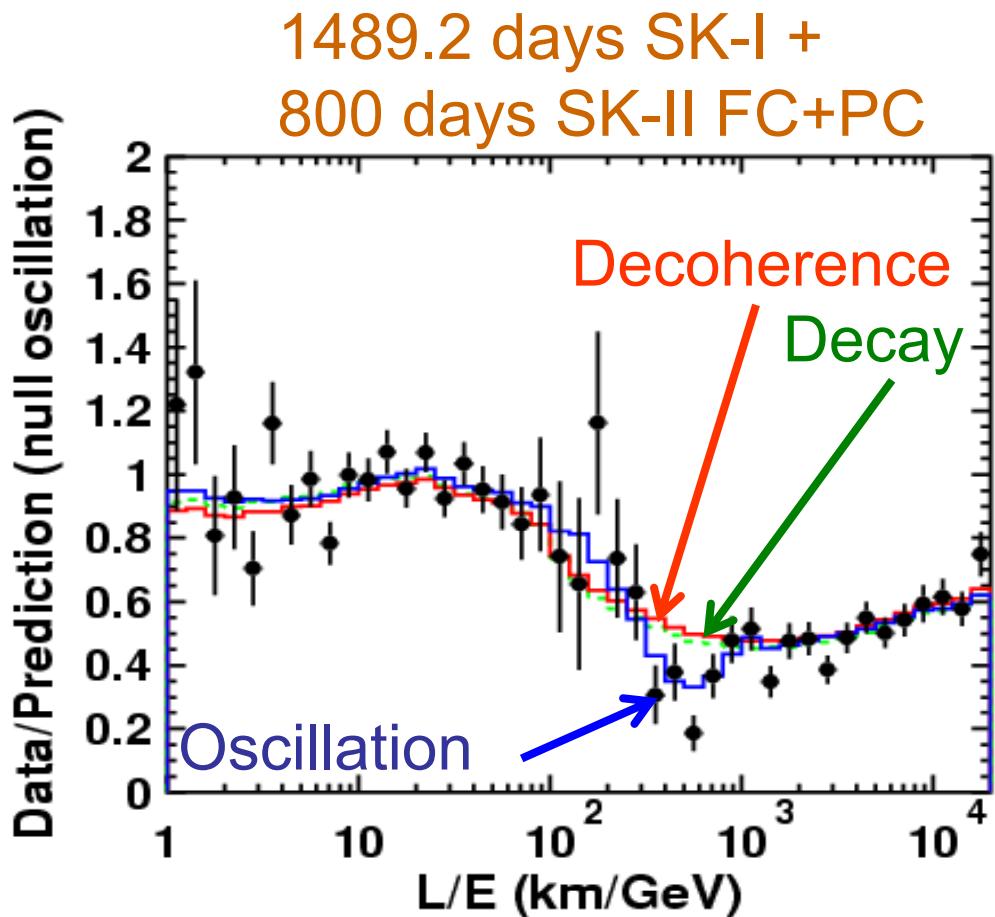


Rejected events

horizontally going events:
low energy events:
→ poor ΔL , $\Delta\theta$ determination

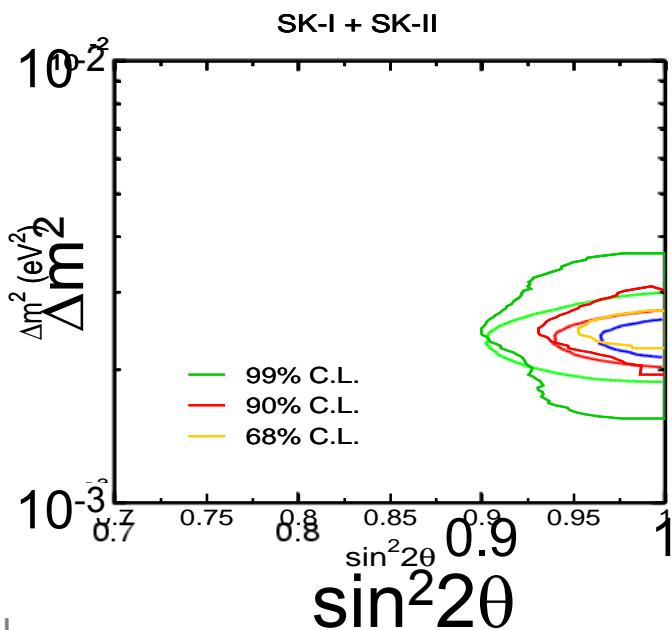


Result of L/E analysis (SK-I + SK-II)



4.8 σ to decay
 5.3 σ to decoherence

- The first dip has been observed at \sim 500km/GeV
- The first dip observed cannot be explained by other hypotheses
- This provides a strong confirmation of neutrino oscillation



K2K (KEK to Kamioka)

Super-K

Experiment started in March, 1999
Completed in November, 2004

KEK
12GeV
PS



$$prob. = \sin^2 2\theta \cdot \sin^2 \left(\frac{1.27 \Delta m^2 L}{E_\nu} \right)$$

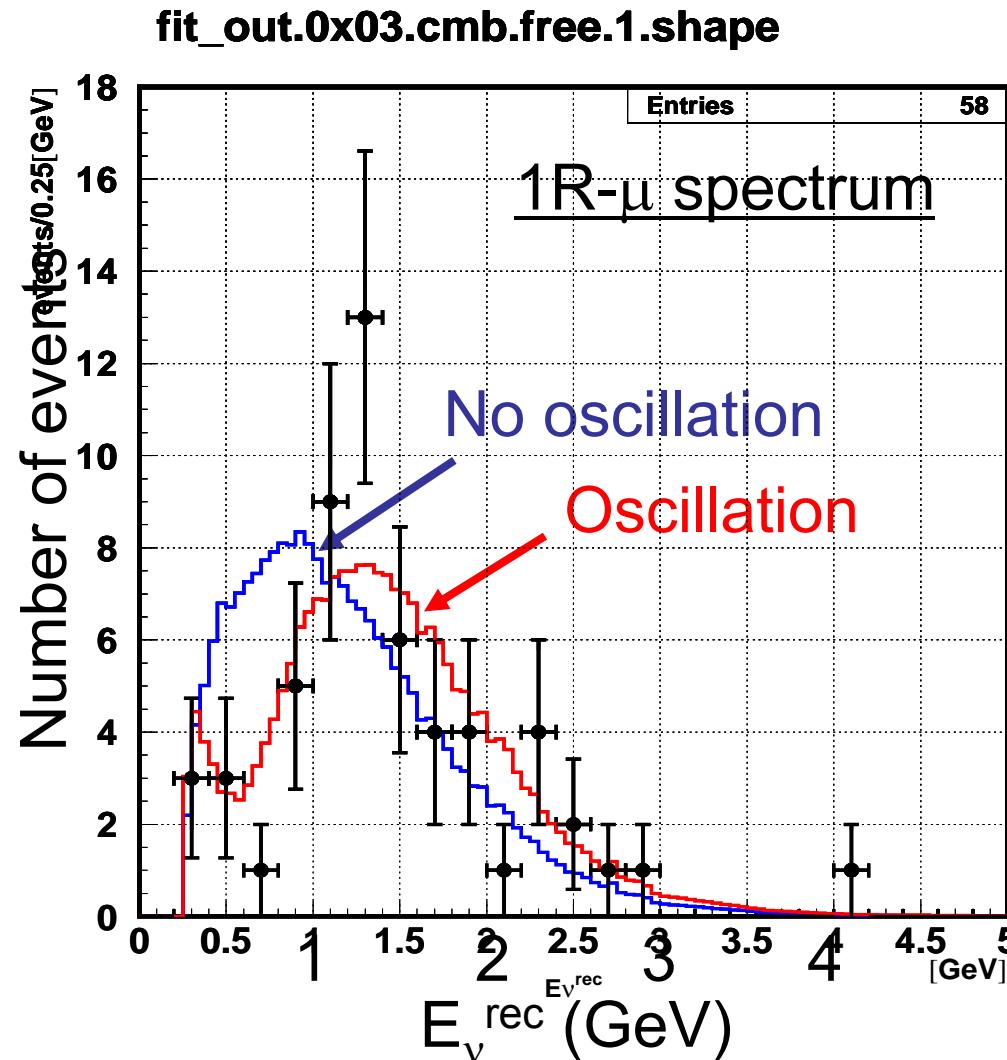
$L=250\text{km}$ (fixed), $\langle E_\nu \rangle \sim 1.3\text{GeV}$
 $\Delta m^2 = 2.5 \times 10^{-3} \text{ eV}^2$, $\sin^2 2\theta = 1$

~ 0.3 Expect ~70% survival

Total POT delivered
Jun.1999 – Nov.2004
 1.0×10^{20} POT

Used for analysis
 0.9×10^{20} POT

K2K_SK event summary

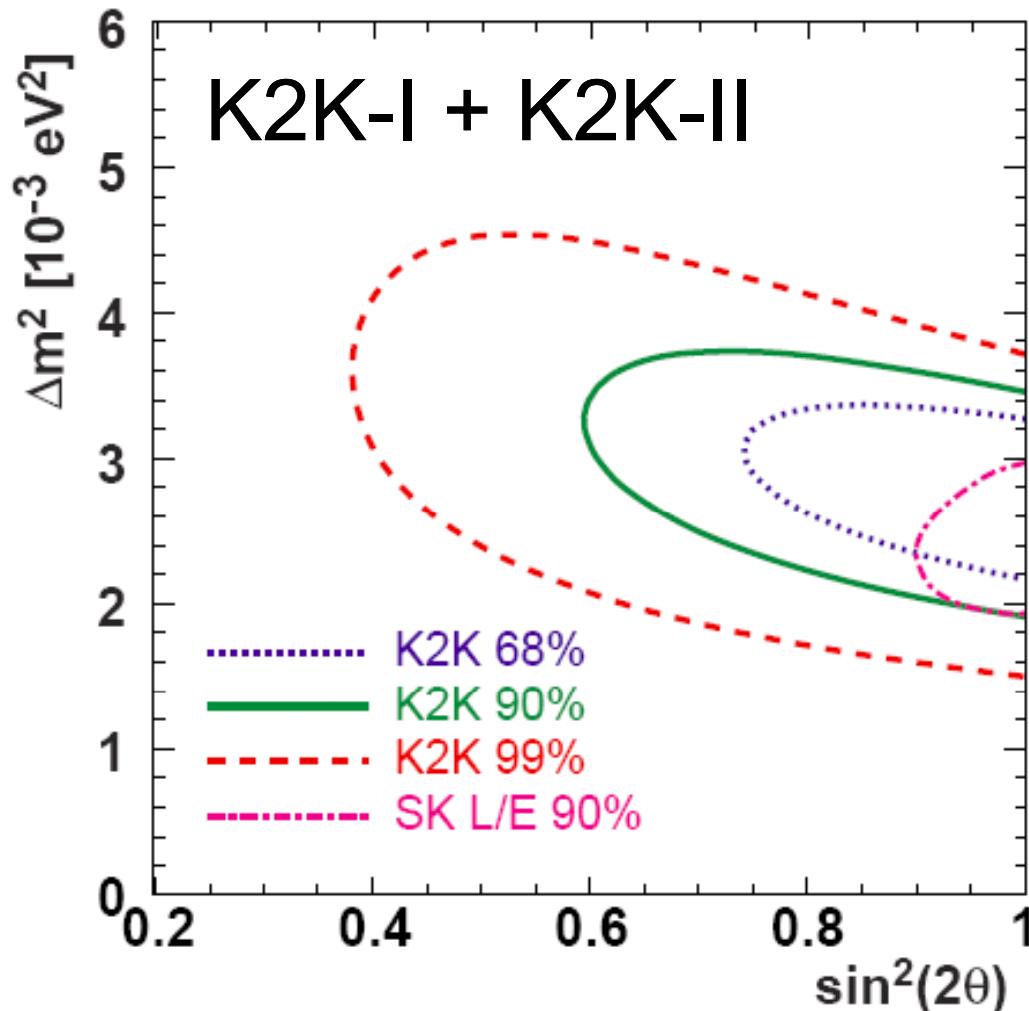


	$N_{\text{sk}}^{\text{obs}}$	$N_{\text{sk}}^{\text{pred}}$
All	112	155.9
1 ring	67	99.0
μ -like	58	90.8
e-like	9	8.2
multi-ring	45	56.8

Spectrum systematics (1 ring μ)
(depend on the energy bin)

Ring count	$\sim 3\text{--}5\%$
Fiducial volume	2%
Particle Id	<1%
Energy scale	$\sim 2\%$

Allowed parameter region



Confirmation of the oscillation consistent with the atmospheric neutrino oscillation

Best fit value
(all region)
 $\sin^2 2\theta = 1.19 \pm 0.23$
 $\Delta m^2 = (2.55 \pm 0.40) \times 10^{-3} \text{ eV}^2$
(in physical region)
 $\sin^2 2\theta = 1.0$
 $\Delta m^2 = (2.76 \pm 0.36) \times 10^{-3} \text{ eV}^2$

$$1.88 \times 10^{-3} \leq \Delta m^2 \leq 3.48 \times 10^{-3} \text{ eV}^2 \text{ (90% CL)} @ \sin^2 2\theta = 1$$

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25

Future Activities

Tokai to Kamioka (T2K)

J-PARC(50 GeV)
(60km N.E. of KEK)



- Long baseline oscillation experiment from JPARC-PS@Tokai to SK
- Beam Intensity: ~50 x K2K
- Baseline: 295km
- Experiment: 2009 ~

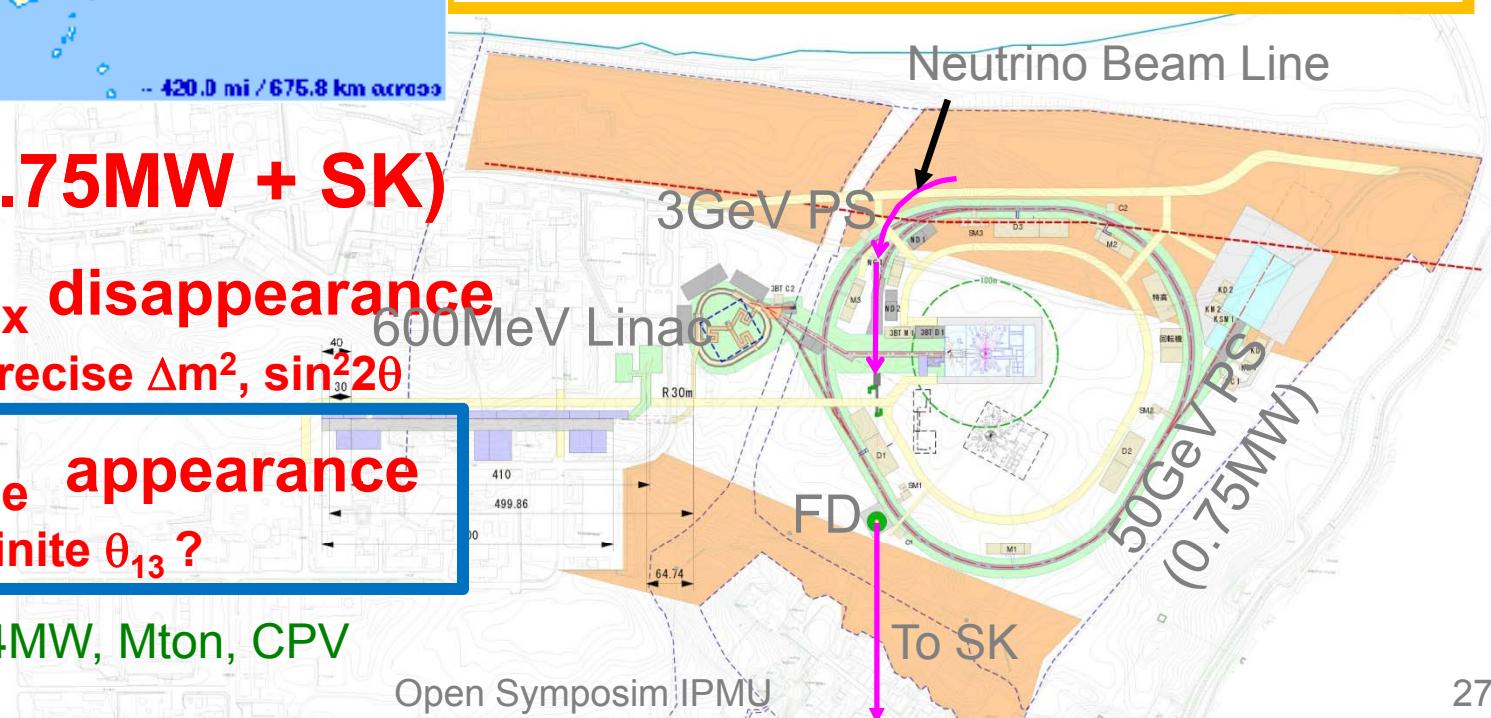
Phase 1 (0.75MW + SK)

- $\nu_\mu \rightarrow \nu_x$ disappearance
 - Precise Δm^2 , $\sin^2 2\theta$

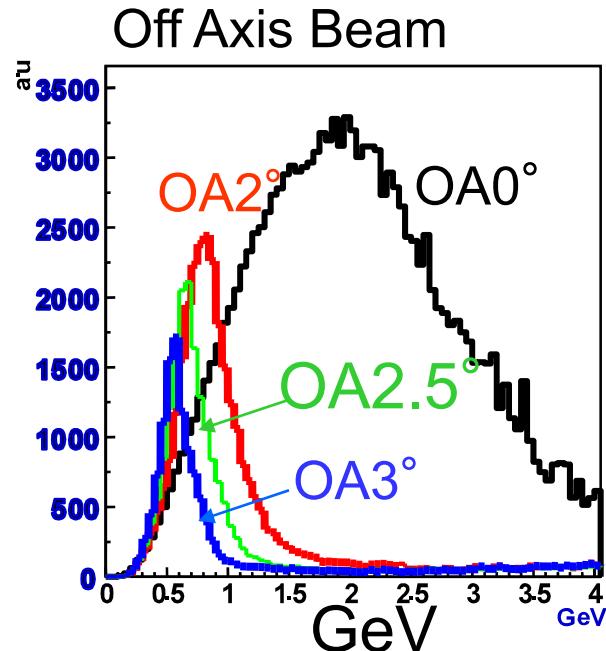
- $\nu_\mu \rightarrow \nu_e$ appearance
 - Finite θ_{13} ?

Phase 2 → 4MW, Mton, CPV

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Event rate and Sensitivity



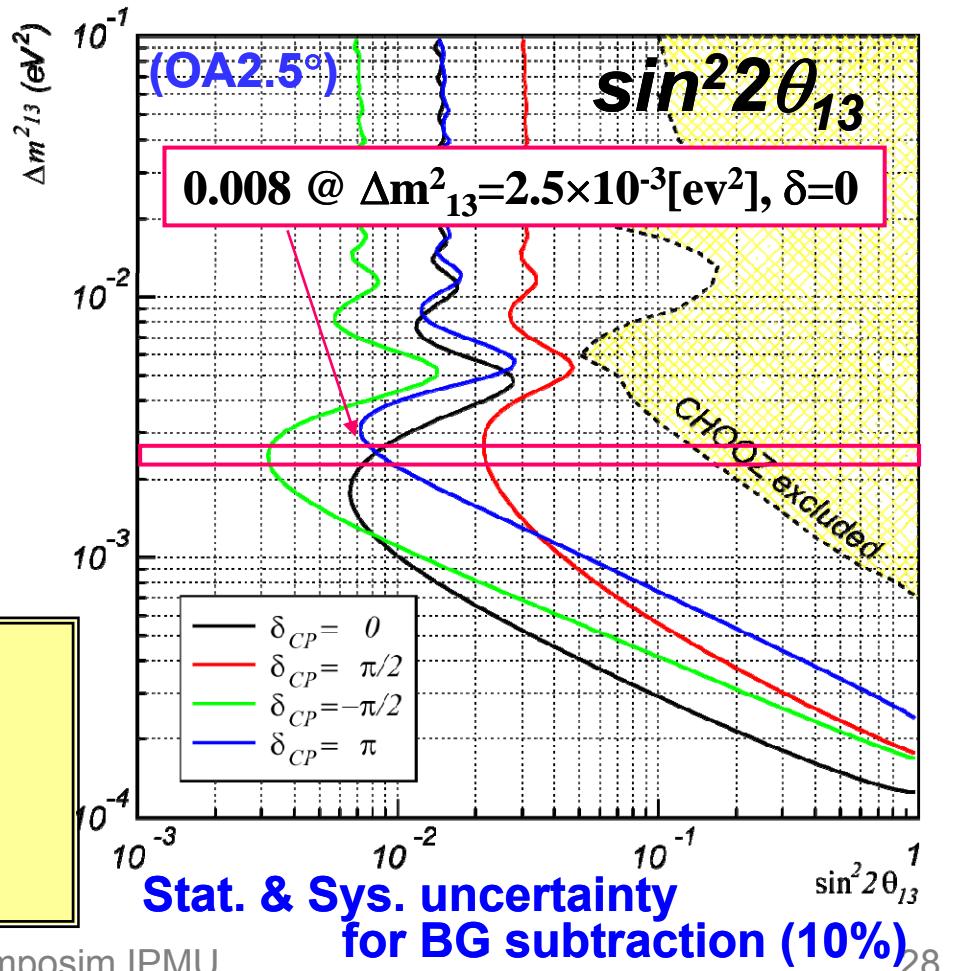
- Quasi Monochromatic
- 2~3 times intense than NBB
- Can be tuned at oscill. max.

Statistics at SK (OAB 2.5 deg, 5 yr)

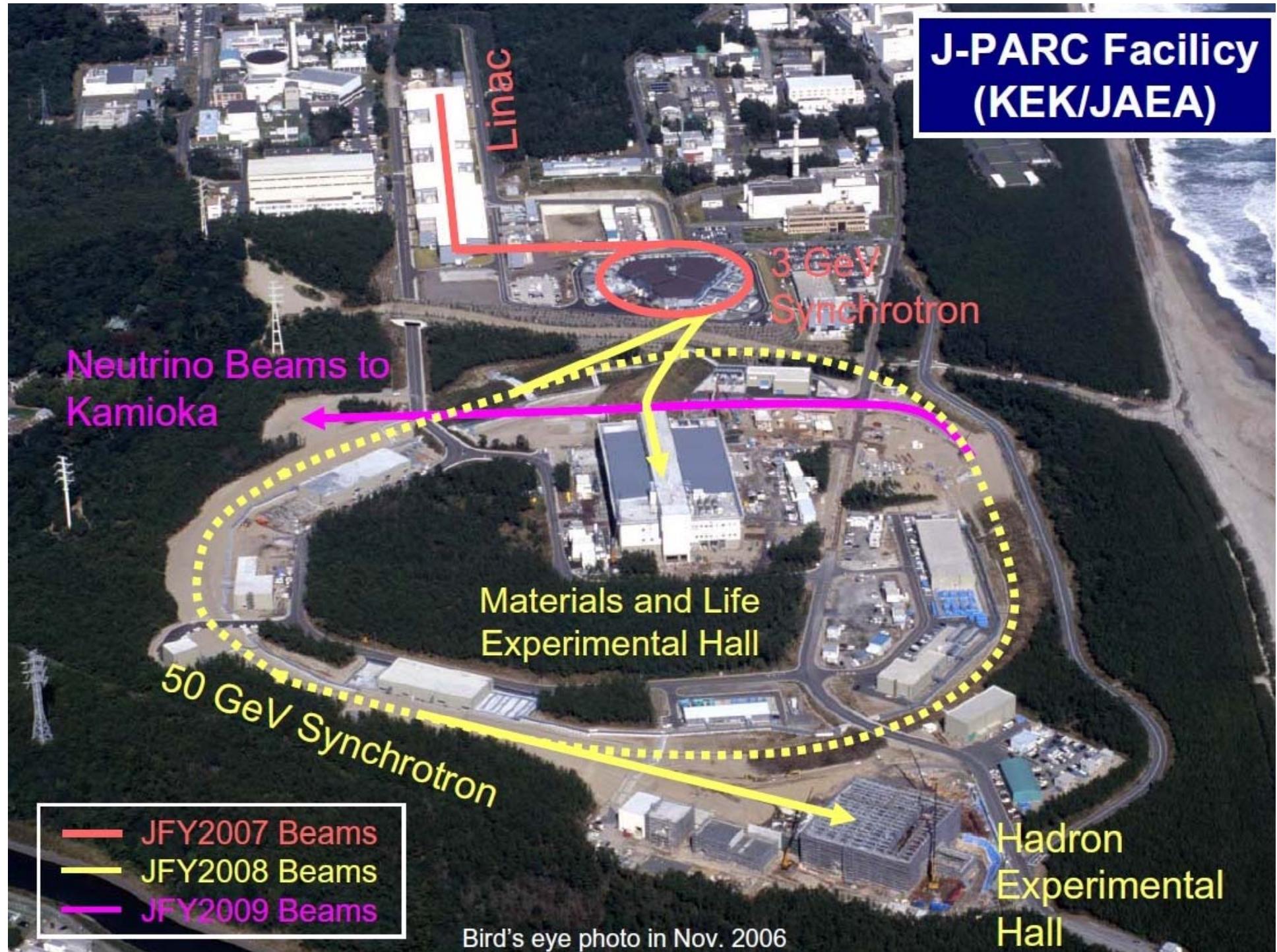
ν_μ	total ~ 11,000
ν_μ	CC ~ 8,000
ν_e	~ 0.4% at ν_μ peak

For 5yr running

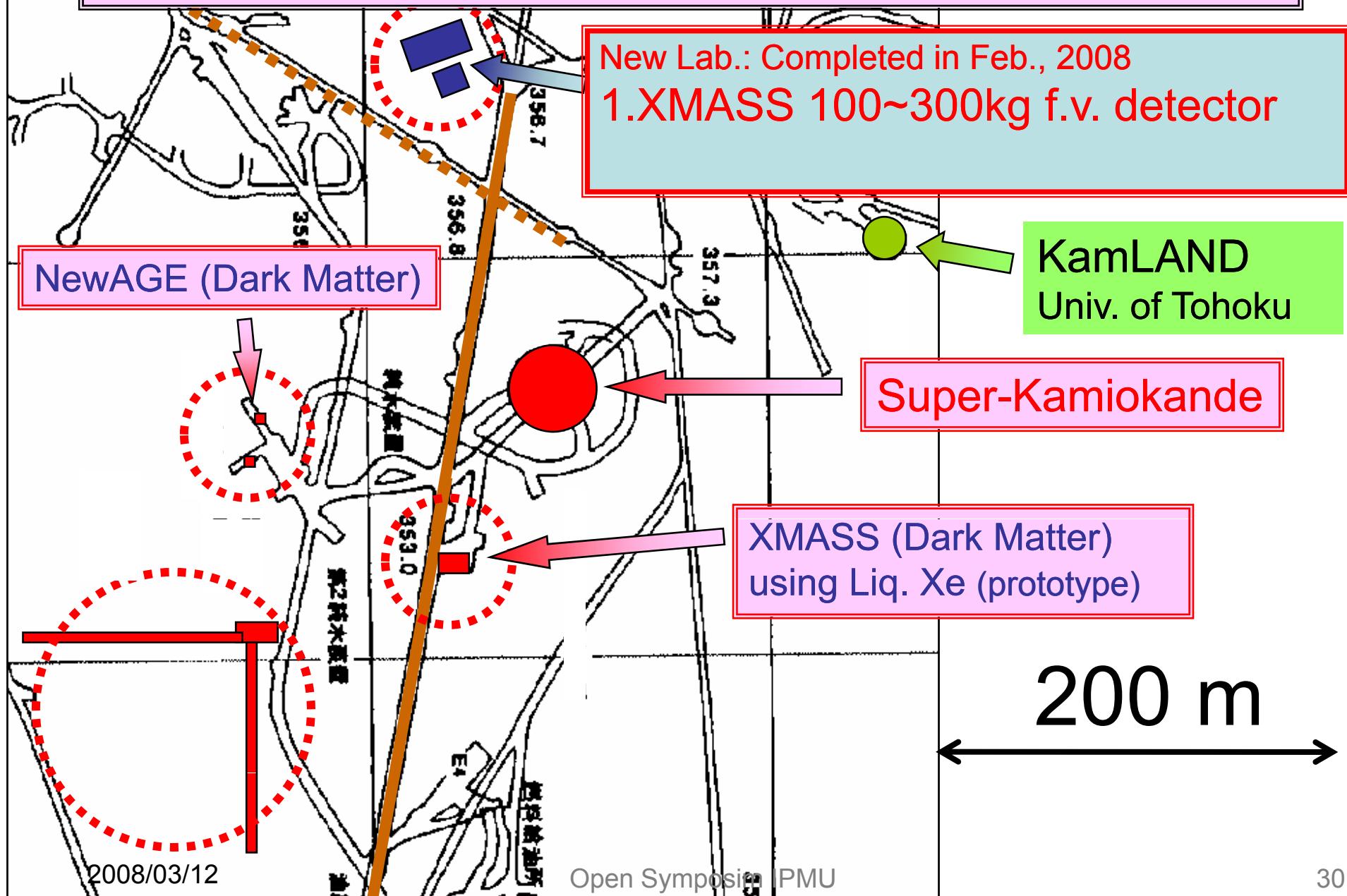
$$\delta(\Delta m^2_{23}) < 1 \times 10^{-4} \text{ eV}^2$$

$$\delta(\sin^2 2\theta_{23}) \sim 0.01$$


J-PARC Facility (KEK/JAEA)



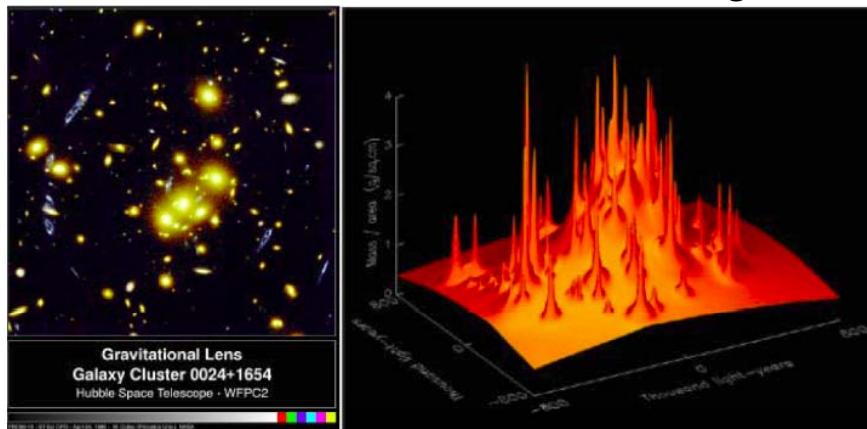
Other Activities for future



Dark Matter

Detailed discussion on Dark Matter will be made
in this afternoon by Prof. Rick Gaitskell

- Cosmological ← WMAP, SDSS
- Cluster of Galaxies ← Gr. lens
Mass distribution of the cluster of galaxies

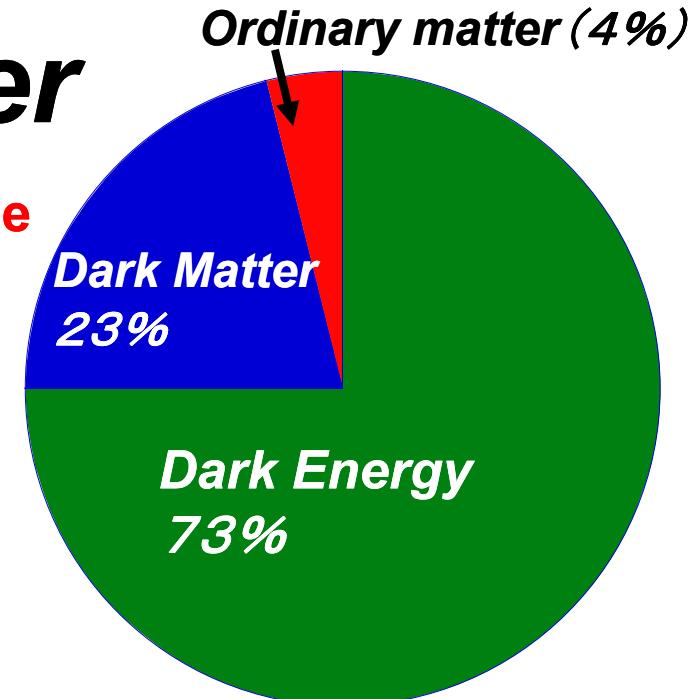


- Galactic Dark Matter
 - velocity: $v_0 = 220 \text{ km/s}$
 - Maxwell Distribution
 - $\rho_{\text{DM}} \sim 0.3 \text{ GeV/cm}^3$

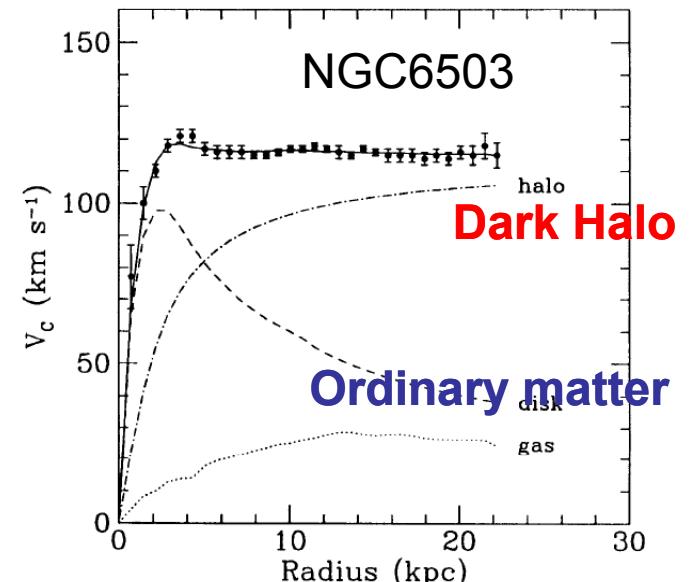
We know dark matter exists

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Rotation Velocity



Direct detection experiments

But we do not know what it really is !
→ Need direct detection

- Rate (aimed sensitivity: $\sigma \sim 10^{-45} \text{ cm}^2$)
 $O(1\text{event}/10\text{days}/100\text{kg})$
- Experimental Requirements

Large volume ~100kg

← low signal rate

Low background

← low signal rate

Low energy threshold (~ a few keV)

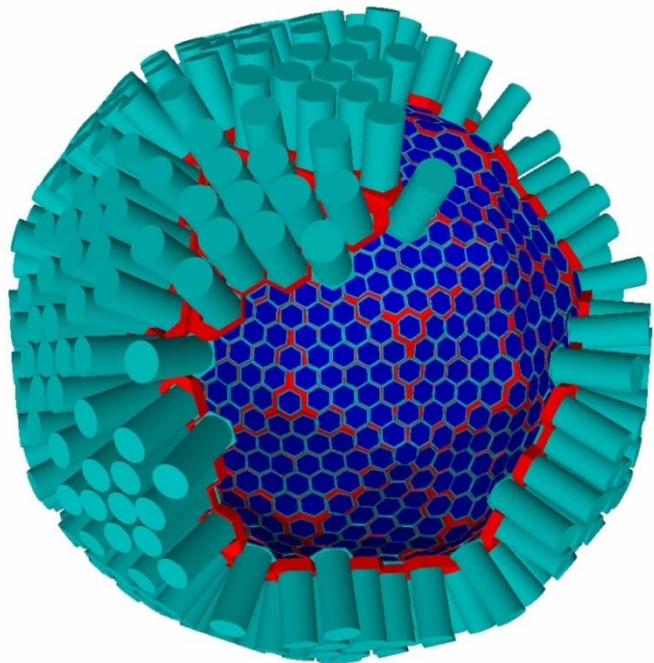
← low energy peak

I will just concentrate on the Kamioka Activities

XMASS

~1ton liquid xenon detector

Why liquid Xenon



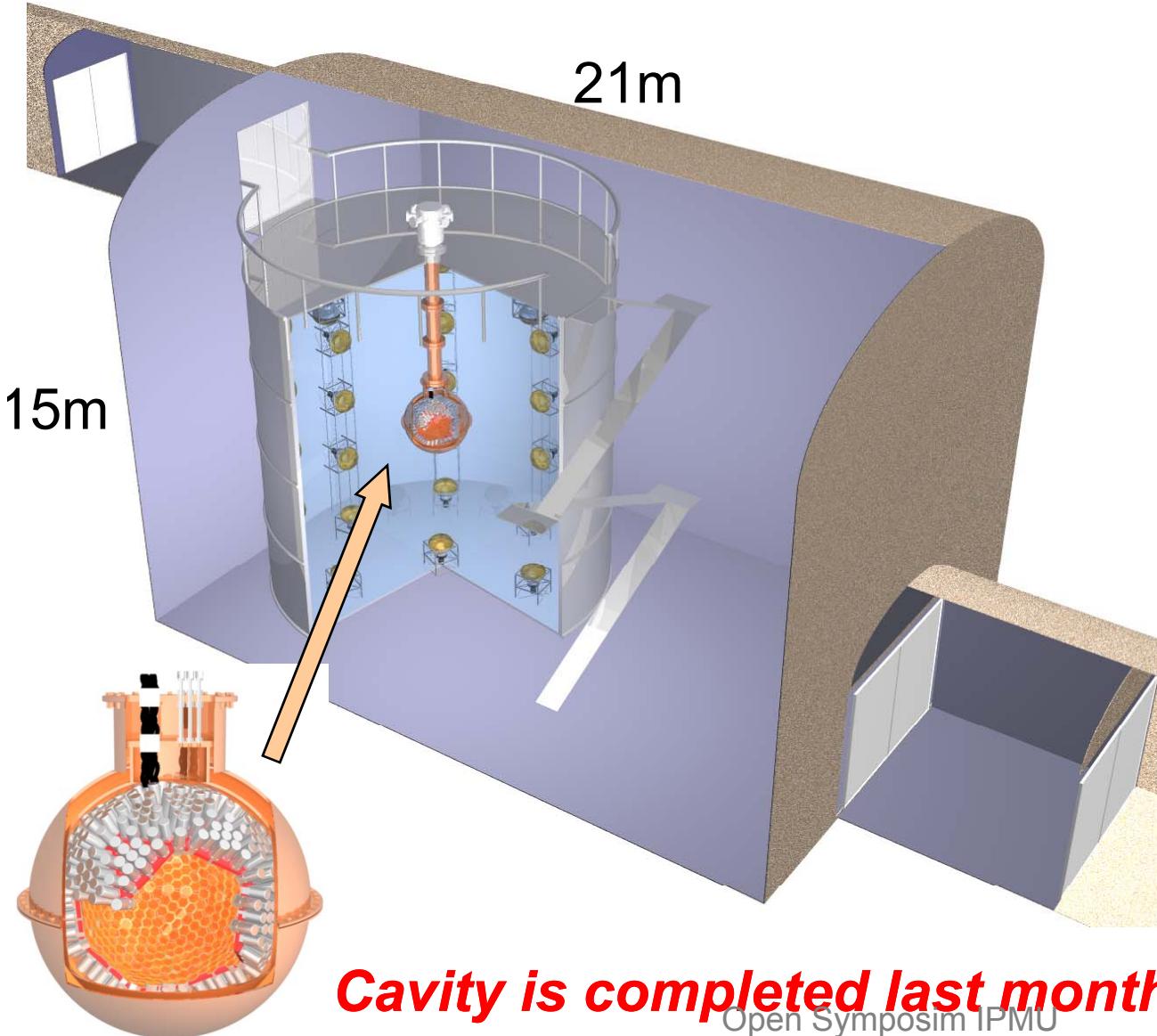
- Large photon yield (~42 photons/keV ~ NaI(Tl))
→ Low threshold
- High density (~3 g/cm³)
→ Compact detector (80cm in diameter)
- Large Z = 54
→ Shielding effect of itself is large: Ext. BG
- Purification is easy (distillation) : ⁸⁵Kr
- No long life radioactive isotope in Xe
- Scintillation wavelength is 175 nm,
→ detected directly by PMT

XMASS: uses 812 PMTs providing ~70% photo-cathode coverage and also give fiducial volume of ~200kg (20 cm self-shielding layer)

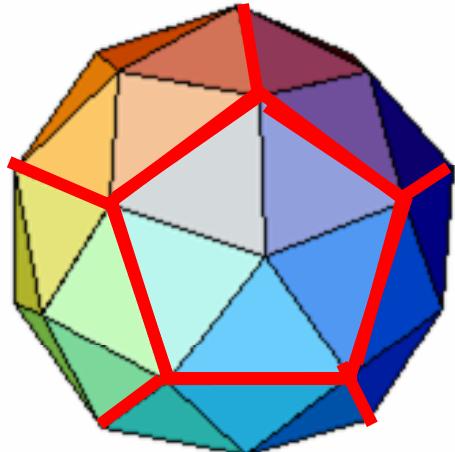


We can achieve *low energy threshold and low background (aim 10⁻⁴ /keV/kg/day)*

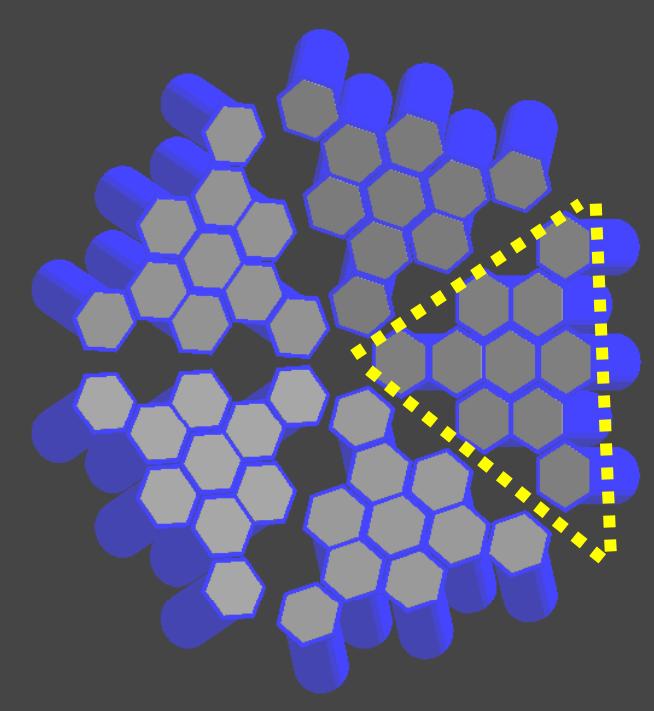
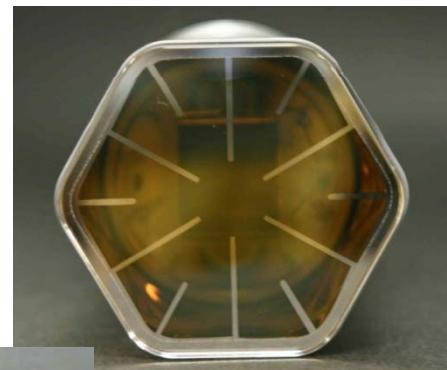
XMASS experimental hall



Structure of the detector



Pentakis-dodecahedron
12 pyramids →



5 triangles make
pentagonal pyramid

- Total 812 PMTs: Photo-cathod coverage 67%
- Center to inner surface (photocathode) ~45cm

Mock up



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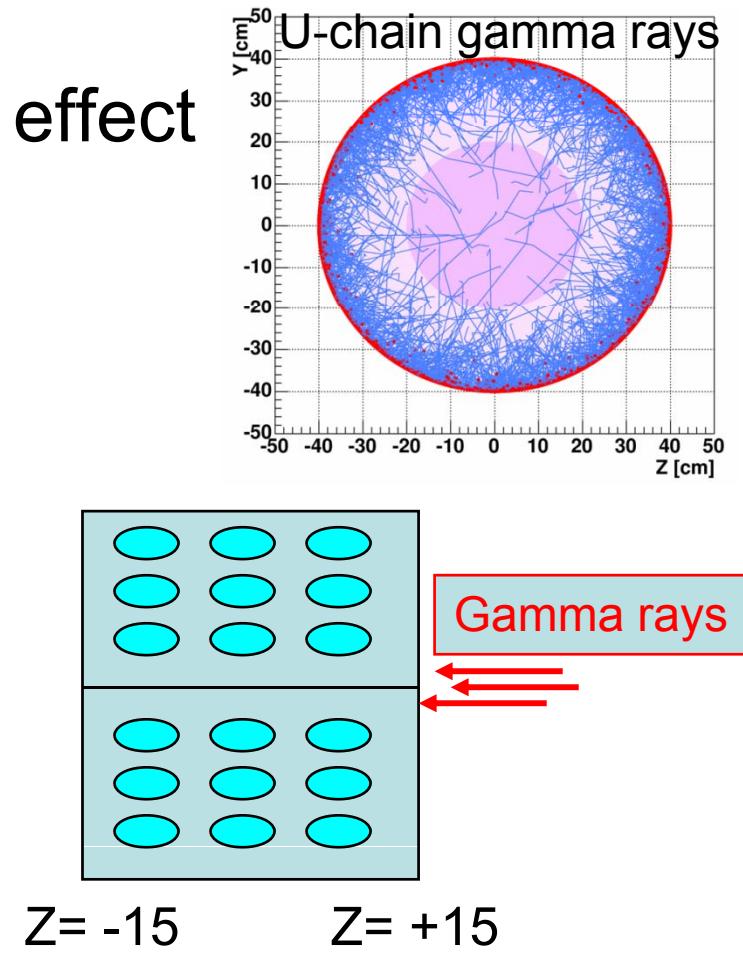
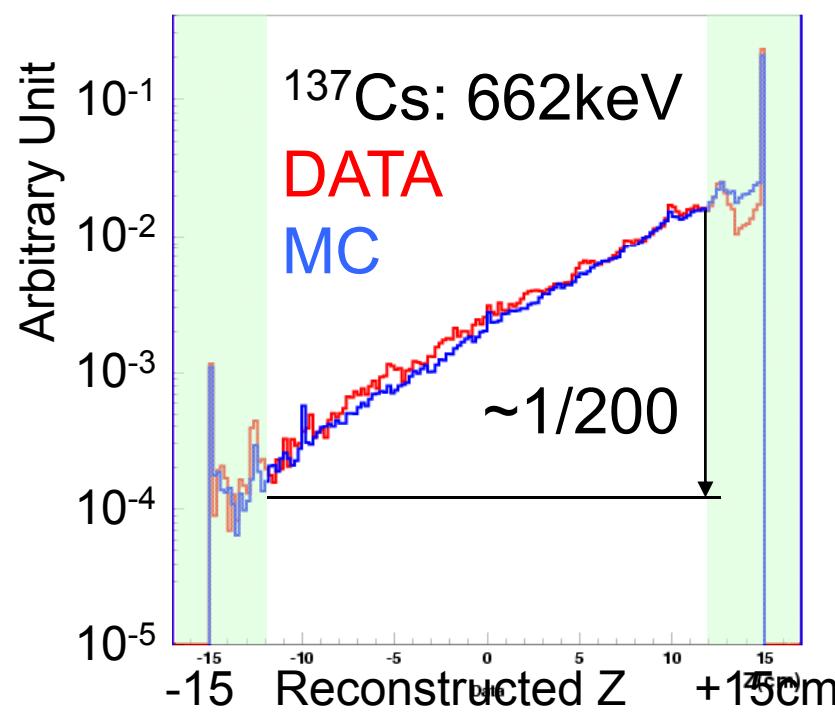
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36

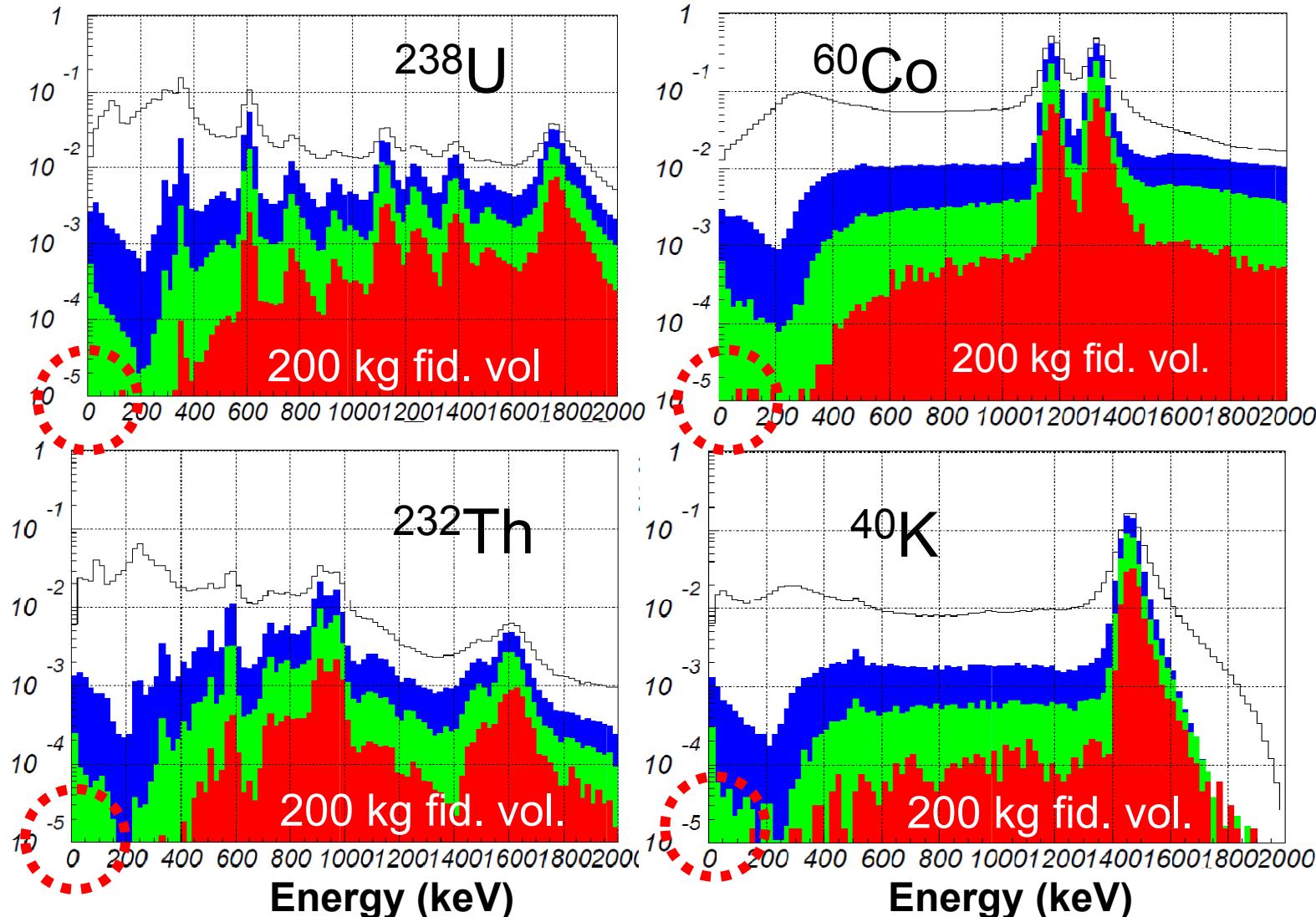
Development of low BG PMT

(most BG among external origin)

- U/Th → ~ 1mBq/PMT: almost achieved
- Reduce BG further by liq. Xenon self-shielding effect



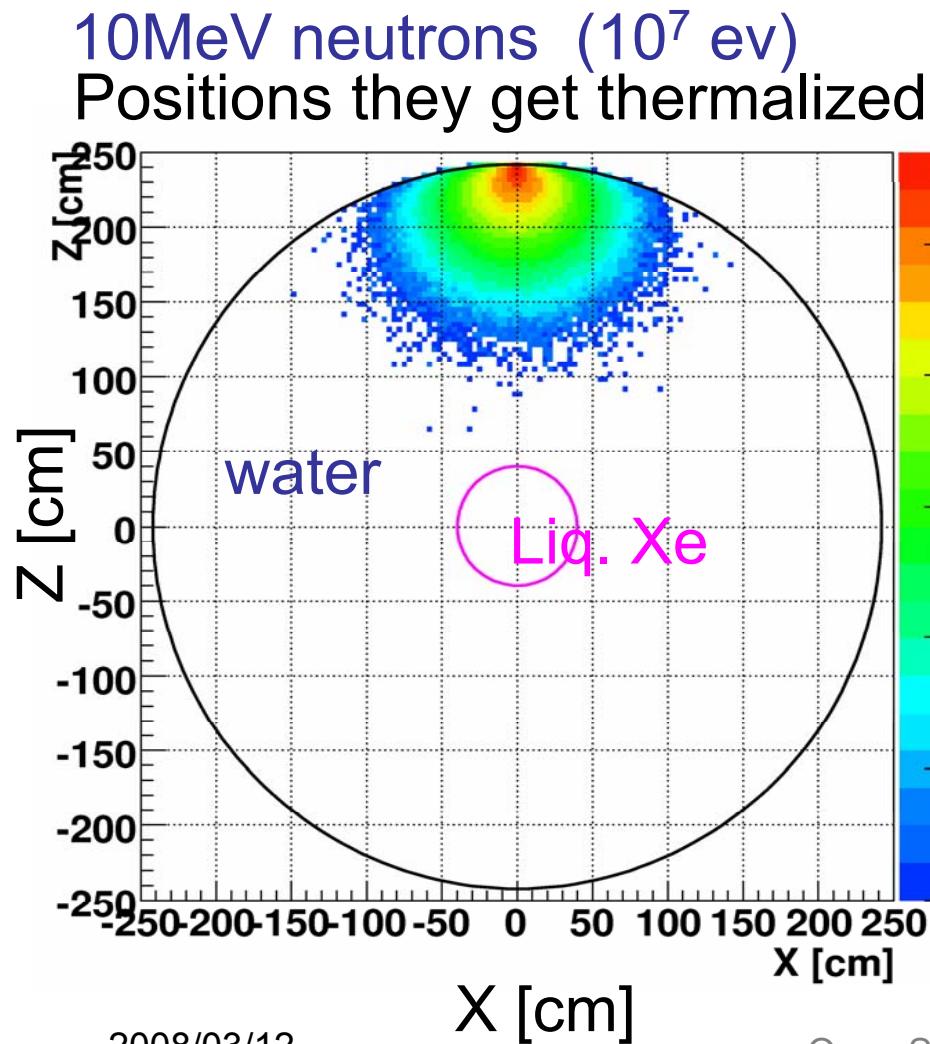
Remaining BG in the fiducial volume from PMT BG



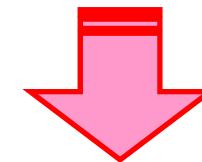
2008/03/12 **BG level : <<10⁻⁴/day/keV/kg for <300keV**
Open Symposium IPMU

Environmental BG: fast neutron, γ -rays from surrounding rocks

We will have >3m thickness of water shield



Fast neutron flux
@Kamioka mine:
 $(1.15 \pm 0.12) \times 10^{-6} / \text{cm}^2/\text{sec}$



$< 2 \times 10^{-4}$ counts/day/kg

200cm of water is enough
to reduce the fast neutron

200cm is also sufficient
to reduce γ BG

Internal BG

Radioactive contamination in Liq. Xenon

Achieved with the
prototype detector

Target Value

^{238}U : $(9 \pm 6) \times 10^{-14} \text{ g/g}$	→	$< 1 \times 10^{-14} \text{ g/g}$ (~1decay /100kg /day)
Further reduction by filter		
^{232}Th : $< 23 \times 10^{-14} \text{ g/g}$	→	$< 2 \times 10^{-14} \text{ g/g}$ (~1decay/100kg/day)
Upper limit, use filter		
^{85}Kr : $3.3 \pm 1.1 \text{ ppt}$	→	$< 1 \text{ ppt}$
by a prototype distillation tower		

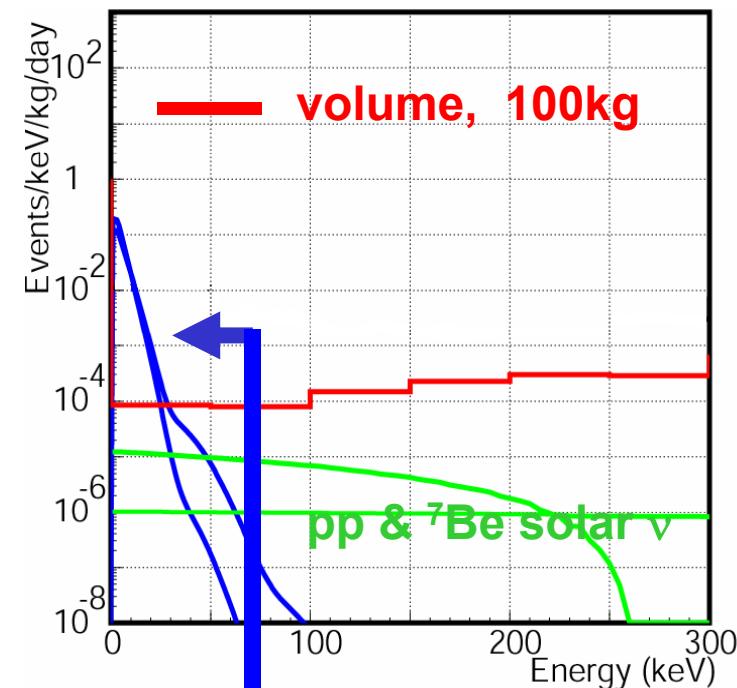
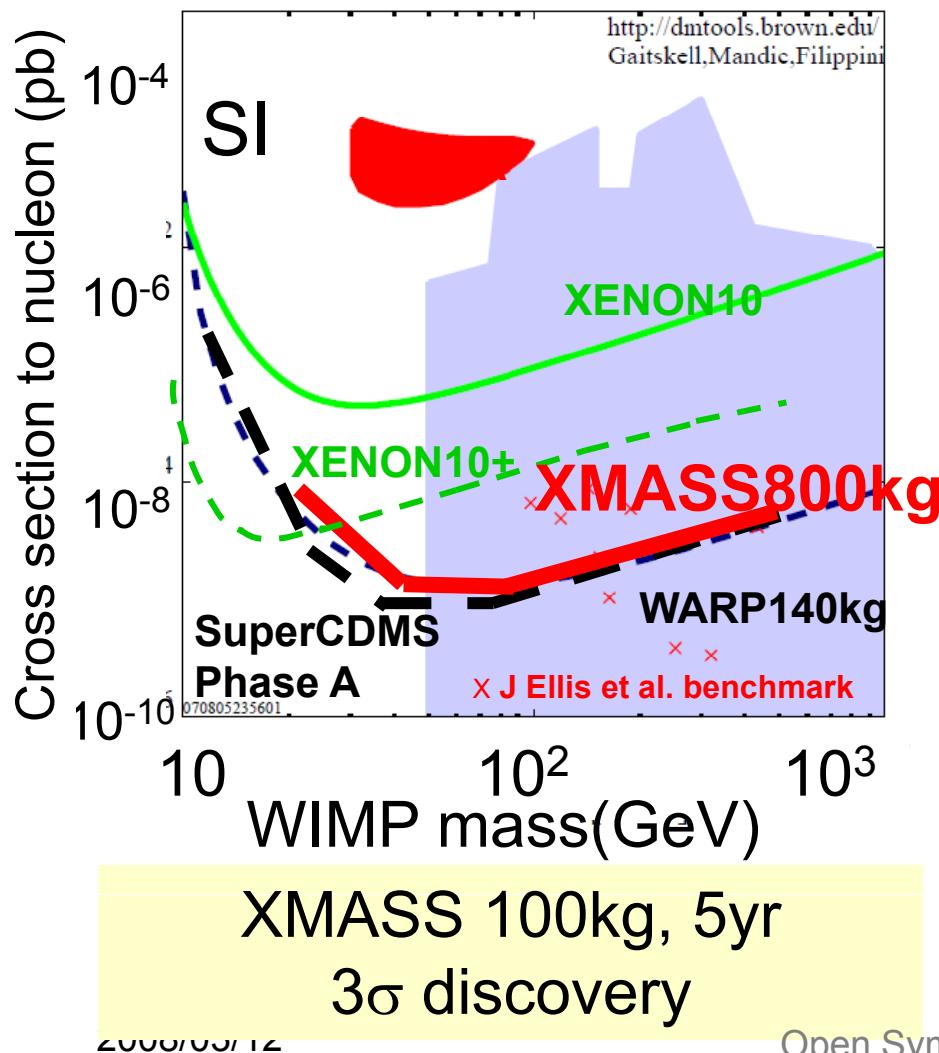
U, Th, Kr near the target value

Sensitivity of the 800kg detector

Plots except for XMASS

<http://dmtools.berkeley.edu>

Gaitskell & Mandic



Schedule of XMASS

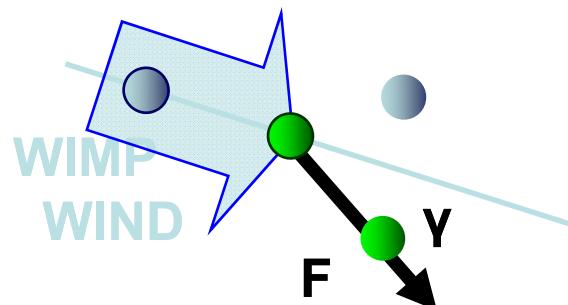
- Excavation finished in February.
- We are making detail design of the detector.
 - Structure, Inner & Outer Detectors
 - Water shield,
 - Purification system
 - Cooling system
 - Electronics and etc.....
- Finish the construction in one year.
- The experiment will started in 2009

NEWAGE @ Kamioka (Kyoto university)

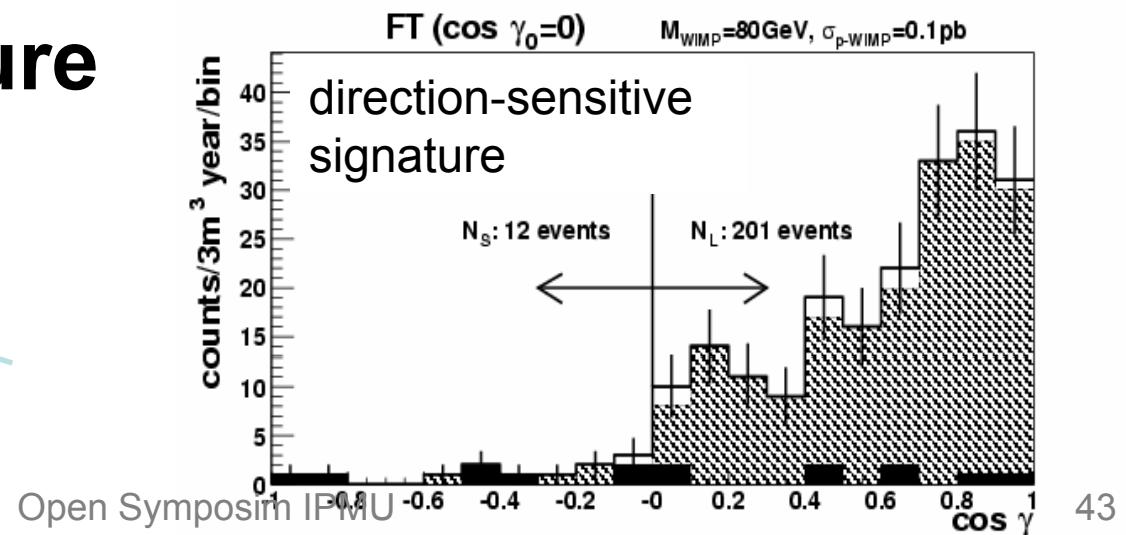
(New generation WIMP search with an advanced gaseous tracker experiment)

PLB 578 (2004) 241 PLB 654 (2007) 58 (Miuchi et.al.)

- “WIMP-wind” detection
 - DM: Maxwellian distribution $v_0 \sim 220\text{km/s}$
 - Earth’s motion in our Galaxy
 - WIMP wind...
- Direction-sensitive detector provides a robust signature



2008/03/12



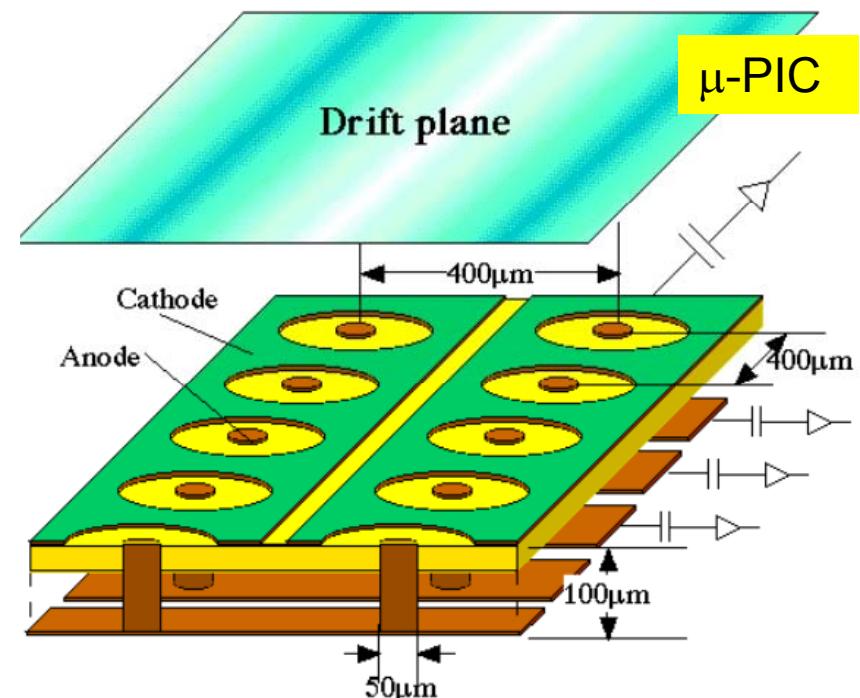
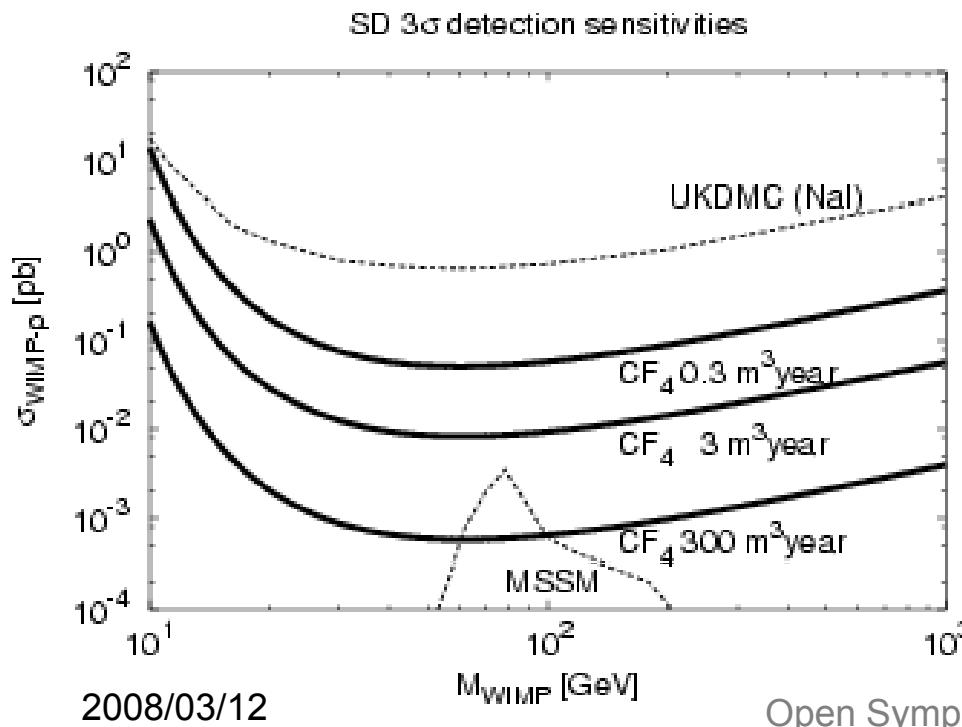
NEWAGE : Detector

Micro-TPC (time-projection-chamber)
gaseous 3D tracking device
Goal:

- CF₄ gas (0.05 bar)
- Large vol. > 10m³

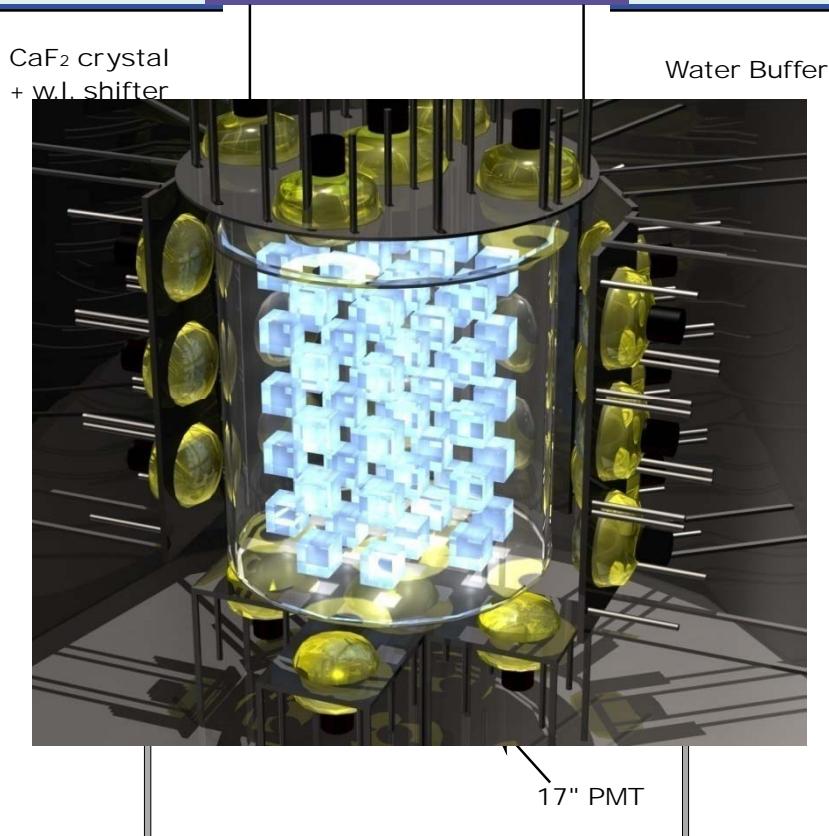
CURRENT:

- CF₄ 0.2 bar · 30cm cube
- first direction-sensitive results by neutron
- underground studies 2007~



Other Activities for future

CANDLES



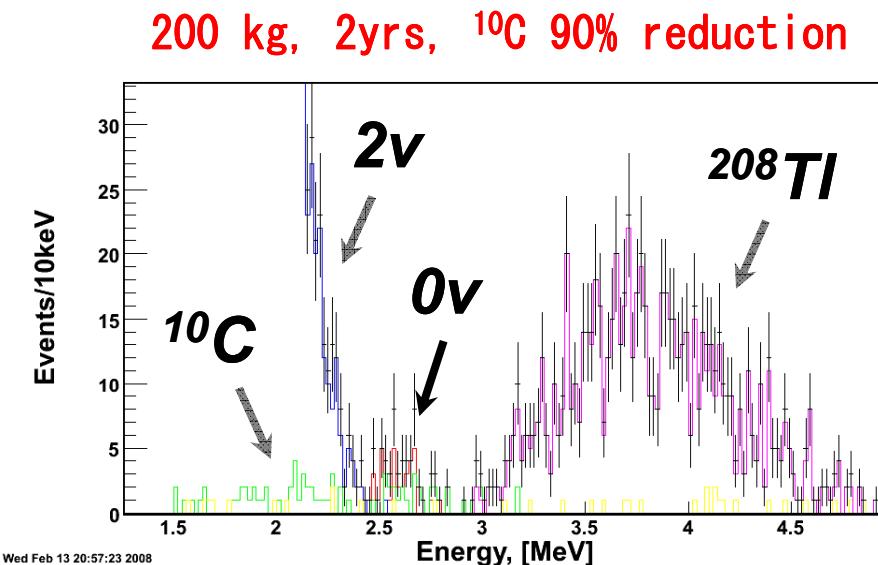
New Lab.: Completed in Feb., 2008

1. XMASS 100~300kg f.v. detector
2. 0νββ detector (⁴⁸Ca) (Osaka U.)

- undoped **CaF₂** (CaF₂(pure))
 - **⁴⁸Ca (0.187%) Q=4.27 MeV**
 - 305 kg (III-chika) 10³cmx96
- 3.4 t (IV) ~0.1 eV
- 30 t, 2% enriched (V)
~30 meV (best NME)
- Liquid Scintillator (LS)
 - 4π active shield
- Photomultiplier
 - large photo-coverage
- Water buffer → Passive shield

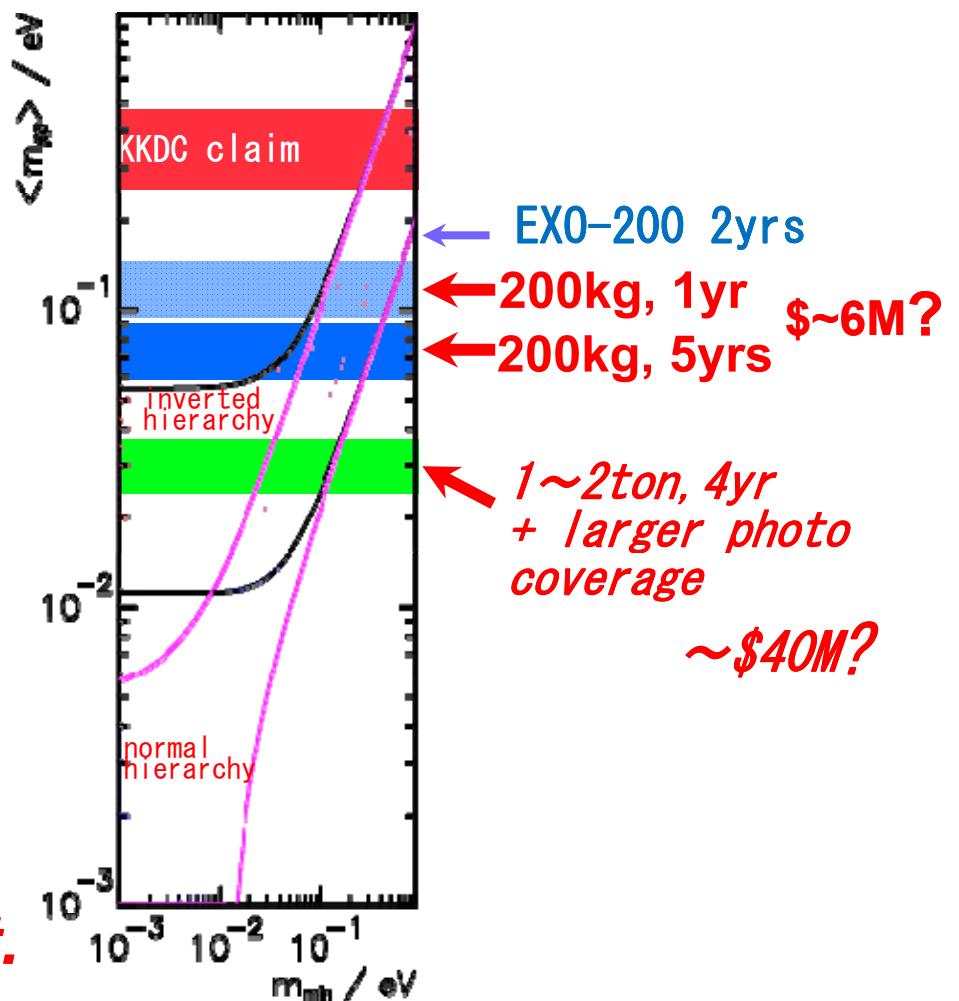
KamLAND: double beta with ^{136}Xe

Resolve enriched ^{136}Xe
Into liquid scintillator

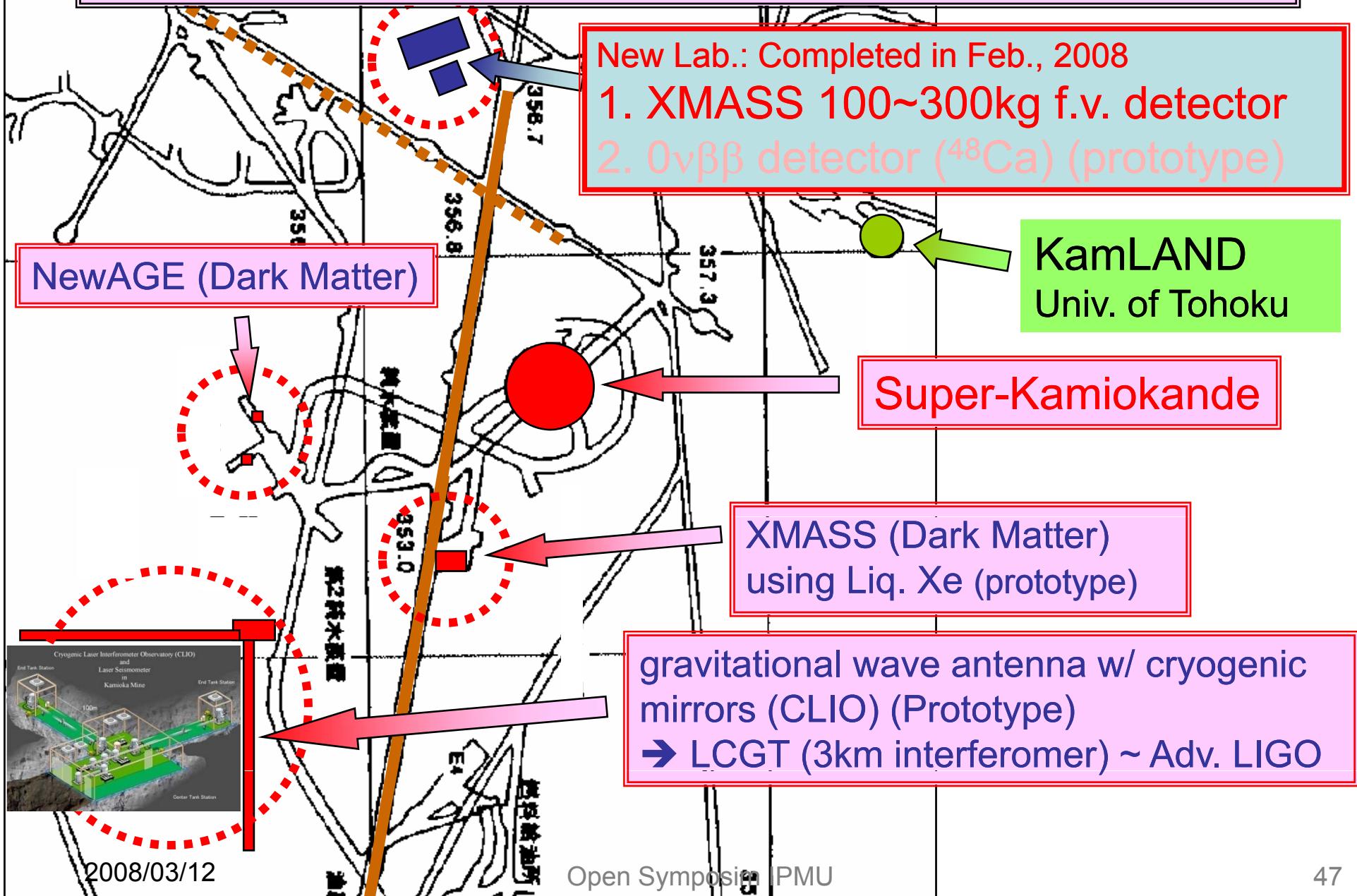


**$\text{KL}+^{136}\text{Xe}$ is very competitive
And probably the lowest cost.**

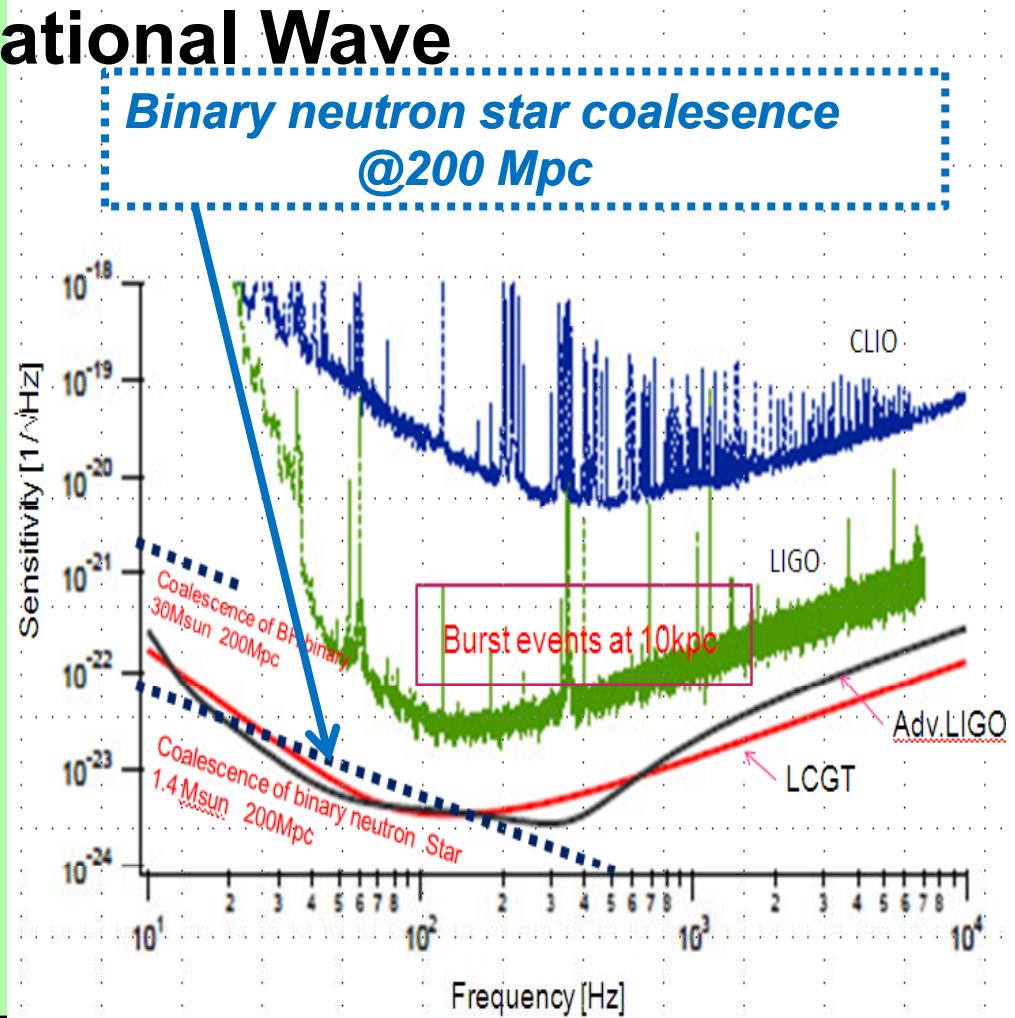
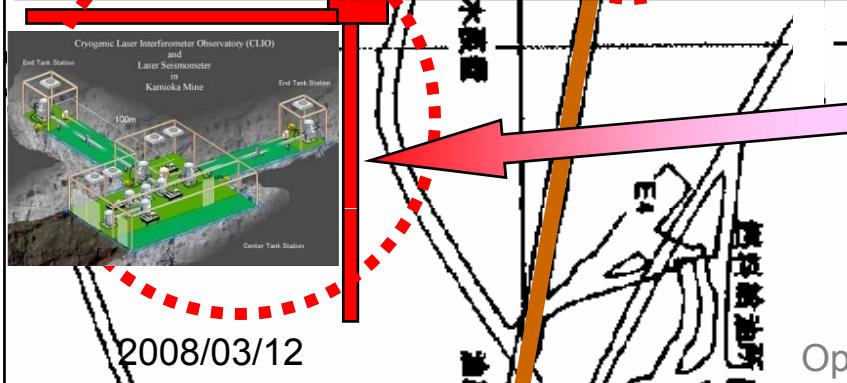
Sensitivities
KamLAND+ ^{136}Xe



Other Activities for future



- Large Cryogenic Gravitational Wave Telescope (LCGT)
 - Baseline ~ 3km
 - 150W laser
 - Underground
 - Small Seismic Noise
 - Cryogenic mirror
 - 30kg Sapphire mirrors
 - Reduce thermal Noise
 - Budget request
 - Prototype CLIO
 - 100m interferometer



gravitational wave antenna w/ cryogenic mirrors (CLIO) (Prototype)
→ LCGT (3km interferometer) ~ Adv. LIGO

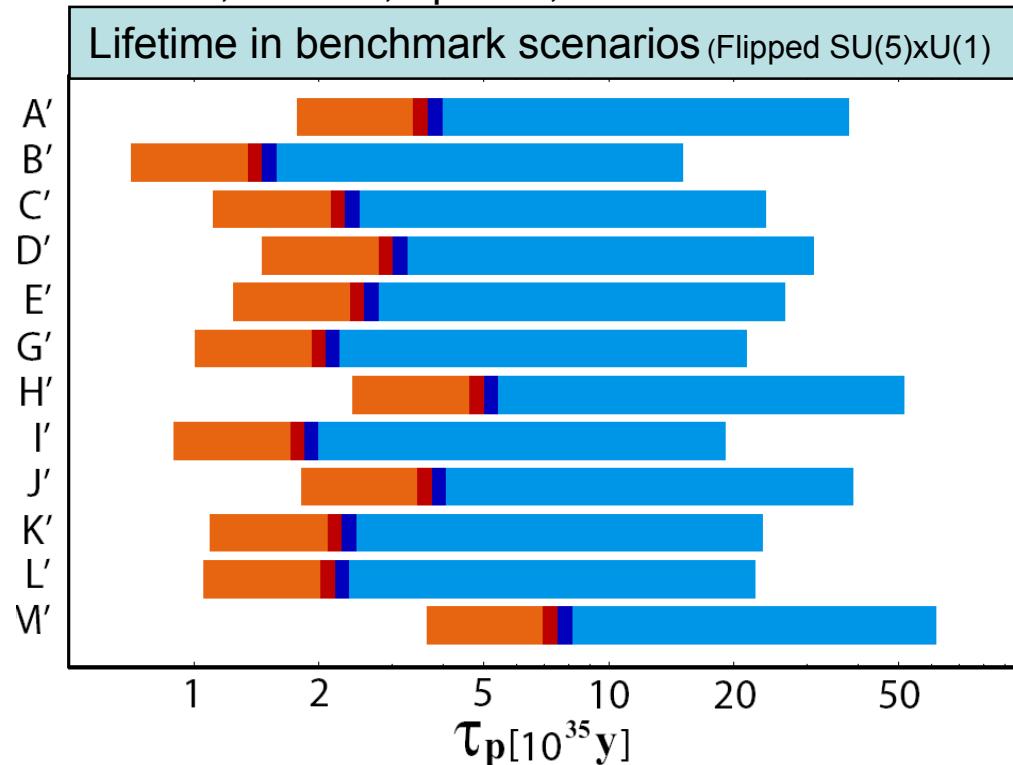
There is Proton Decay in the end

*If you really want to pursue
a ‘discovery’ experiment*

→ *Beyond ‘Underground’*
Where ??

Required Sensitivity

J. Ellis, NNN05, April 7th, 2005



Theorists do not give us any guarantee, but

Theorists' best bet ???

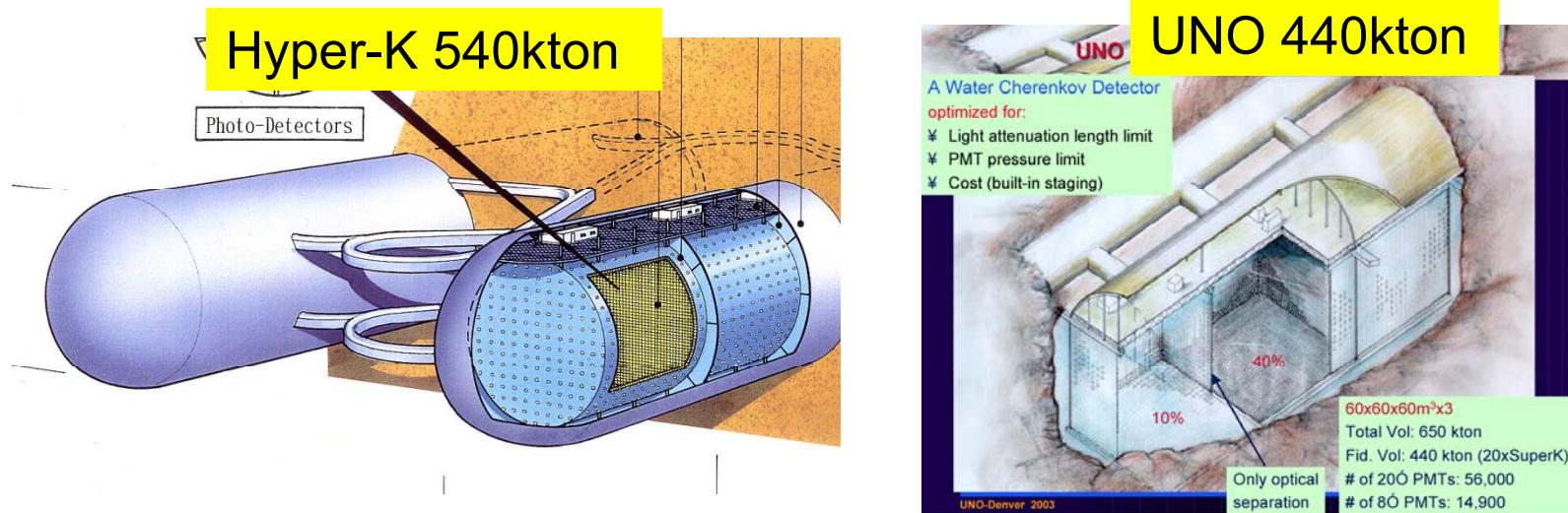
$\sim 10^{35} \sim 10^{36}$ yr for $e\pi^0$

$< 10^{35}$ yr for $\nu K, \mu K$

May determine the size of future detectors

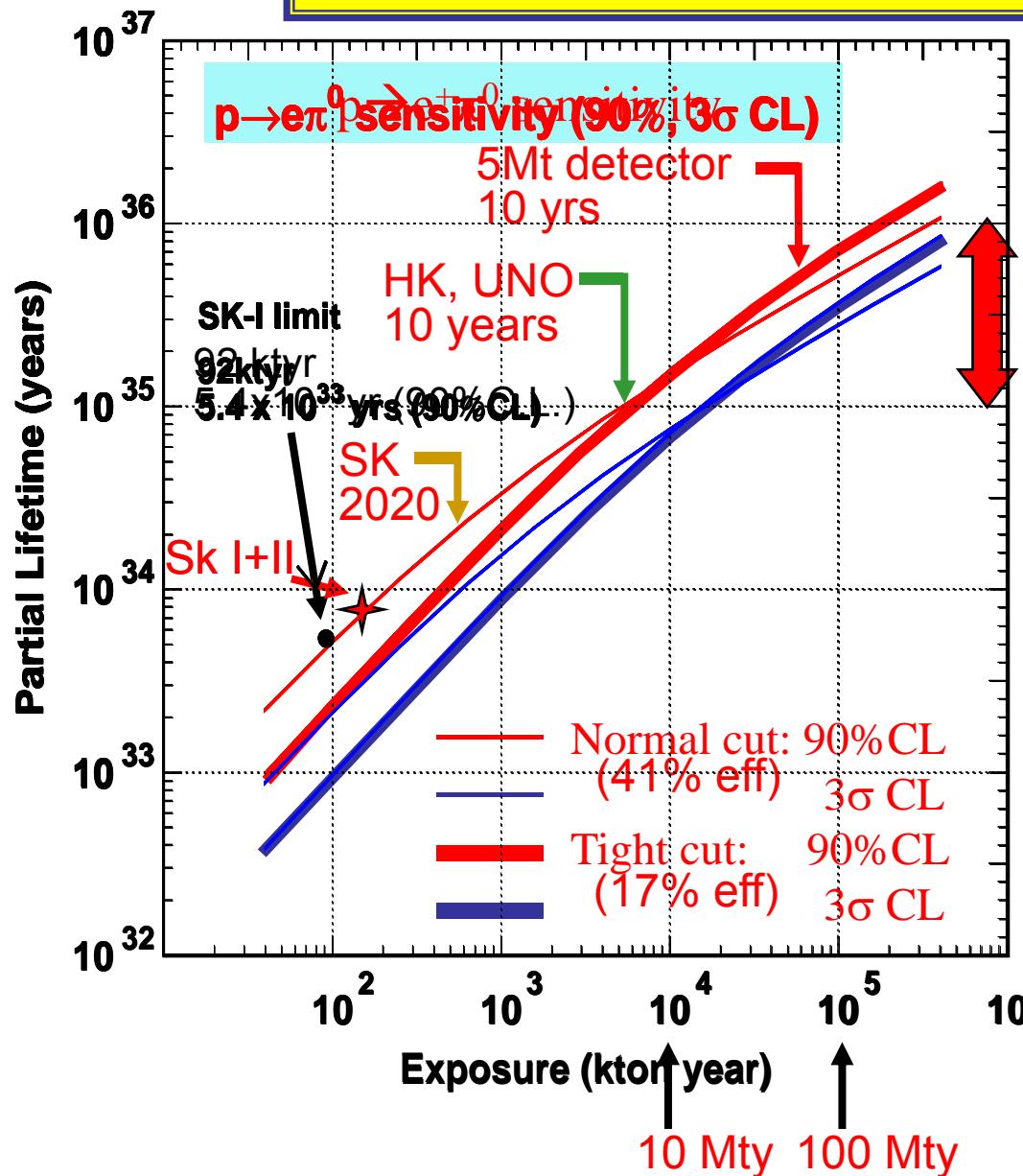
Another argument

- **How much of the volume is needed.**
 - Super-Kamiokande (22.5kton) until **2020**
(~start time for UNO, HK,,,...)
→ achieve ~0.5 Mtyr exposure (25yrs)
- ~ 0.5 Mt fid. detector : HK, UNO etc.



- Only factor 3=sqrt(10) improvement
(for 10 years operation: 2020 ~ 2030)
- “NEED” ~ 5 Mt fiducial mass for
factor 10=sqrt(100) improvement in 10 years

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

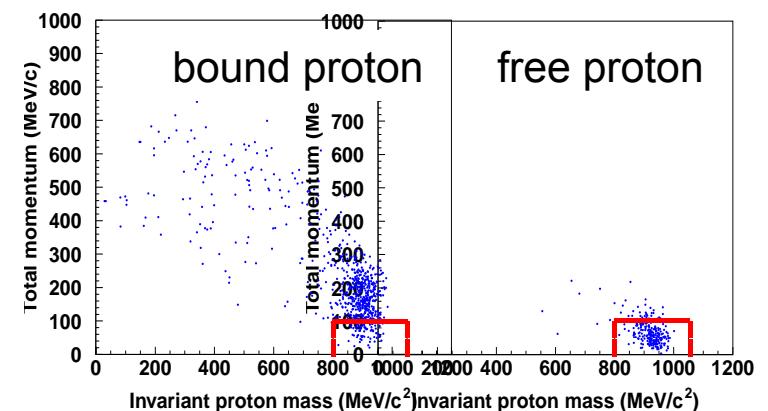
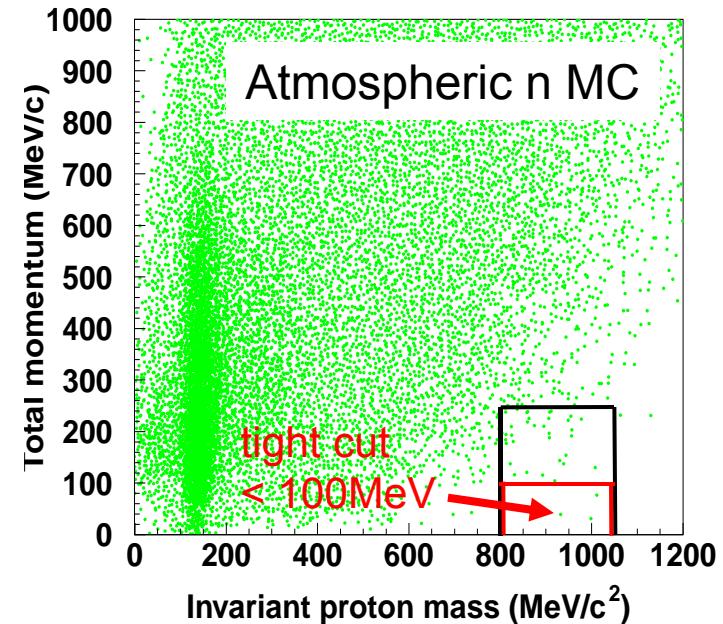
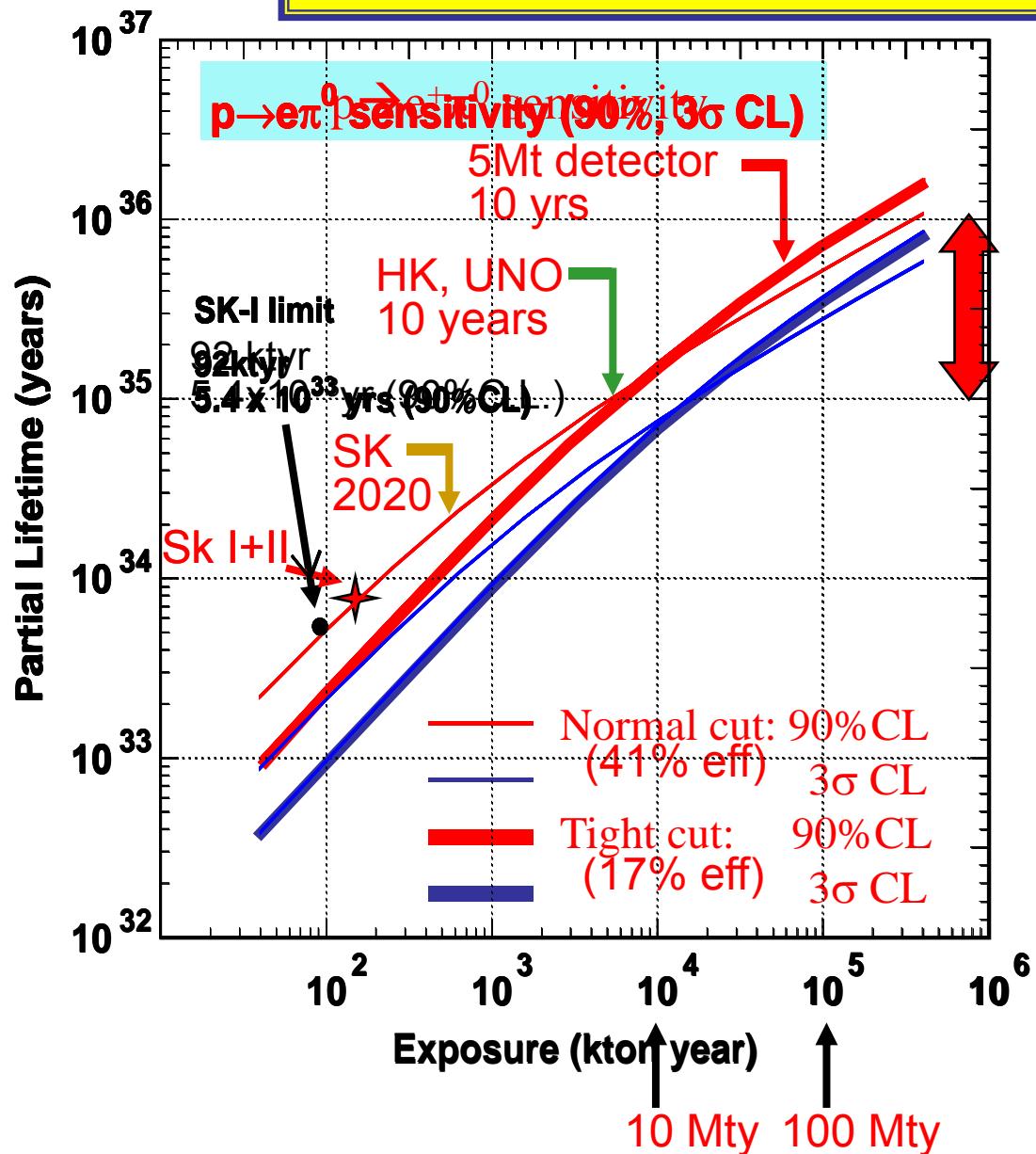


SK (22.5 kt)
 25 yrs operation (2020)
 $\rightarrow \sim 3 \times 10^{34} \text{ yrs}$

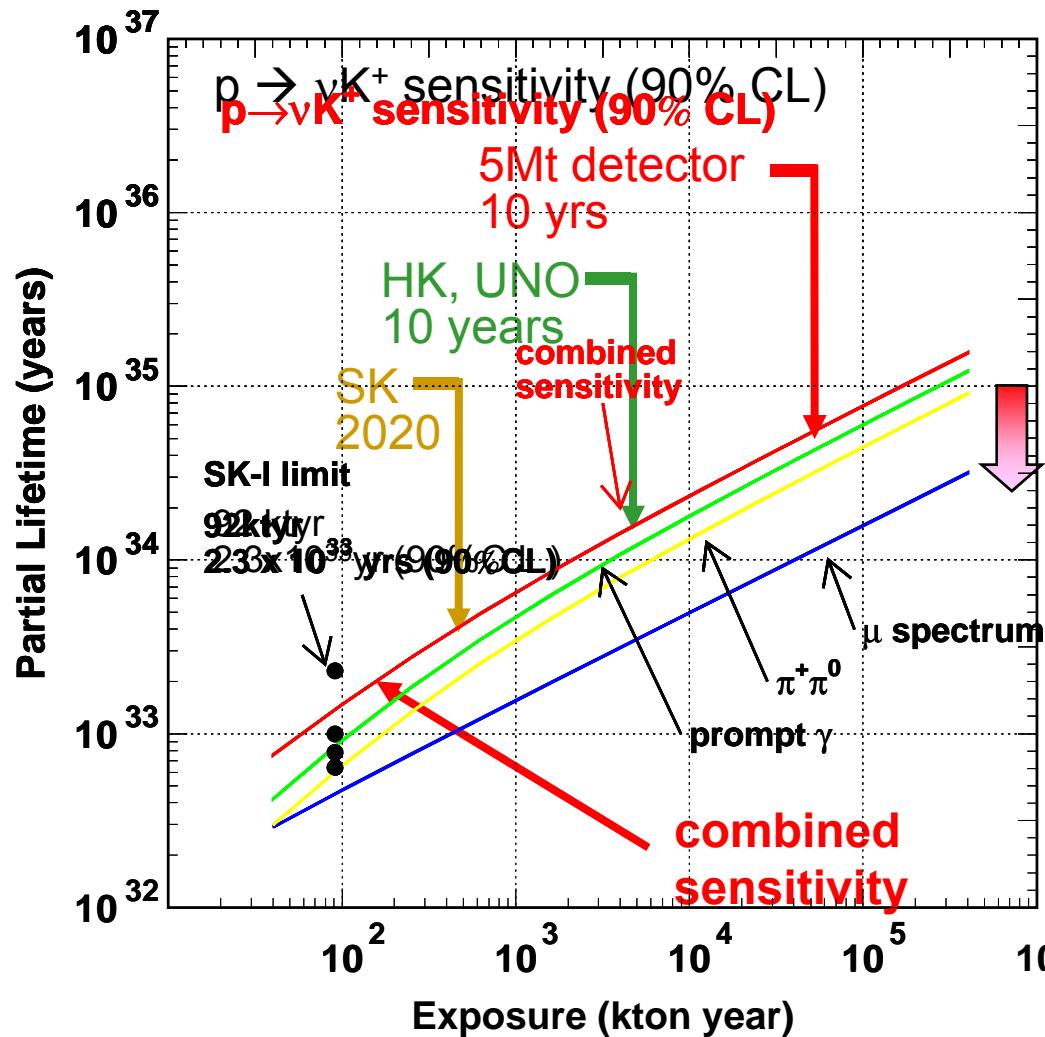
HK, UNO ($\sim 0.5 \text{ Mt}$)
 10yrs operation
 $\rightarrow \sim 1 \times 10^{35} \text{ yrs}$

5 Mt detector
 10 yrs operation
 $\rightarrow \sim 7 \times 10^{35} \text{ yrs}$
 for tight cut:
 which is effective
 only for $> 10\text{Mtyr}$
 exposure

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



Sensitivity for $p \rightarrow \nu K^+$



Combine three methods,
Lifetime: $> 2.3 \times 10^{33}$ years
for SK-I

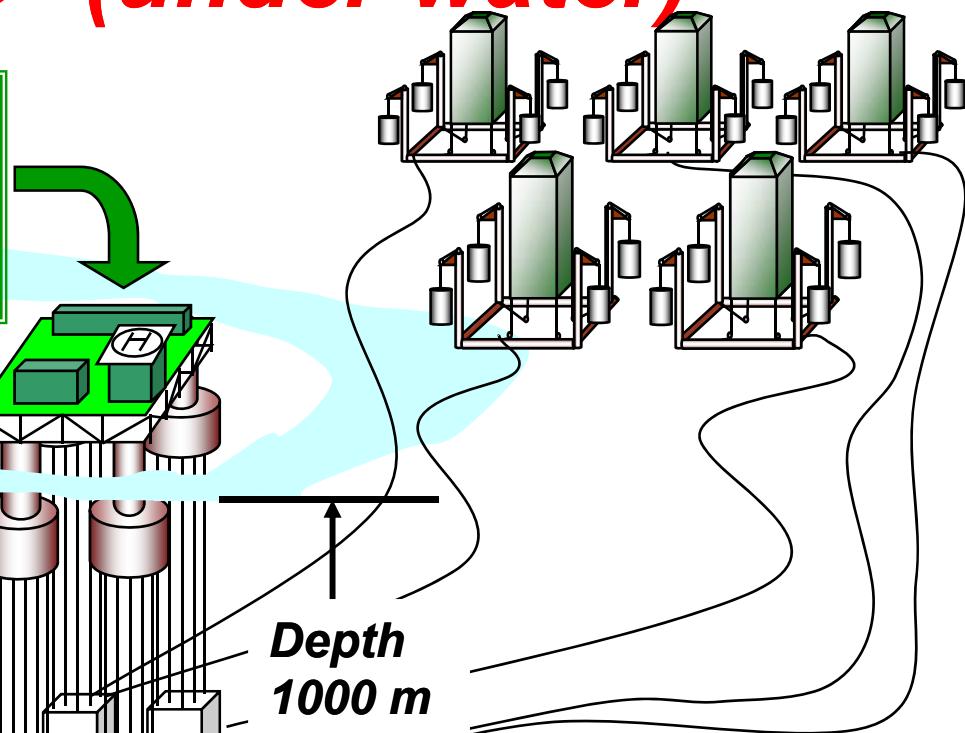
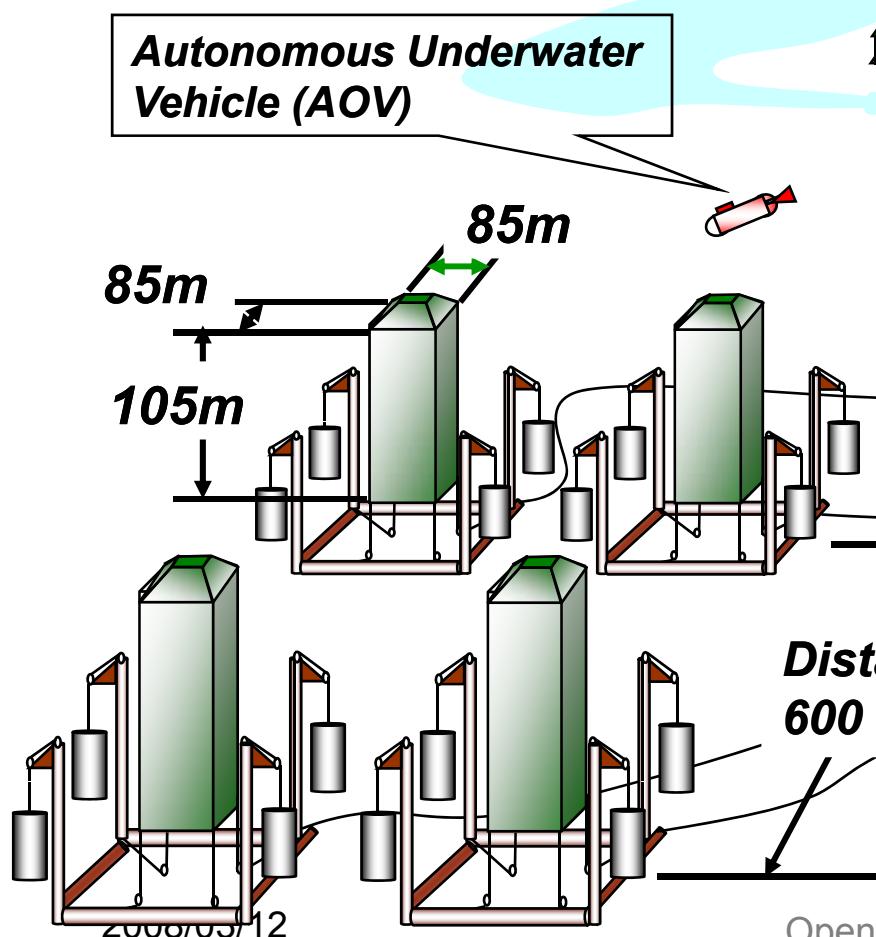
How does a 5 Mt detector look like?

Requirements for the detector

- 1) Scalability: May start with 1 Mt
but can be expandable
- 2) Better to place > 700m depth (w.e.)
- 3) Low cost
- 4) Short construction time

Deep-TITAND (under water)

Tension Leg Platform (TLP)
Laboratory, Office, Café, Power station,
Water purification sys., Dormitory etc.

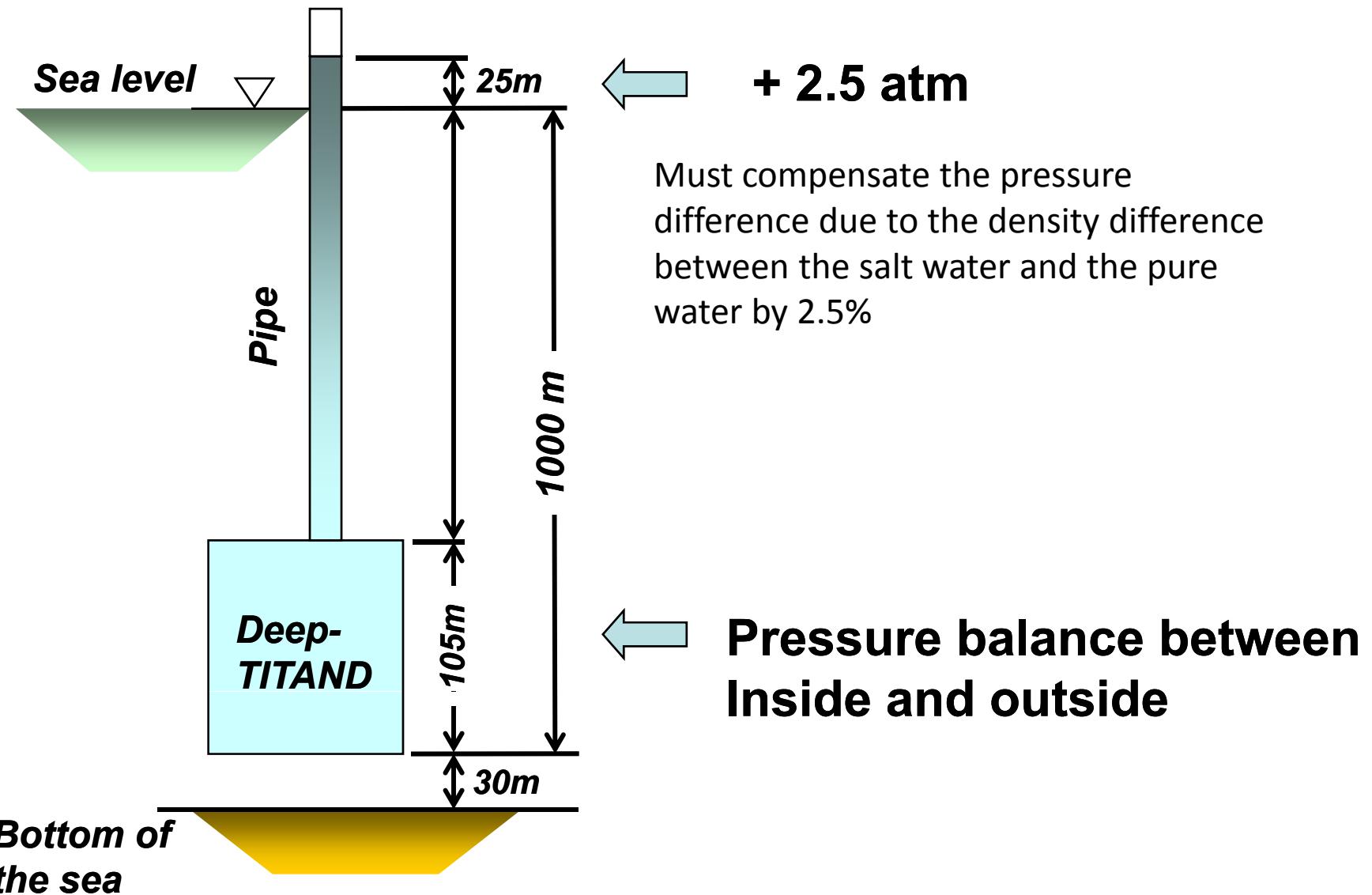


$$85\text{m} \times 85\text{m} \times 105\text{m} = 0.76\text{Mt}$$
$$76 \times 76 \times 96\text{m}^3 = 0.554\text{Mt (fiducial)}$$
$$\text{Inner surface: } 44800\text{ m}^2$$

9 units → 5.0 Mt (fid.)

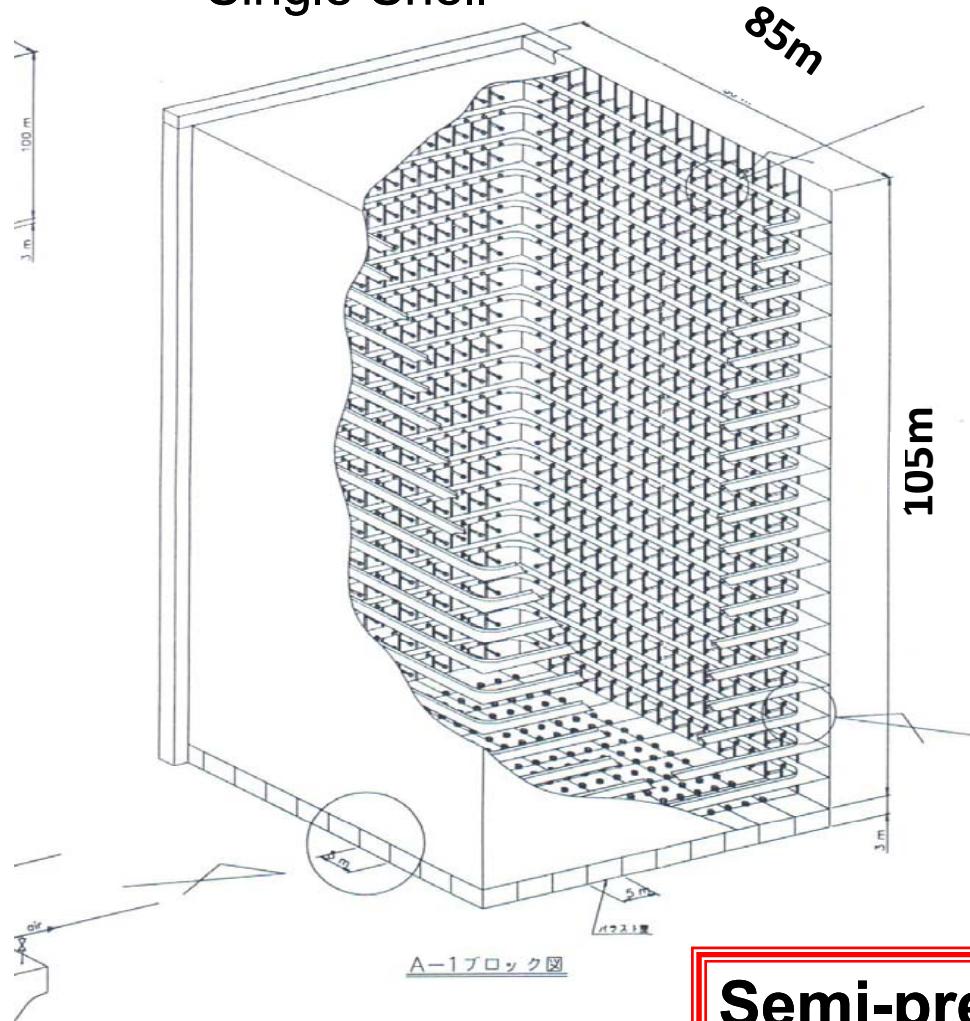
Placed at the depth of ~1000m₅₆

Pressure Head



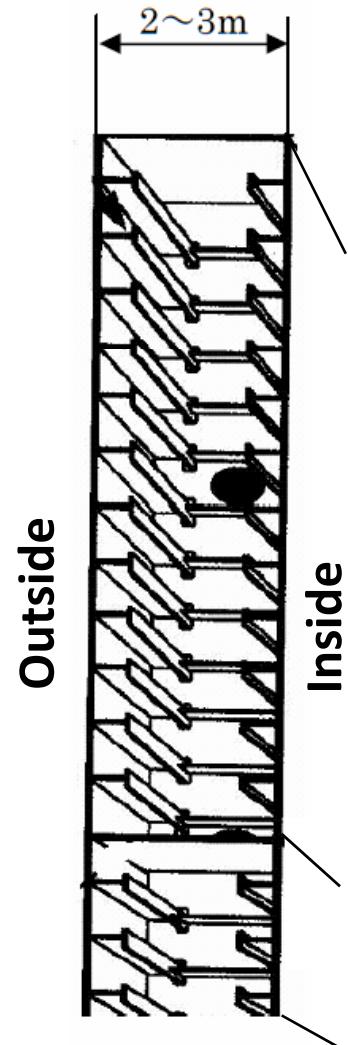
Structure

Single Shell



OR

Double Shell
Structure

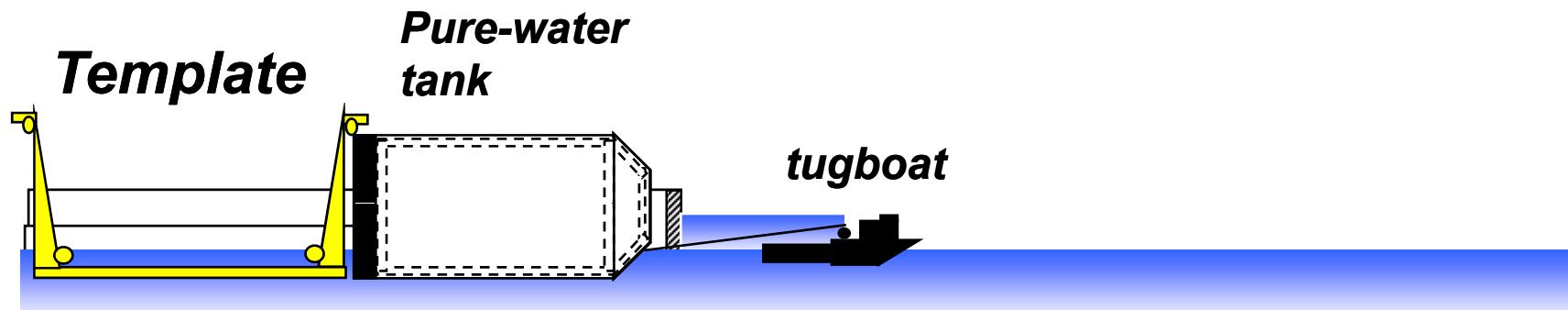


Semi-pressure vessel
upto >0.3 atm (in/out)

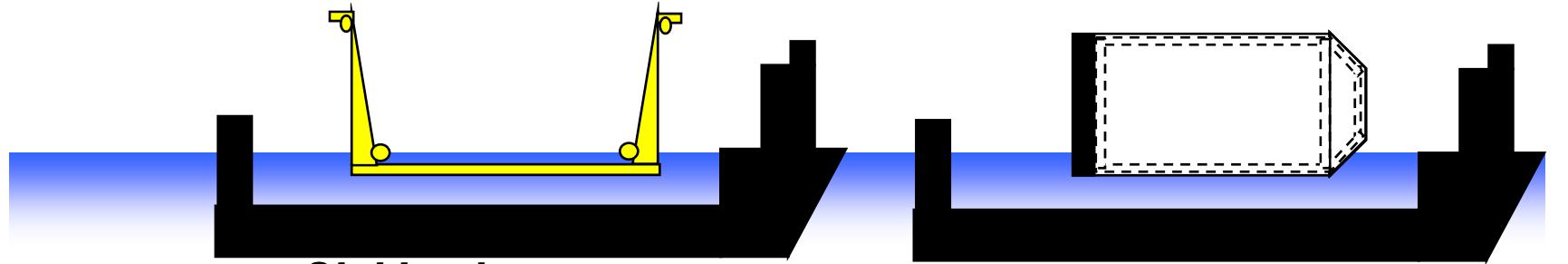
How to construct dockyard



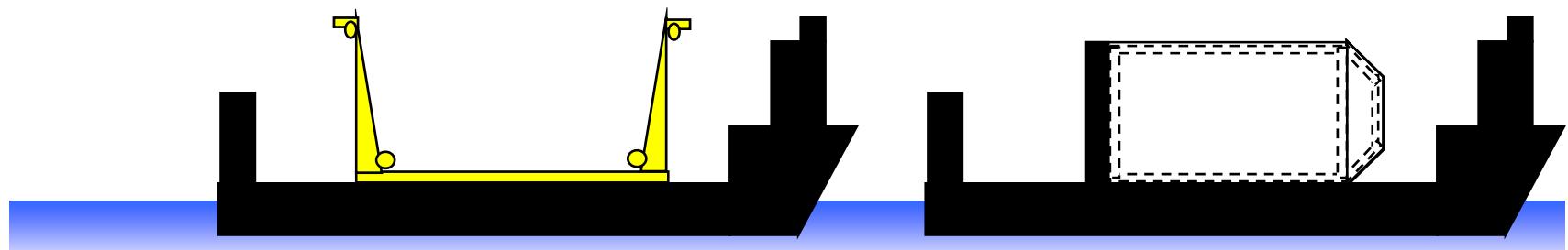
Construct steel container (unit) at the DOCK
85m x 85m x 105m
Maximum size of DOCK in the world
→ width:108m x length: 480m
Install light sensors(LSs) or equivalent
Number of LSs (50cm in dia.)
44,800 LSs for one unit
(for 1/2 SK density)



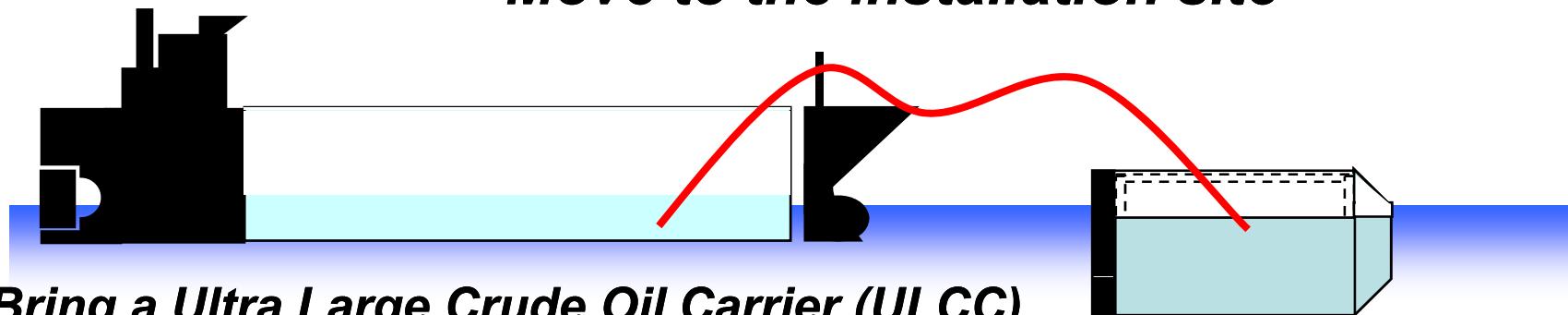
***Tug to offshore for loading
them to the barge***



Sinking barge
(loading capacity: 20,000 ~ 30,000 tons)



Move to the installation site

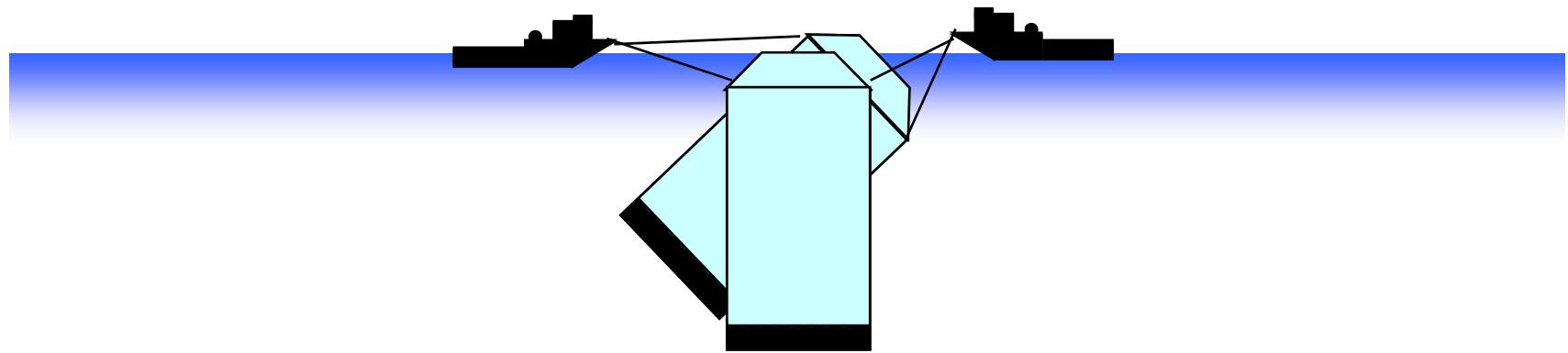


***Bring a Ultra Large Crude Oil Carrier (ULCC)
which contains pure water of 300kton***

Water is poured into a tank

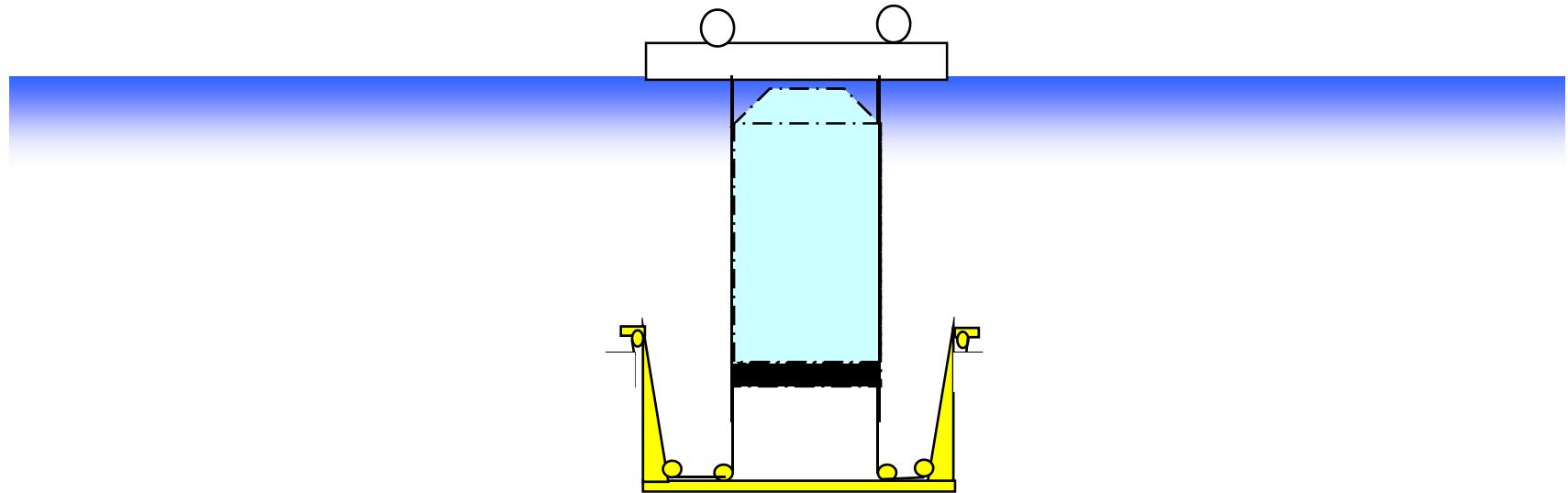
ULCC: 300ktons x 3 → 760ktons for one unit

Transfer speed 10ktons /hour (30 hours /ship)



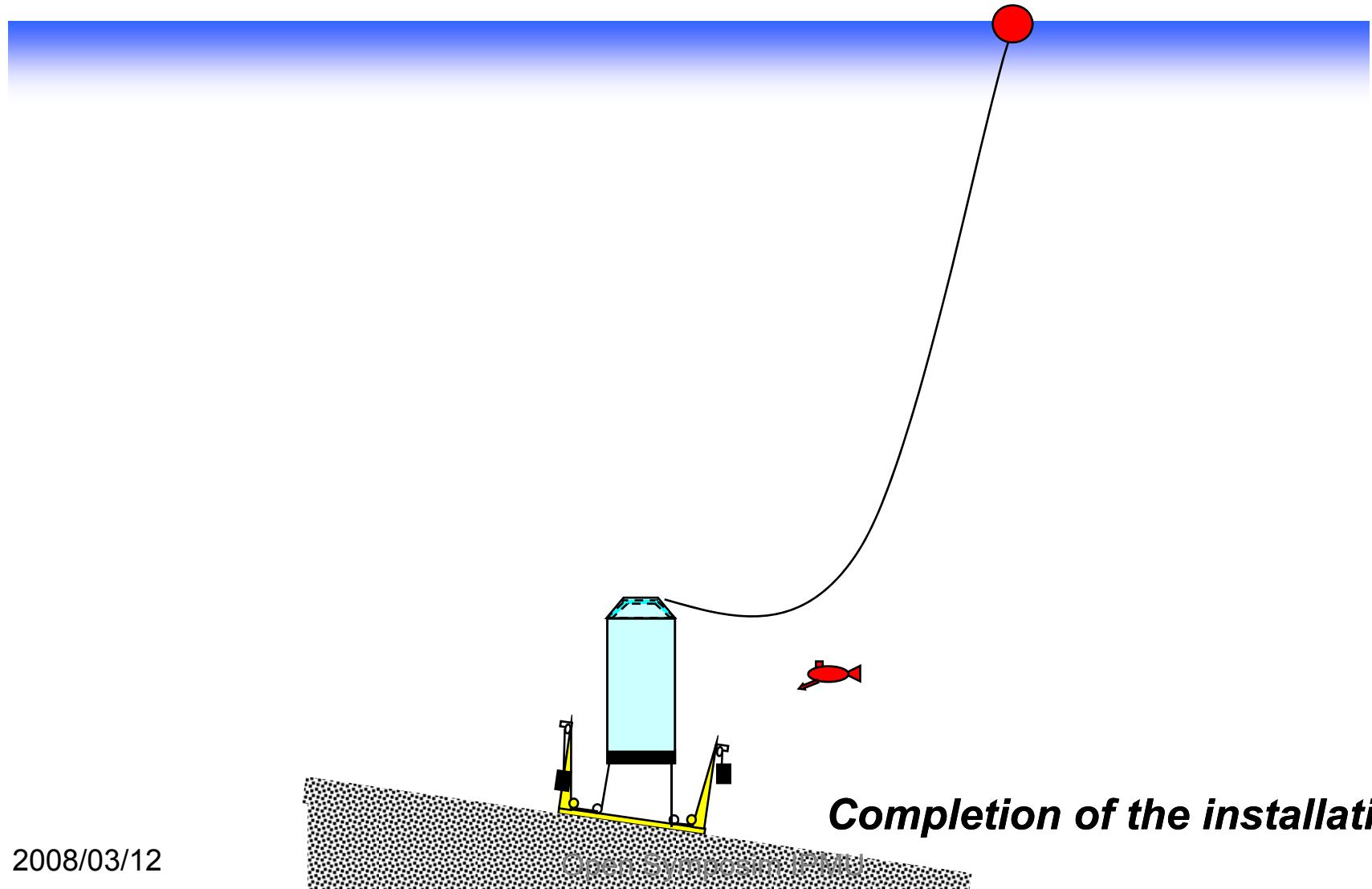
The water tank is rotated

Winch

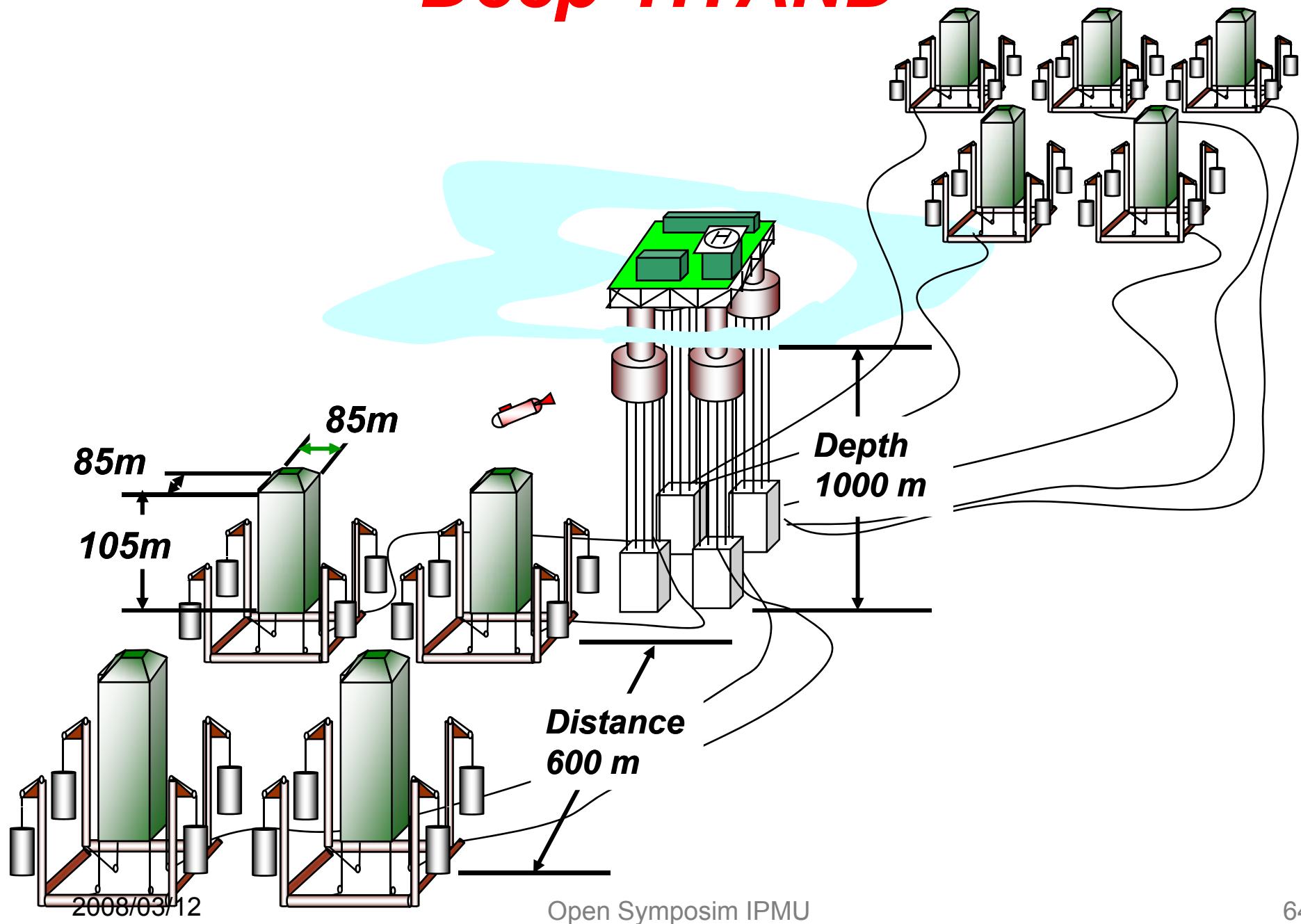


The template and the water tank is joint together

Bring the template and the water tank to the bottom of the sea
2008/03/12 Open Symposim IPMU

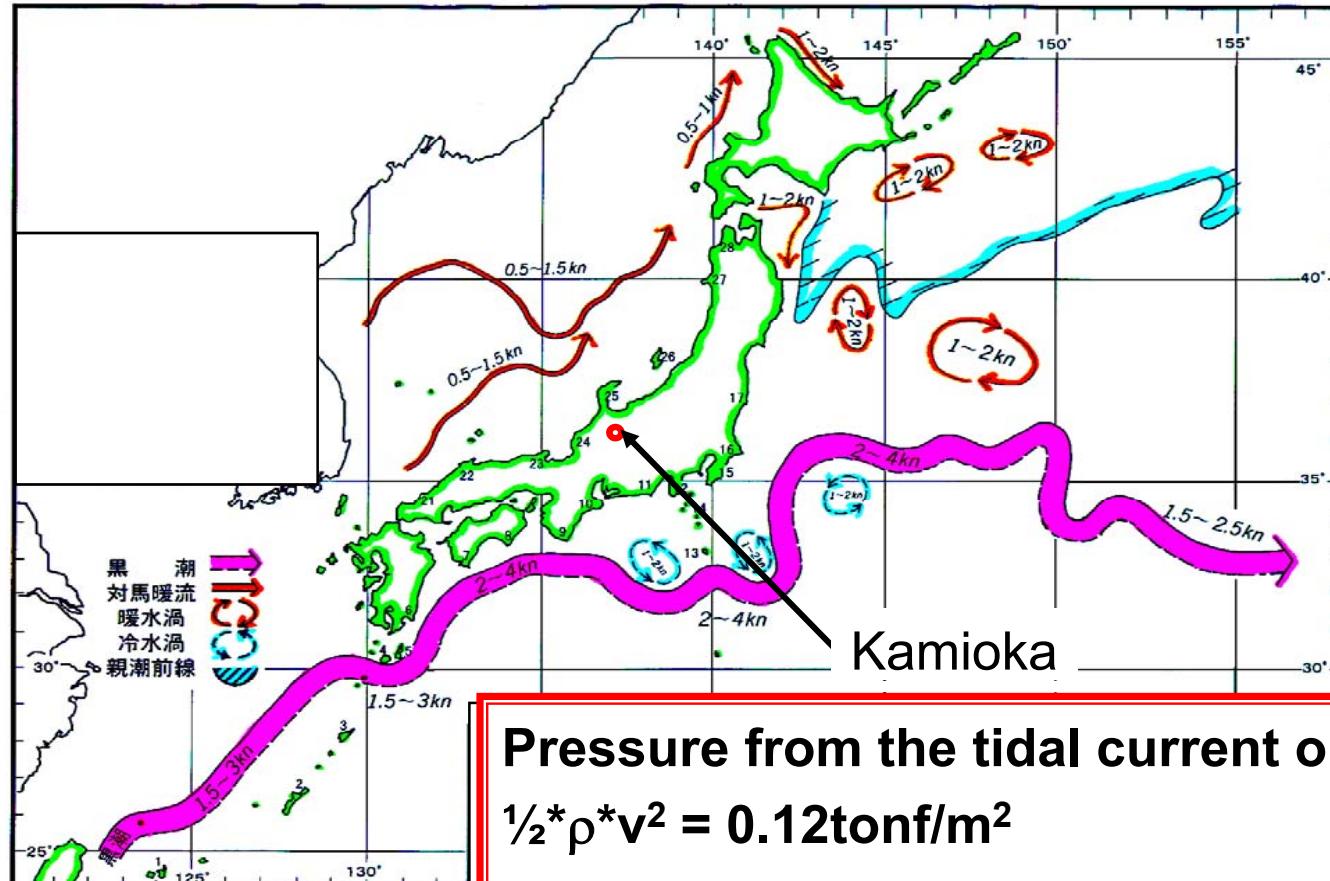


Deep-TITAND



Where we can place the detector?

Tidal current < 3 knot
~ 5.6km/hour (1.5m/s)



Deep-TITAND

- *Proton decay search* $\sim 10^{36}$ yr
- *SN neutrino detection:* ~ 1 every year
 - Reaches 5Mpc w/ ~ 5 events
- *Precise atmospheric neutrino measurements*
- *Flexible location of the detector for a long baseline neutrino oscillation experiment*

Summary (Kamioka in future)

Neutrino Oscillation

T2K	θ_{13}	2009~
T2K phase2 w/HK	CPV	2020 ? ~
KL solar (^7Be , CNO)		2009~, 2011~
SK Solar (Upturn of ^8B)		2009~
SK-GAZOOK	$\bar{\nu}_e$ measurement	2013 ? ~

Dark Matter

XMASS	10^{-45} cm	2009~
NEWAGE	10^{-39} cm SD	201? ? ~

Double Beta

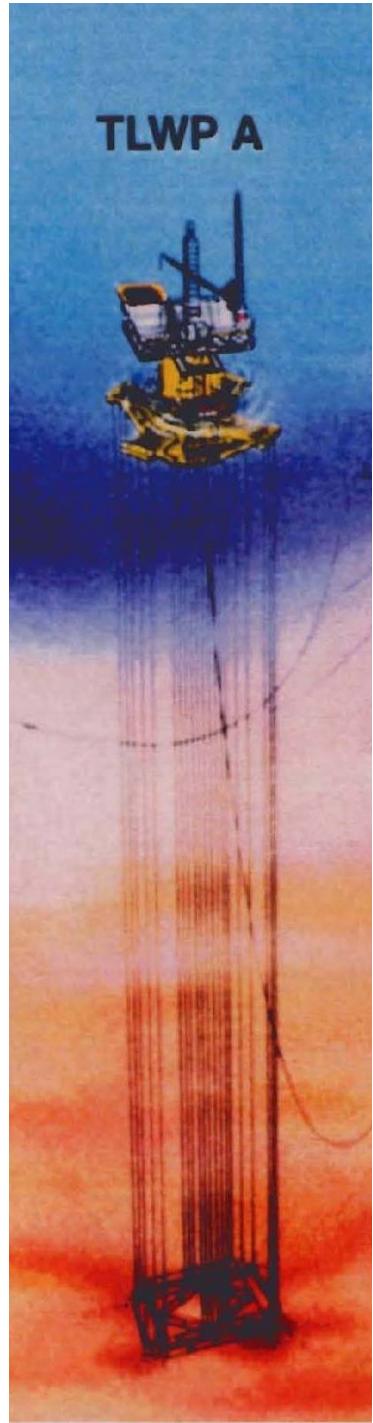
CANDLES	0.1 eV	2013 ? ~
KL ^{136}Xe	0.1~0.06 eV	2011~16 ?
XMASS ^{136}Xe	0.05 eV	2013 ? ~
XMASS ^{136}Xe	< 0.01eV	202?

Gravitational Wave Antenna

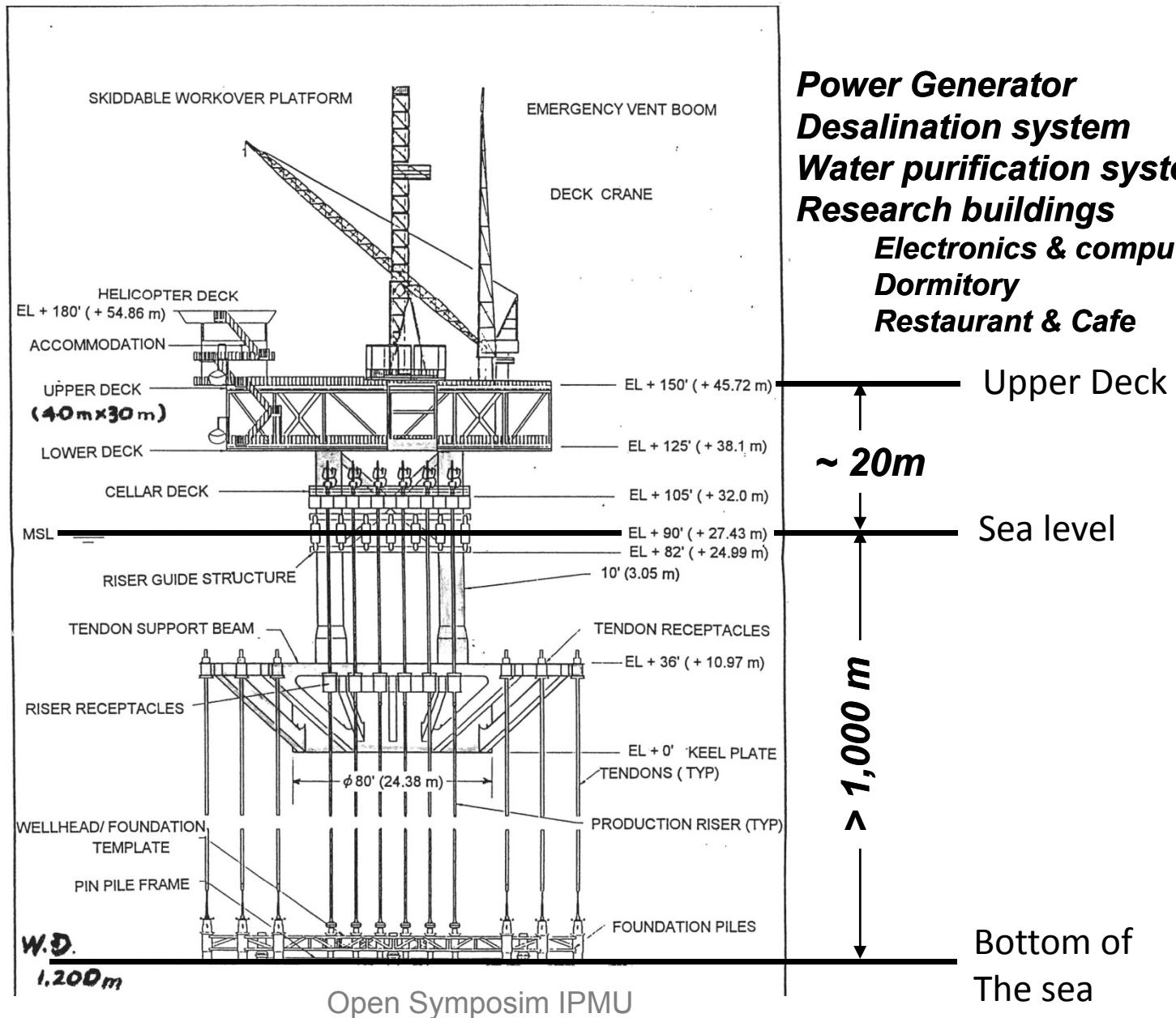
LCGT	$10^{-23} (1/\text{Hz})$	2009 ? ~
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Proton Decay (Personal View)

Deep-TITAND	$\sim 7 \times 10^{35} \text{ yr}$	2030 ? ~
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Tension Leg Platform



Power Generator
Desalination system
Water purification system
Research buildings
Electronics & computer
Dormitory
Restaurant & Cafe