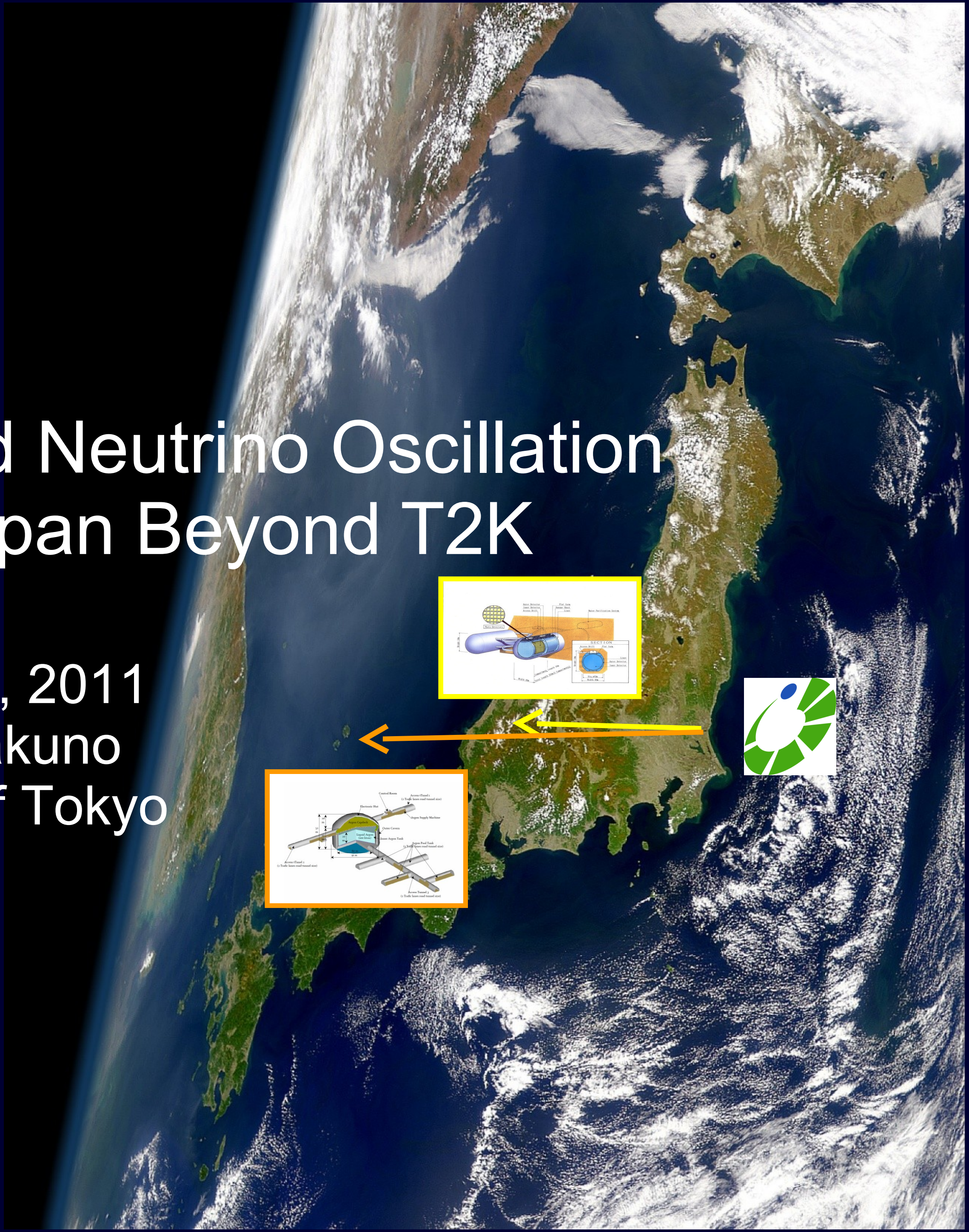
Accelerator Based Neutrino Oscillation Projects In Japan Beyond T2K

2 Aug, 2011

H.Kakuno
Univ of Tokyo



ν_e appearance in LBL experiment

Oscillation probability:

$$P(\nu_\mu \to \nu_e) = \sin^2 2\theta_{13} T_1 + \alpha \sin 2\theta_{13} \overbrace{(T_2 - T_3)}^{\text{Interference}} + \alpha^2 T_4$$

Where:

$$T_1 = \sin^2 \theta_{23} \frac{\sin^2[(A-1)\Delta]}{(A-1)^2} \quad \leftarrow\text{Atmospheric}$$

$$T_2 - T_3 = \sin 2\theta_{12} \sin 2\theta_{23} \cos(\Delta + \delta_{CP}) \frac{\sin(A\Delta)}{A} \frac{\sin[(A-1)\Delta]}{A-1}$$

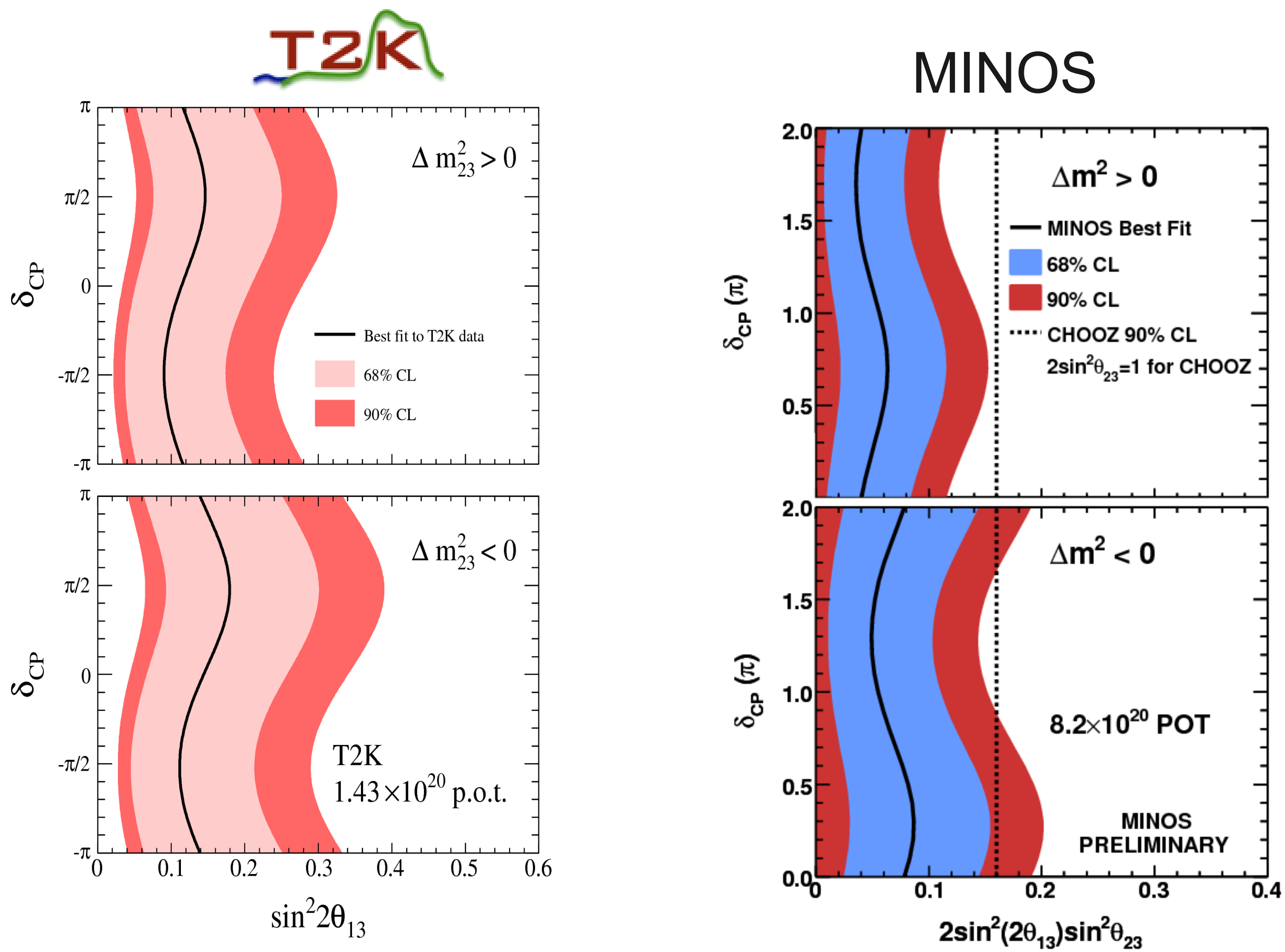
$$T_4 = \cos^2 \theta_{23} \sin^2 2\theta_{12} \frac{\sin^2(A\Delta)}{A^2} \quad \leftarrow\text{Solar}$$

$$A \equiv \frac{2EV}{\Delta m^2_{31}}, \quad \Delta \equiv \frac{\Delta m^2_{31} L}{4E}, \quad \alpha \equiv \frac{\Delta m^2_{21}}{\Delta m^2_{31}}$$

contain information of CPV phase and the mass hierarchy

One can access those information through precise measurement of ν_e appearance

Recent Indication of non-zero θ_{13}



Next generation LBL experiment beyond T2K become more realistic after June 2011

Quest for the Origin of Matter Dominated Universe

One of the Main Subject of the KEK Roadmap

T2K
(2009~)

Discovery of
the ν_e Appearance

Neutrino
Intensity Improvement

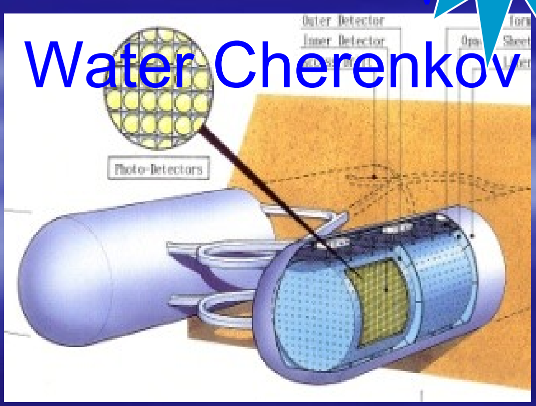
Huge Detector R&D

Establish
Huge Detector
Technology

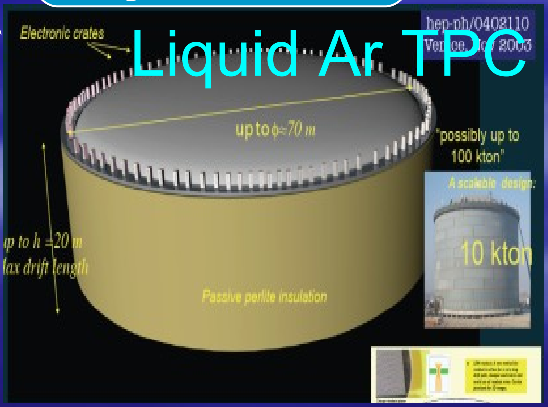
Construction of
Huge Detector

Discovery of
Lepton CP Violation
Proton Decay

Water Cherenkov



Liquid Ar TPC



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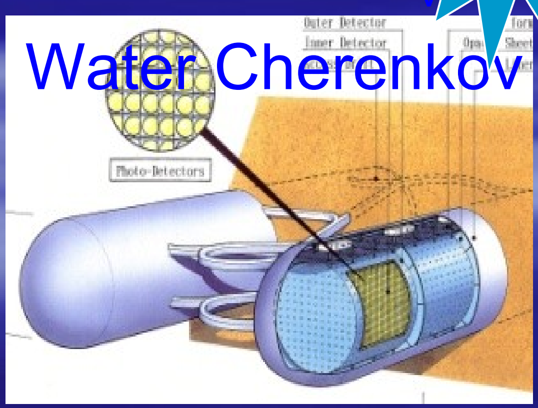

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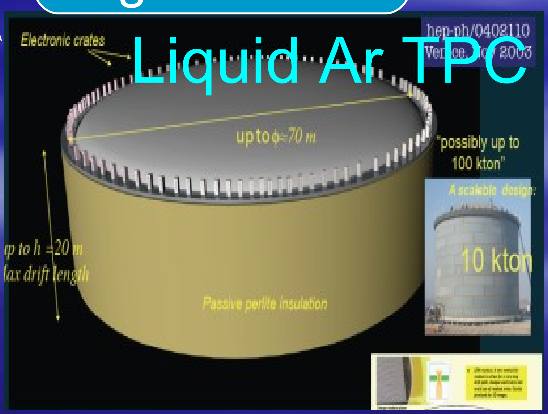


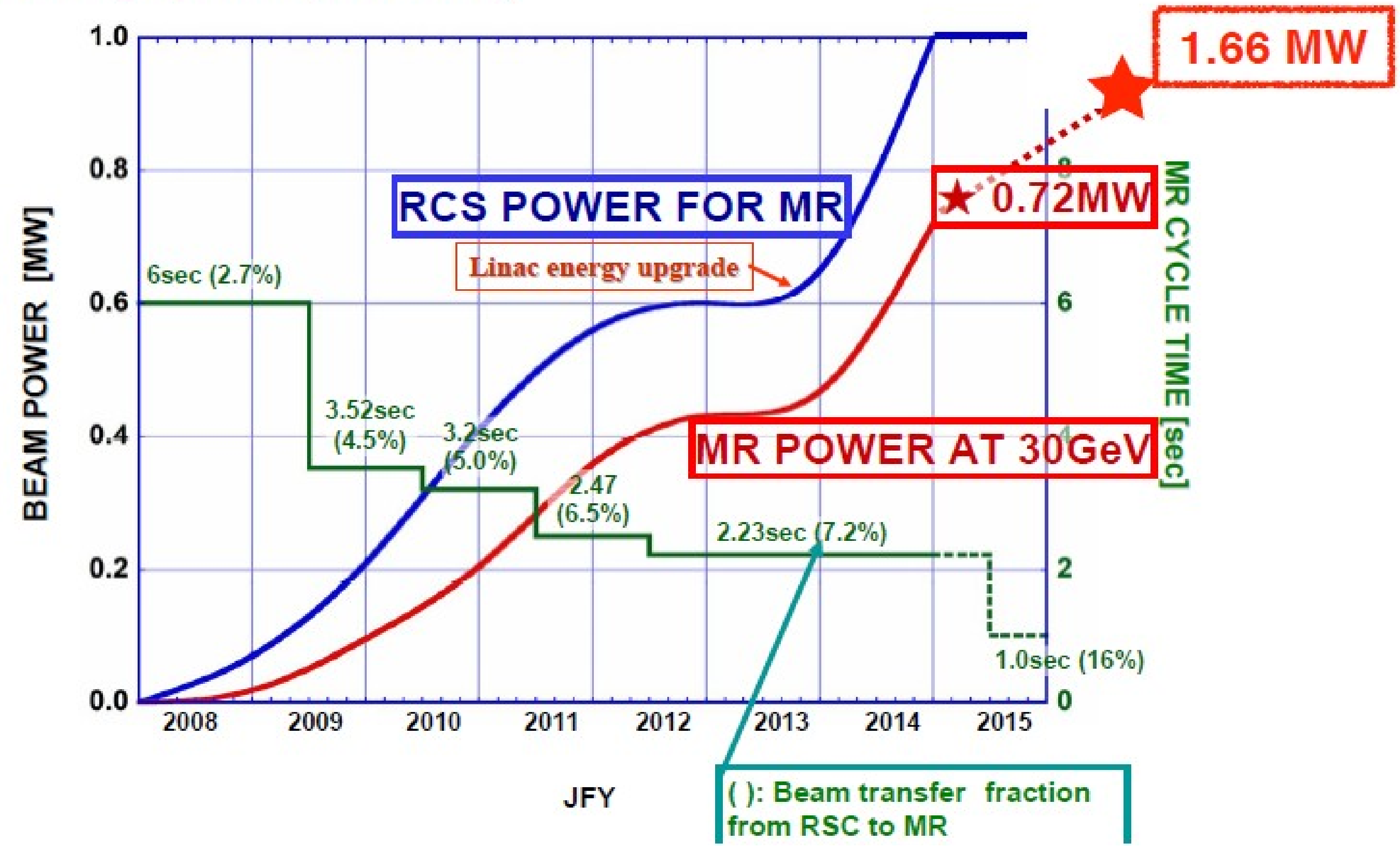
MR Power Improvement scenario

	Day1 Achieved! (up to Mar.2011)	Next Step	KEK Roadmap
Power(MW)	0.145	0.45	>1.66
Energy(GeV)	30	30	30
Rep Cycle(sec)	3.04	2.2	1.92～0.5
No. of Bunch	8	8	8
Particle/Bunch	1.2×10^{13}	2.5×10^{13}	$4.1\sim8.3\times10^{13}$
Particle/Ring	9.2×10^{13}	2.0×10^{14}	$3.3\sim6.7\times10^{14}$
LINAC(MeV)	181	181	400
RCS	h=2	h=2	h=2 or 1

Technically feasible upgrade of J-PARC

MR power improvement scenario(cont'd)

Increase rep. rate and/or increase # of protons toward high power (~1.66MW)



Studies and R&D on Power supply, RF configuration, etc are being made

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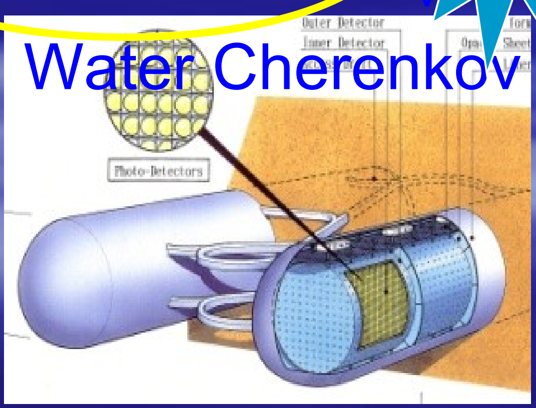

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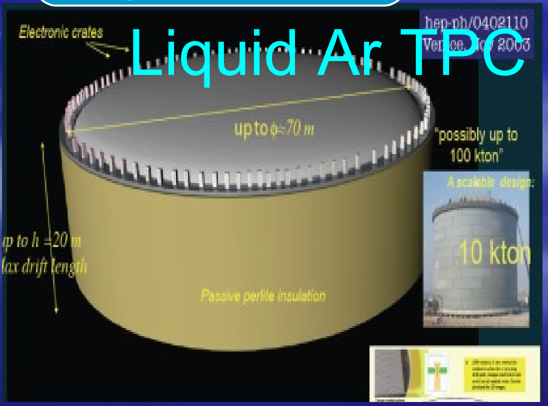


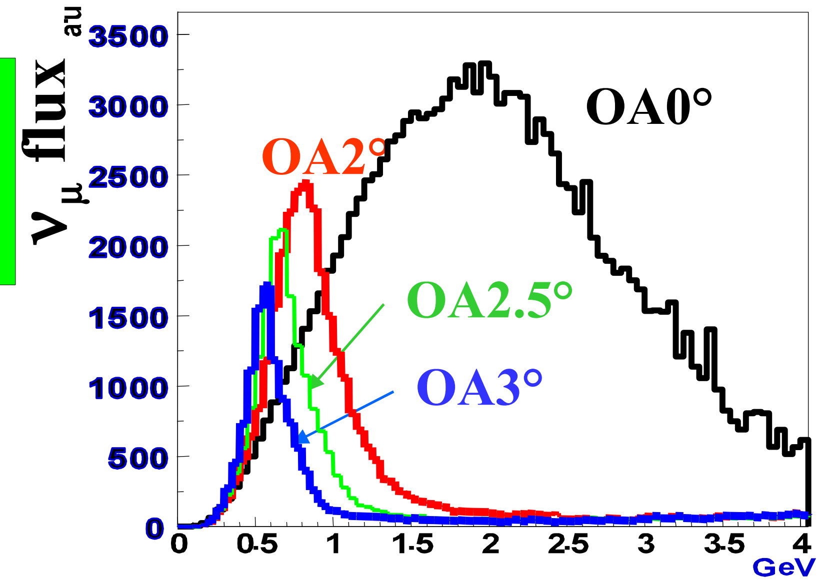
Off-axis angle and Baseline

Off-axis angle

On-axis: Wide energy coverage
Energy: distributed incl. 1st & 2nd Osc. Max.
Require π^0 background control

⬍

Off-axis: Narrow energy coverage
Energy: peaked at 1st (or 2nd) Osc. Max.
π^0 background controlled

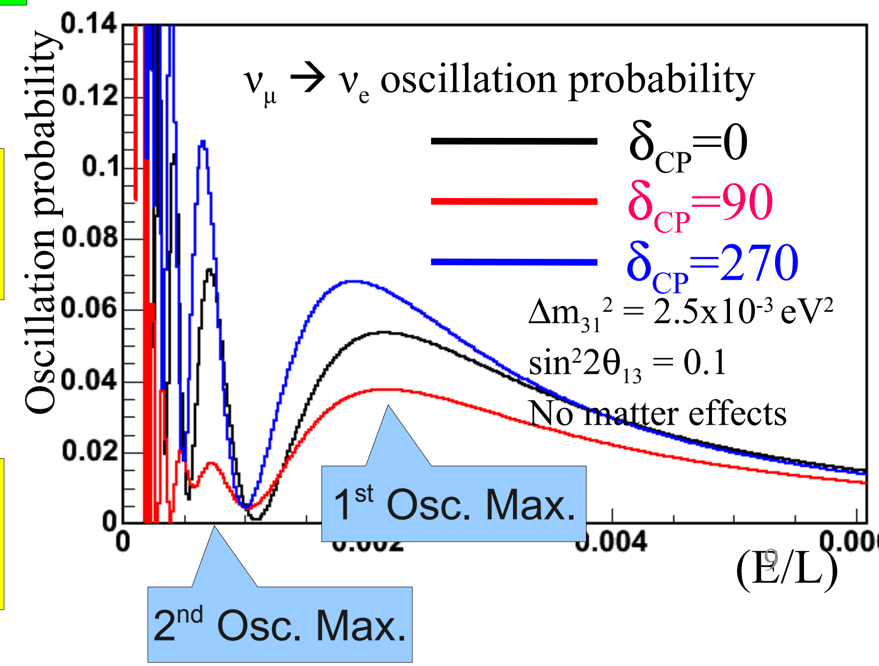


Baseline

Long(>>300km): 2nd Osc. Max. at
Measurable energy

⬍

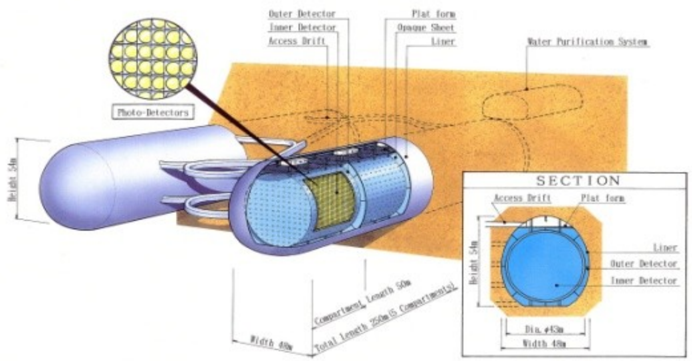
Short(~300km=T2K): 1st Osc. Max.



Two choices

Kamioka L=295km OA=2.5deg

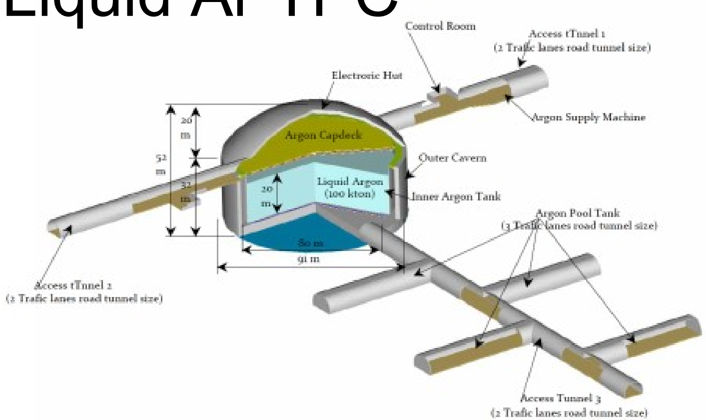
Huge water Cherenkov



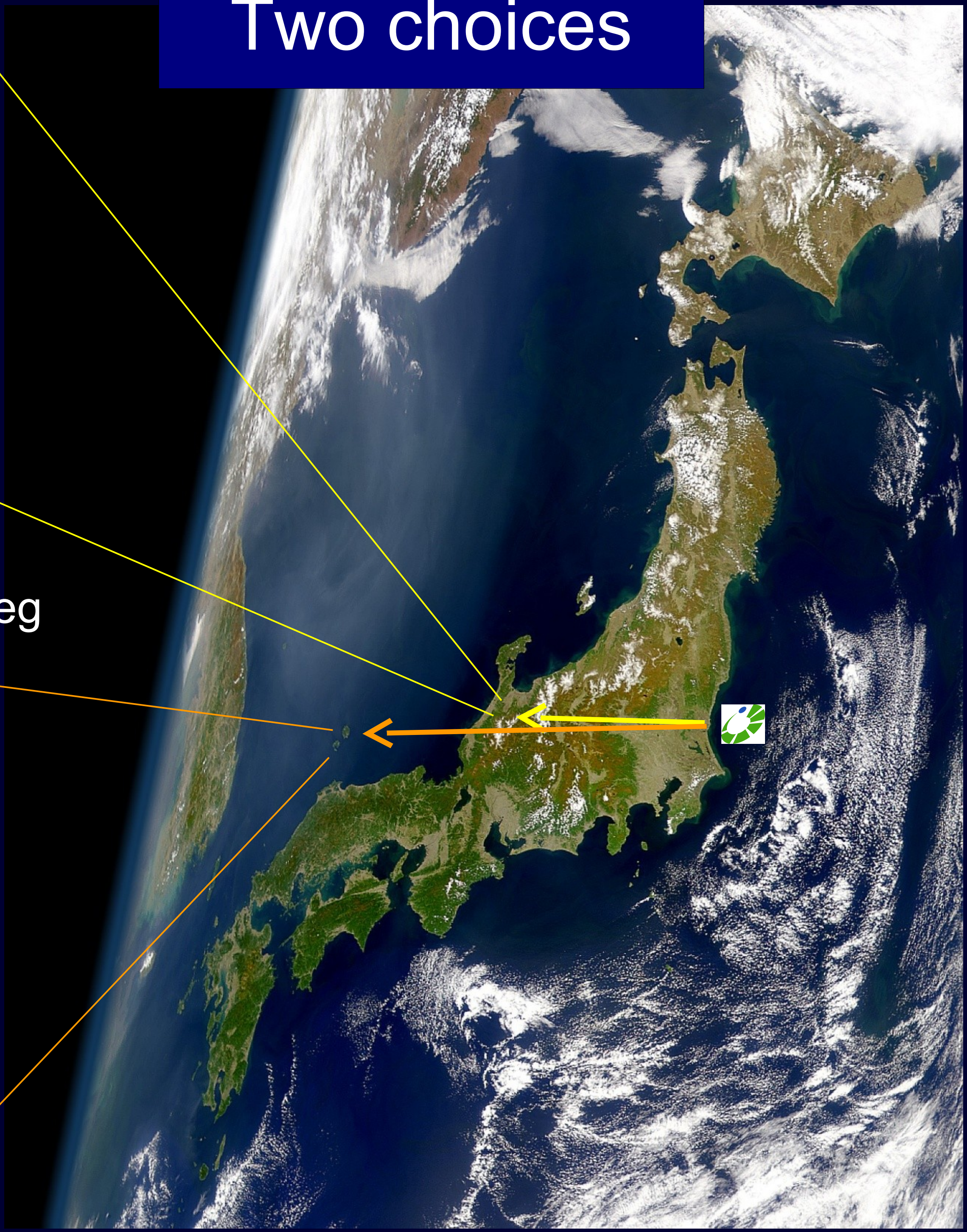
Okinoshima L=658km OA=0.78deg

Almost On-Axis

Liquid Ar TPC



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



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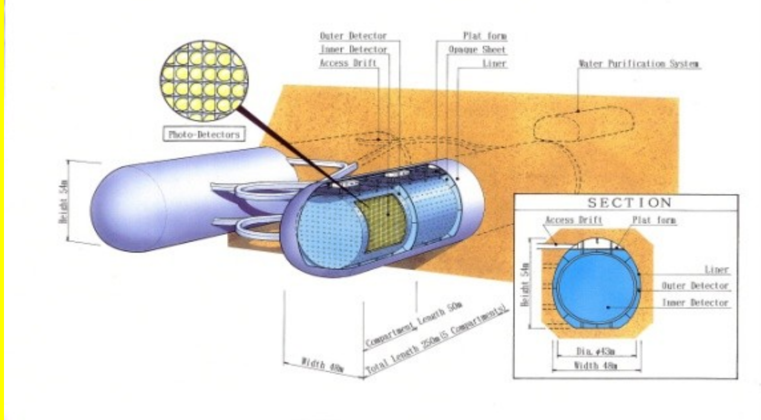

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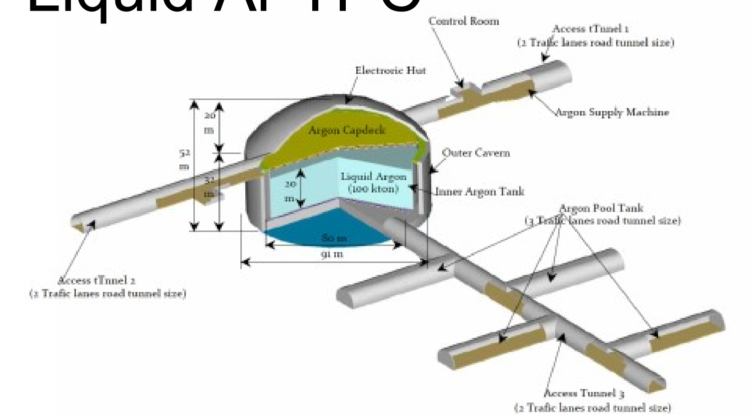

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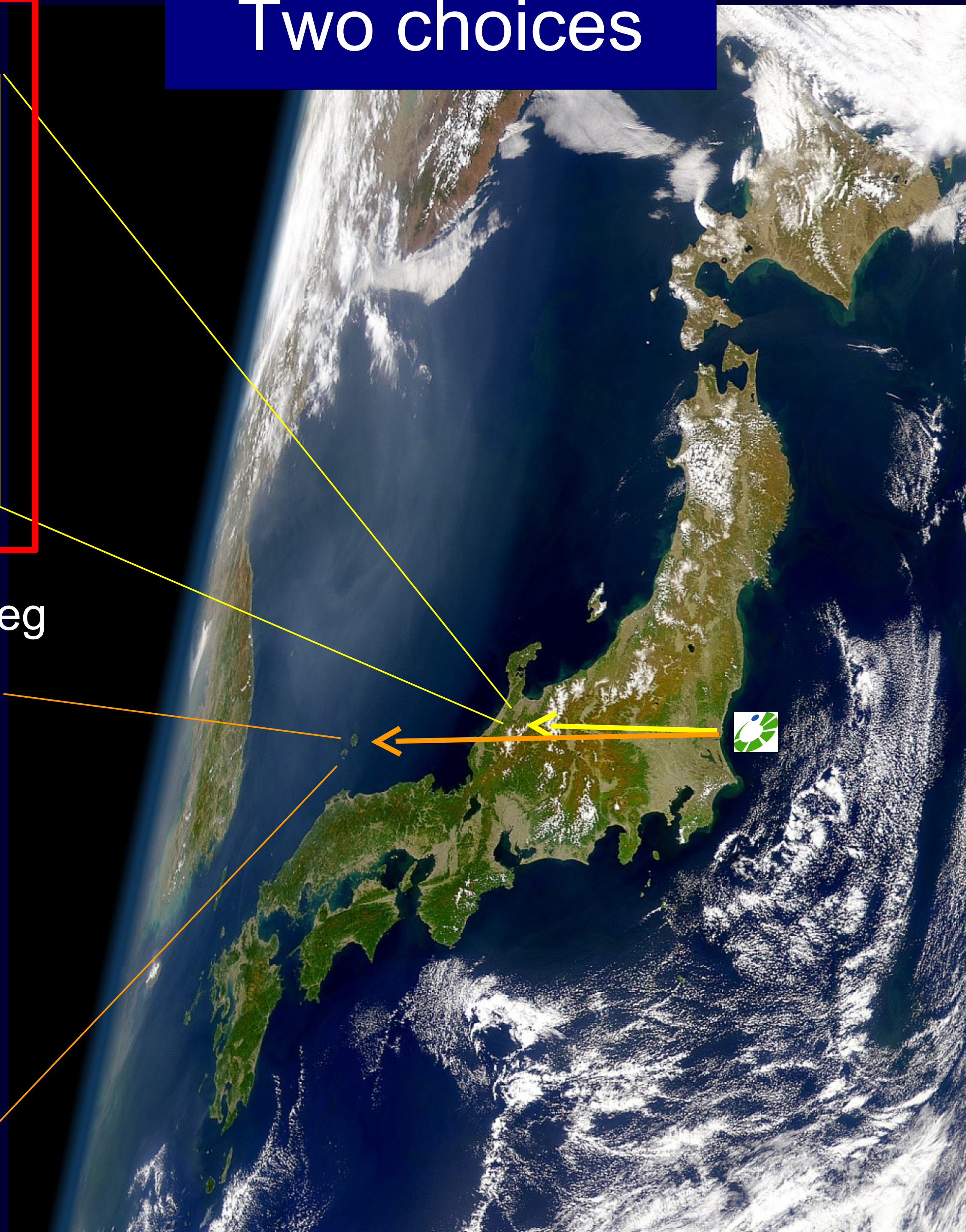
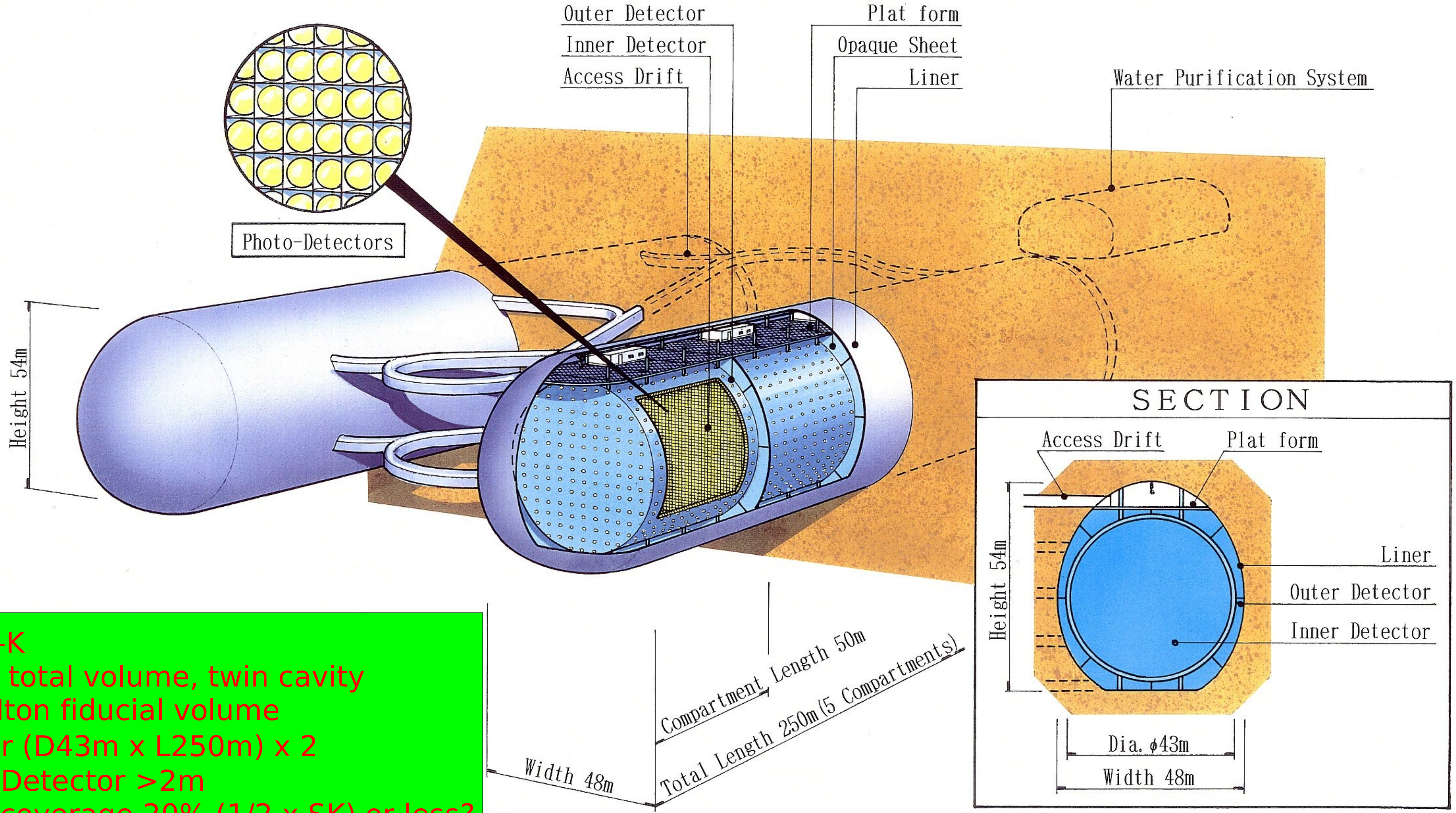


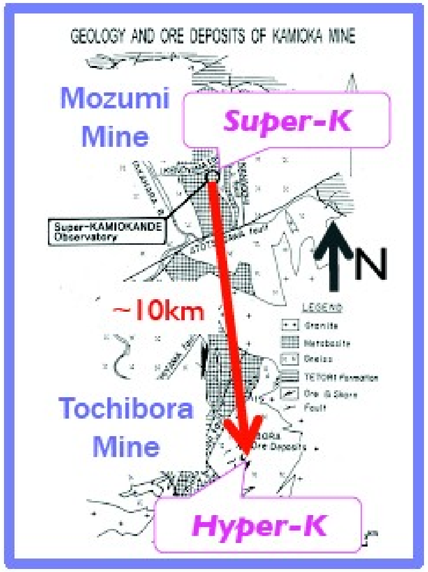
Hyper Kamiokande(HK)

$\nu_\mu + \overline{\nu}_\mu$ run at the first oscillation maximum

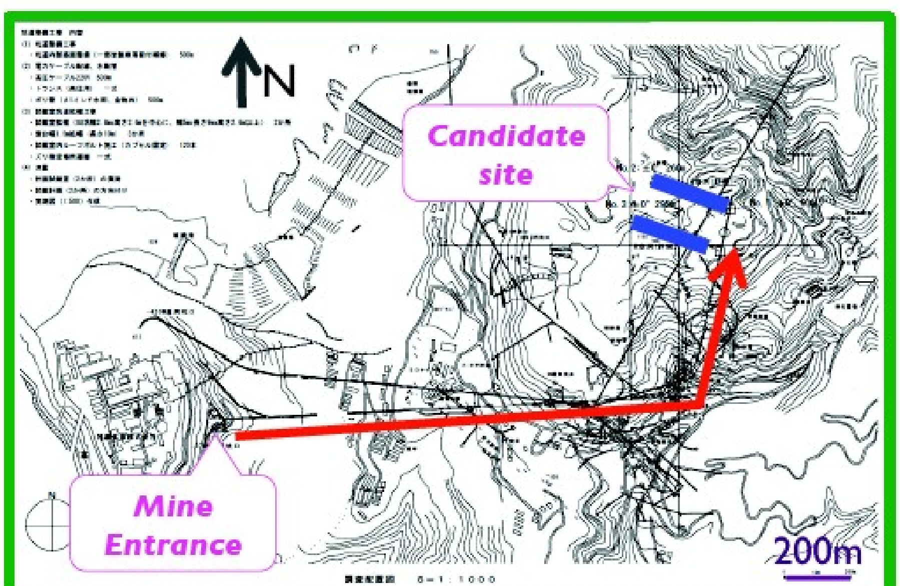


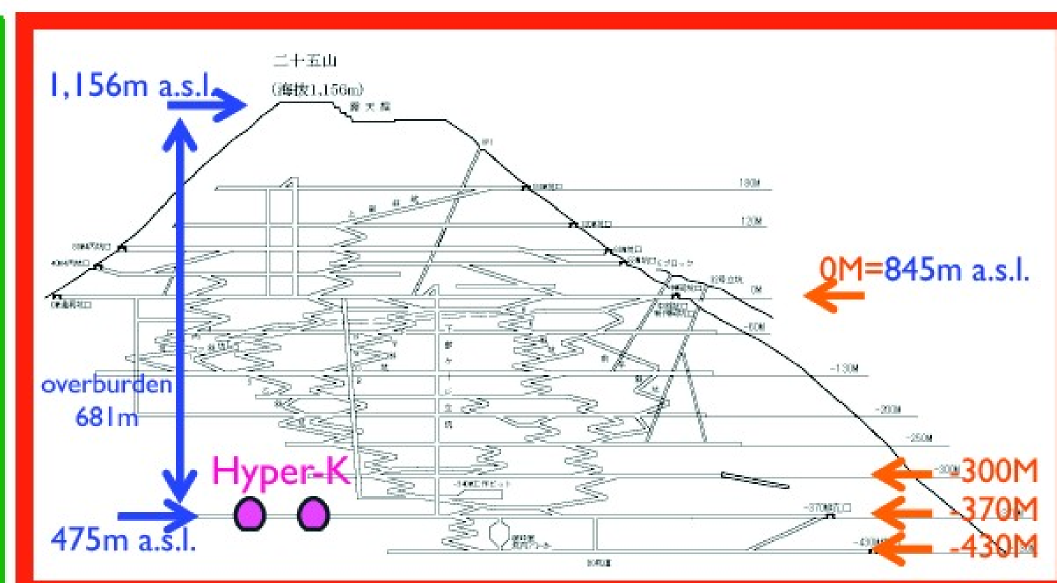
Hyper-K
1Mton total volume, twin cavity
~0.6Mton fiducial volume
Inner (D43m x L250m) x 2
Outer Detector >2m
Photo coverage 20% (1/2 x SK) or less?

Hyper Kamiokande candidate site

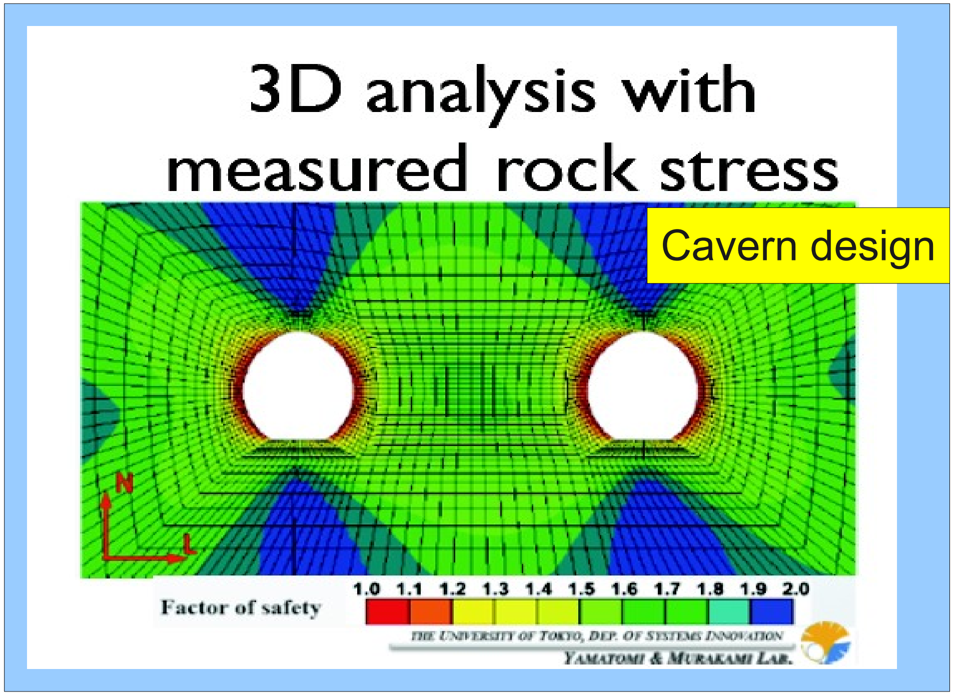


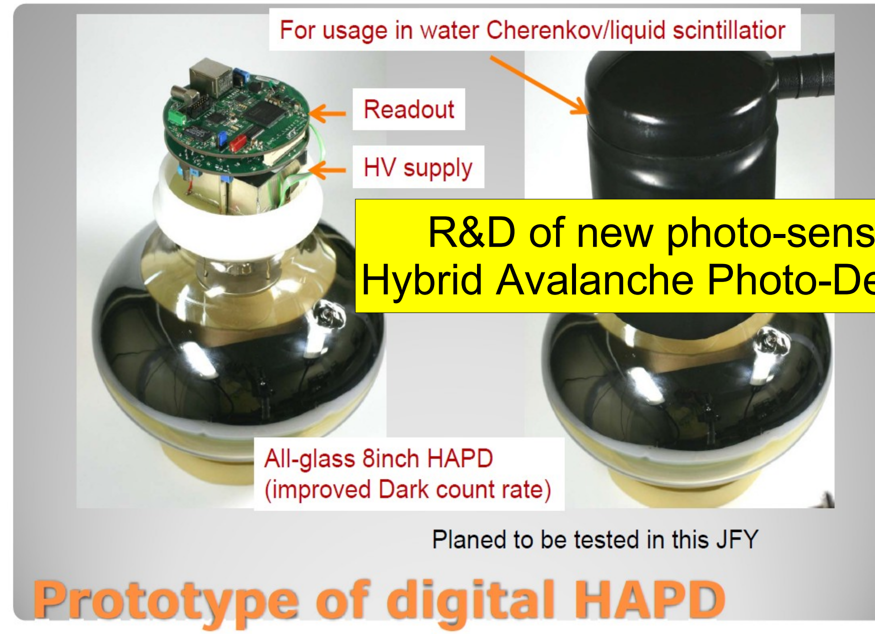
- ✦ 8km south from Super-K
  - ✦ same T2K beam off-axis angle
- ✦ 2.6km horizontal drive from entrance
- ✦ under the peak of Nijuugo-yama
  - ✦ 648m of rock or 1,750 m.w.e. overburden
  - ✦ 508m above sea level
- ✦ dominated by Hornblende Biotite Gneiss and Migmatite
- ✦ 2.3km from waste rock disposal place
- ✦ 13,000 m³/day or 1megaton/80days natural water

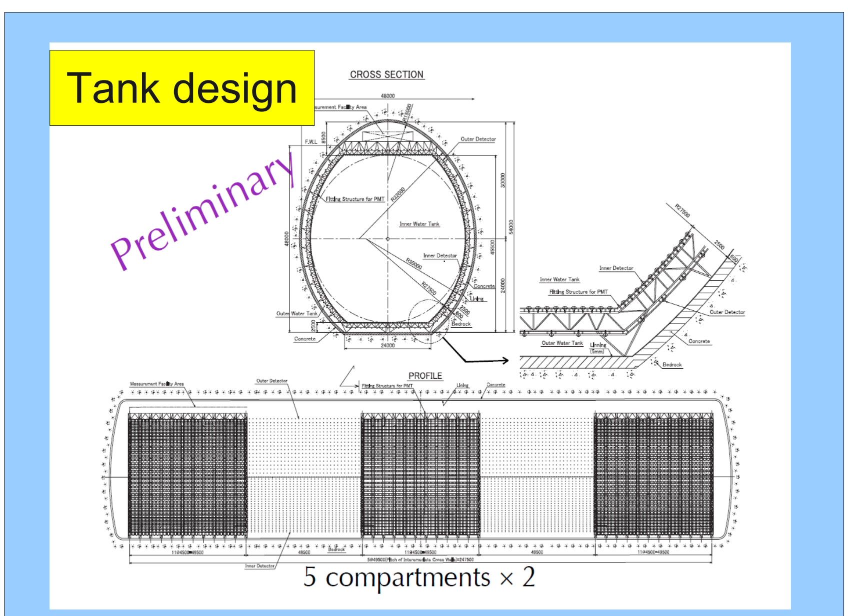




R&Ds toward Hyper-K

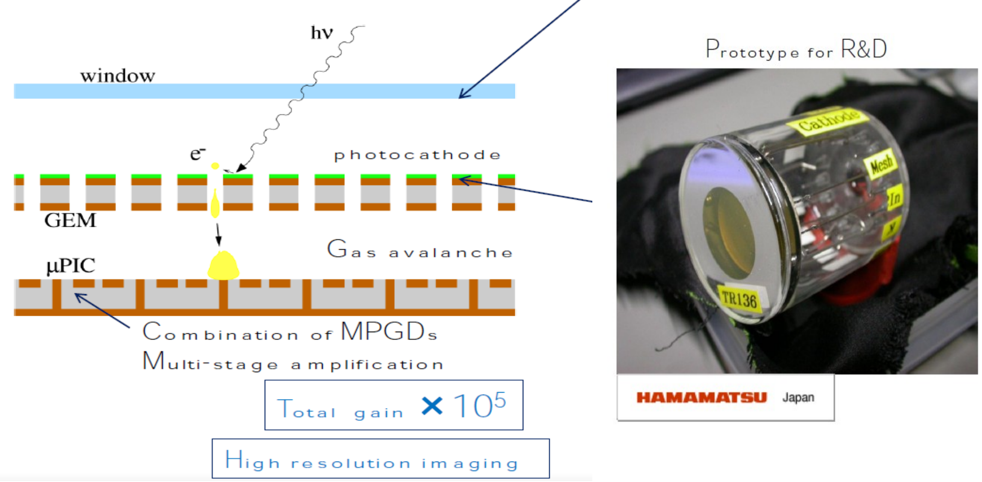






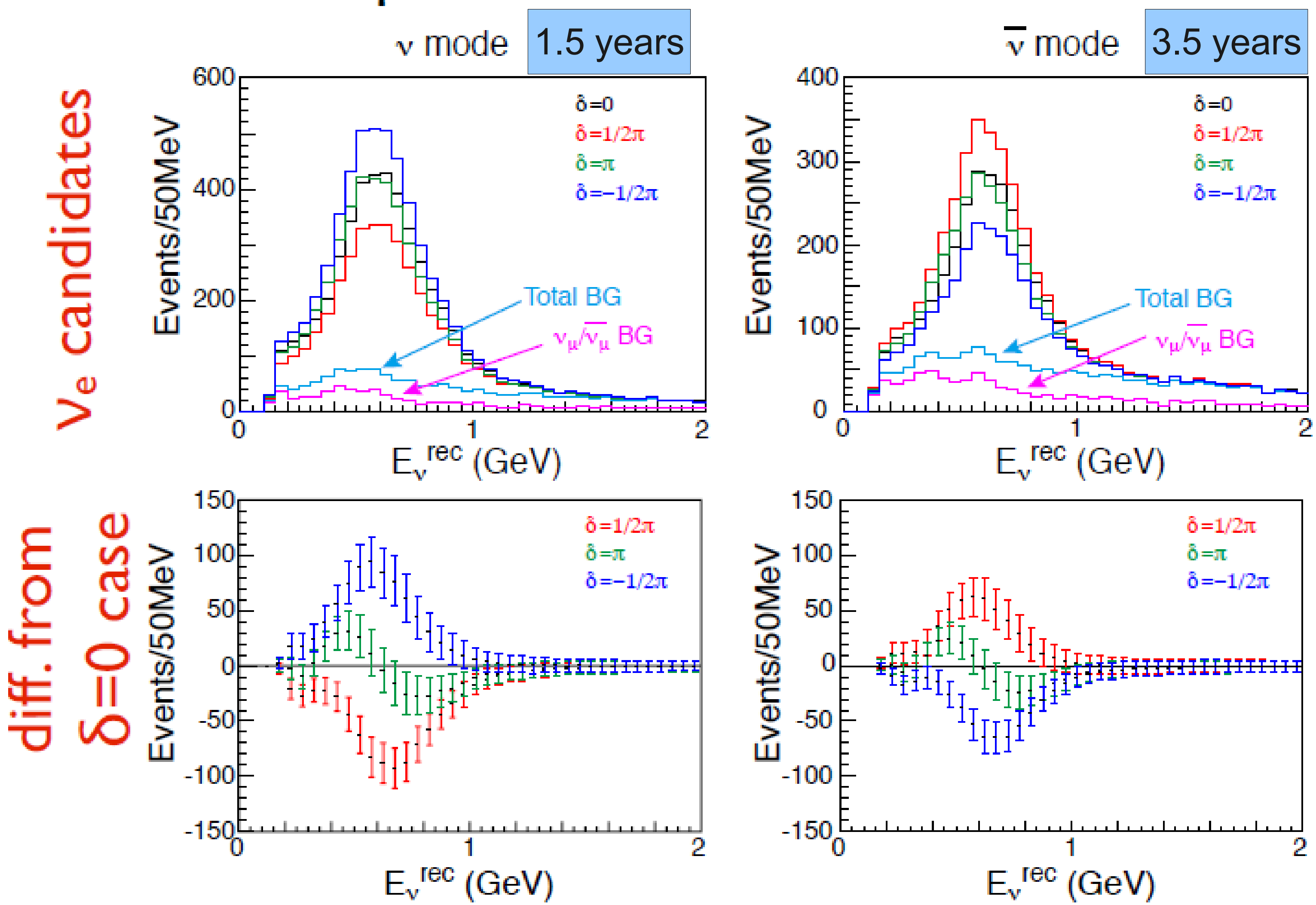
Another candidate of photo-sensor:
Gas Photo-Multiplier

- Photocathode
+ Micro Pattern Gas Detectors



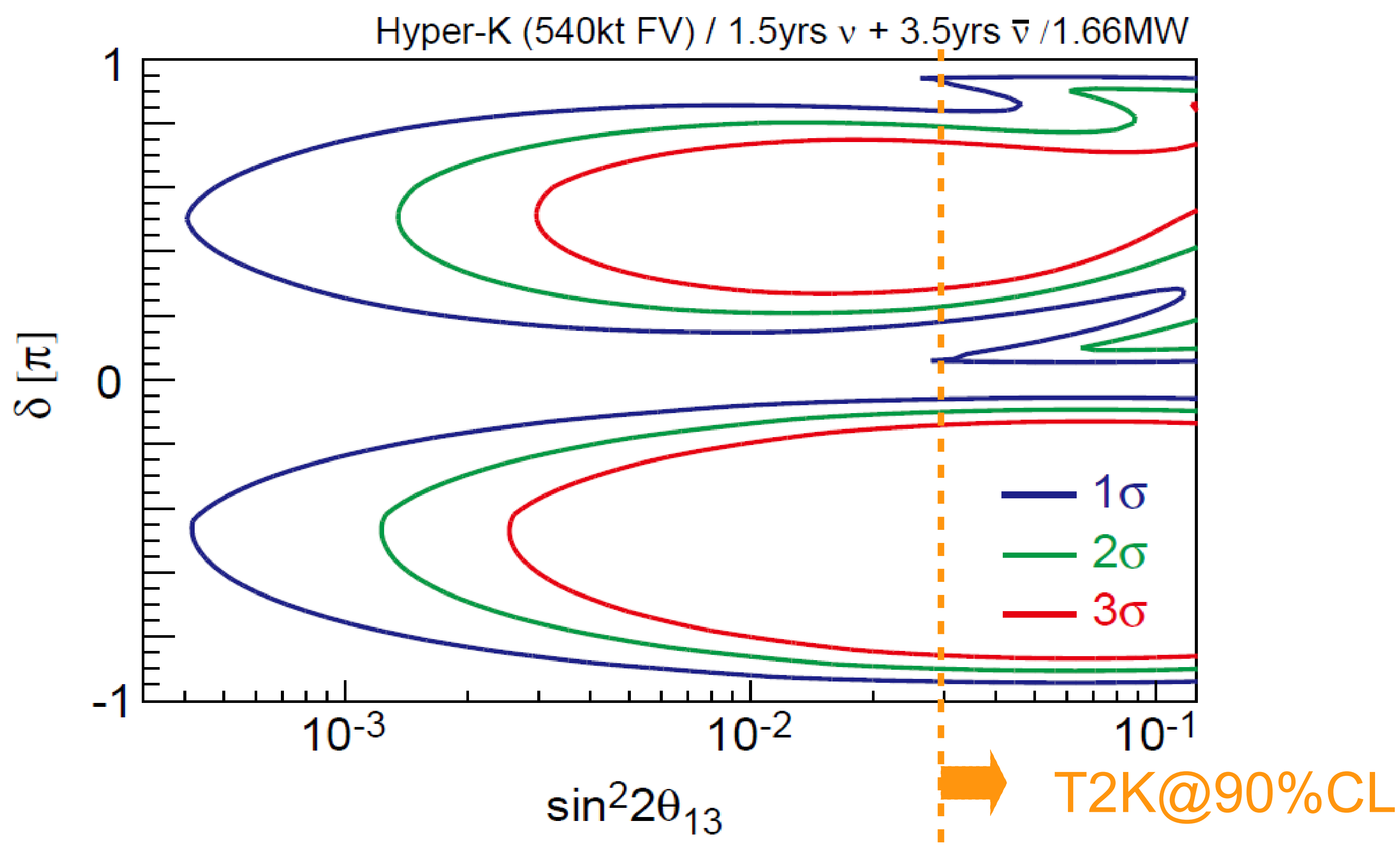
J-PARC HK CPV effect

Compare electron appearance (number and spectrum) in ν and anti-ν beam



$\sin^2 2\theta_{13}=0.1$
Is assumed

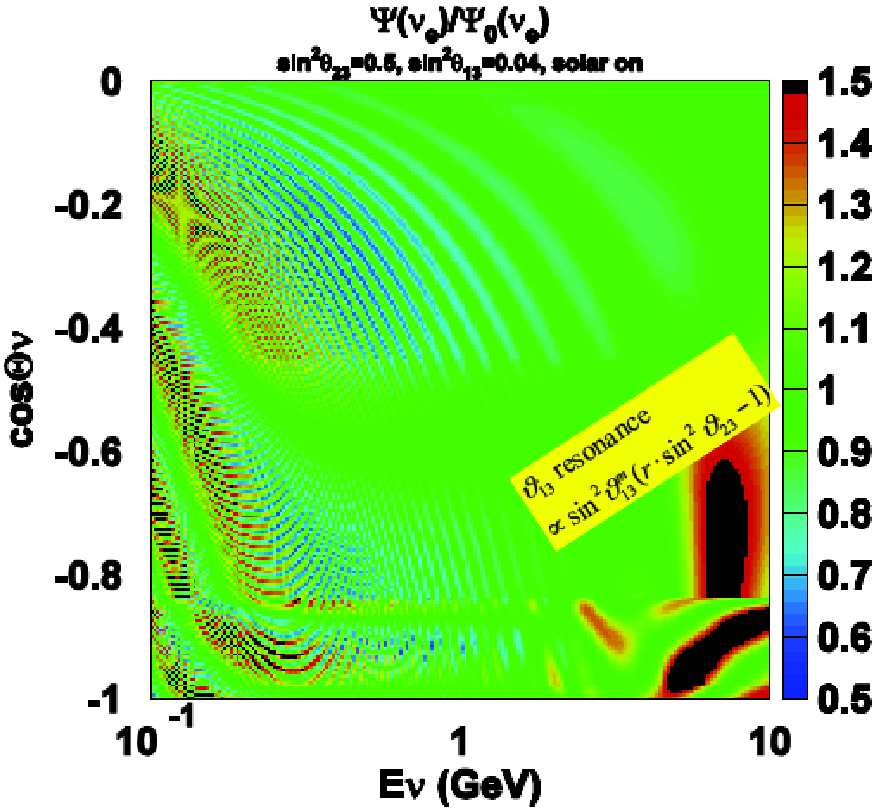
J-PARC HK CPV sensitivity

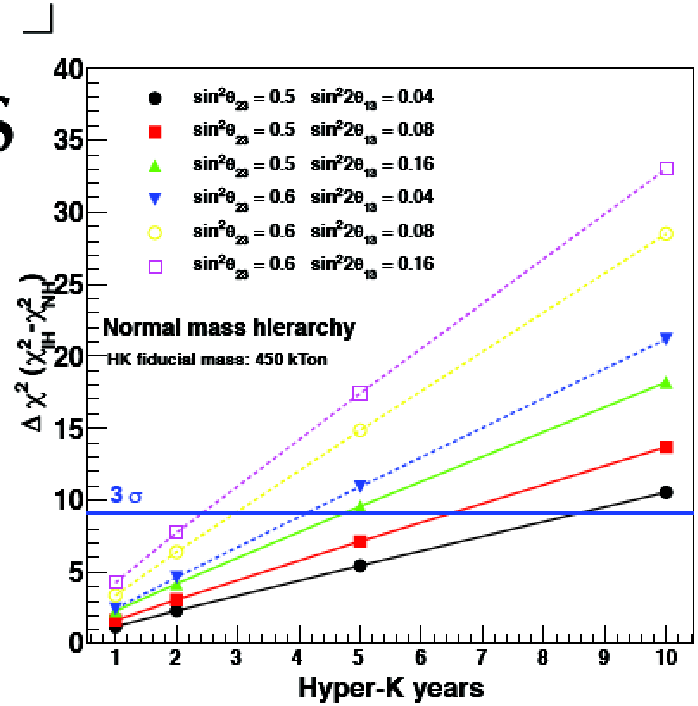


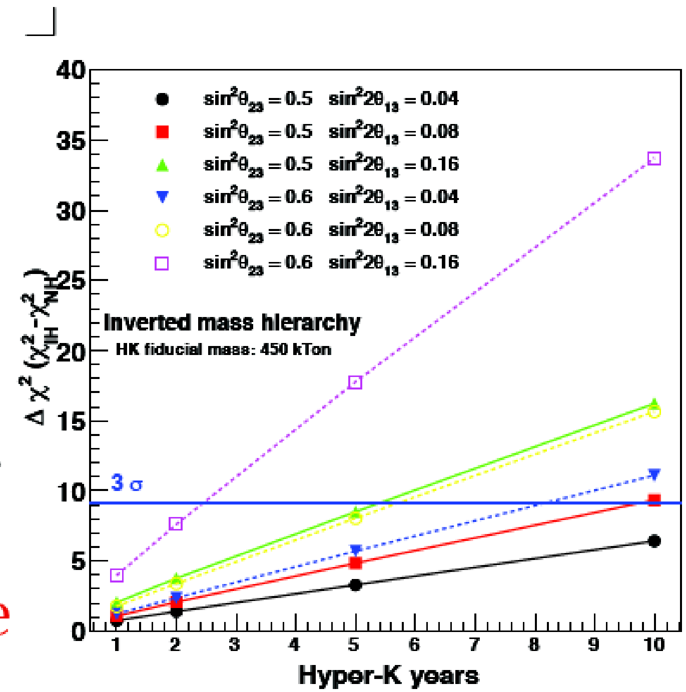
- 5% of systematic uncertainty is assumed
- mass hierarchy is assumed to be ***unknown***

determine together w/ atmospheric ν studies

Atmospheric ν studies (mass hierarchy)



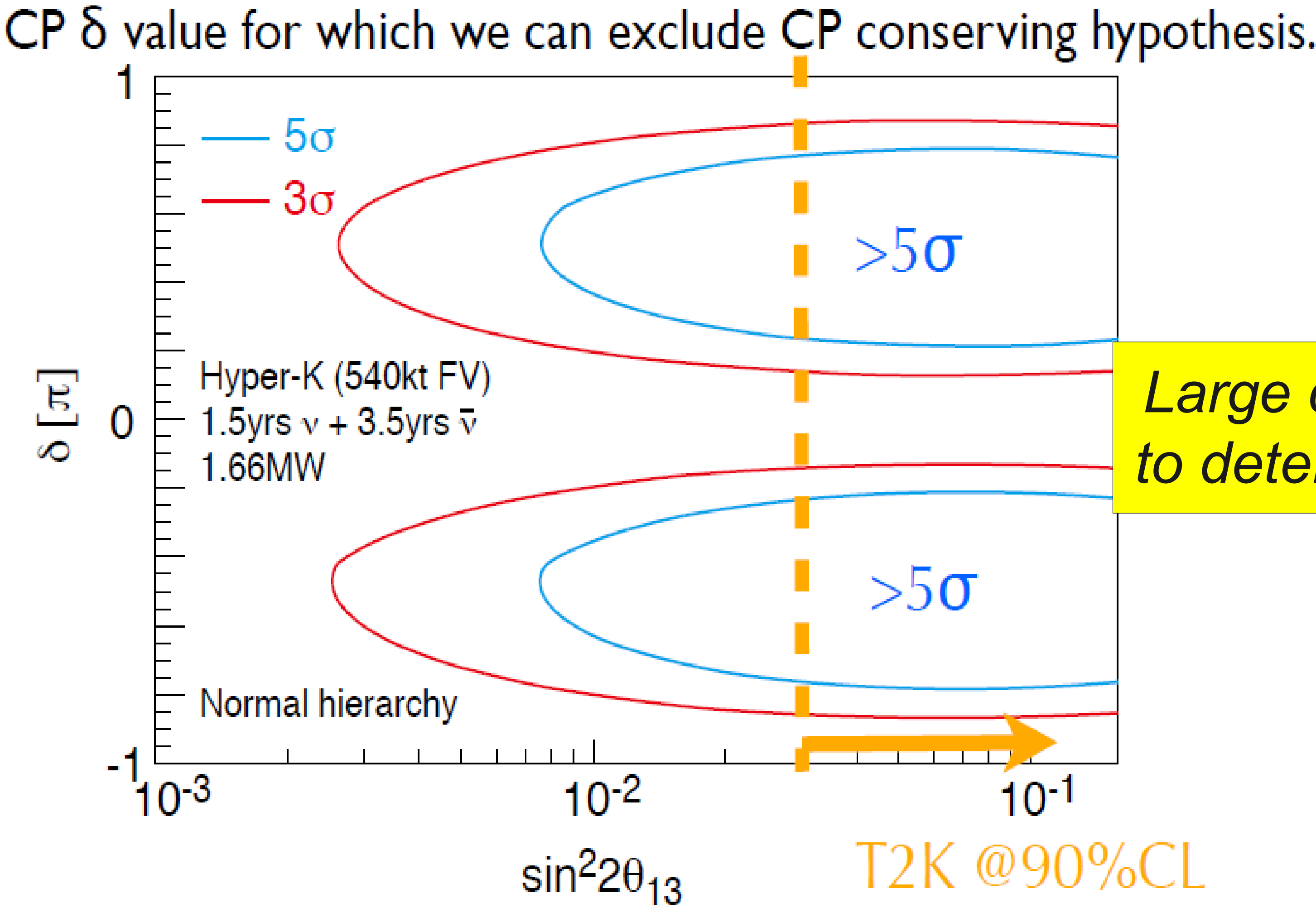




- Normal mass hierarchy → resonance in ν_e appearance
- Inverted mass hierarchy → resonance in anti-ν_e

Good chance if θ_{23} and θ_{13} are large

J-PARC HK CPV sensitivity



Large chance to determine δ

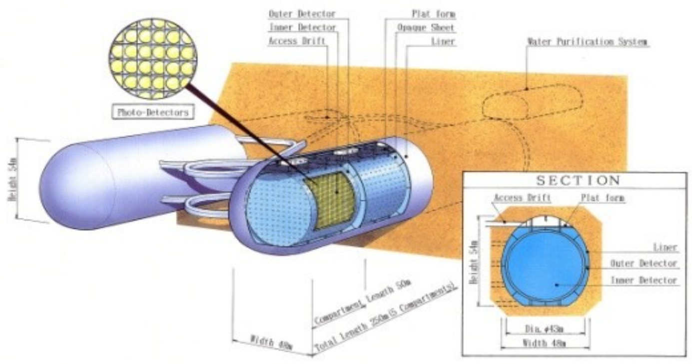
- 5% of systematic uncertainty is assumed
- mass hierarchy is assumed to be ***known***

determine together w/ atmospheric ν studies

Two choices

Kamioka L=295km OA=2.5deg

Huge water Cherenkov



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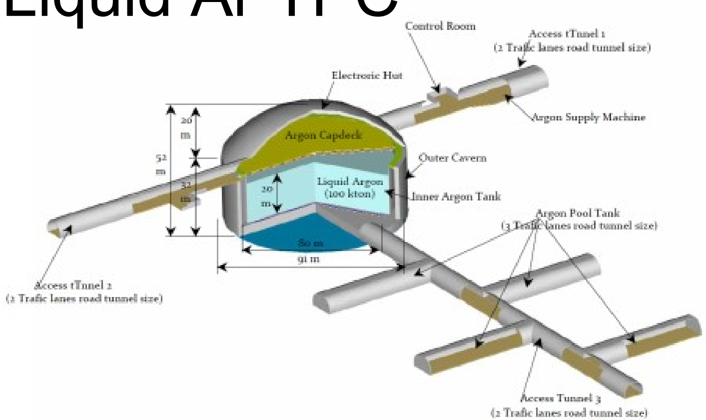

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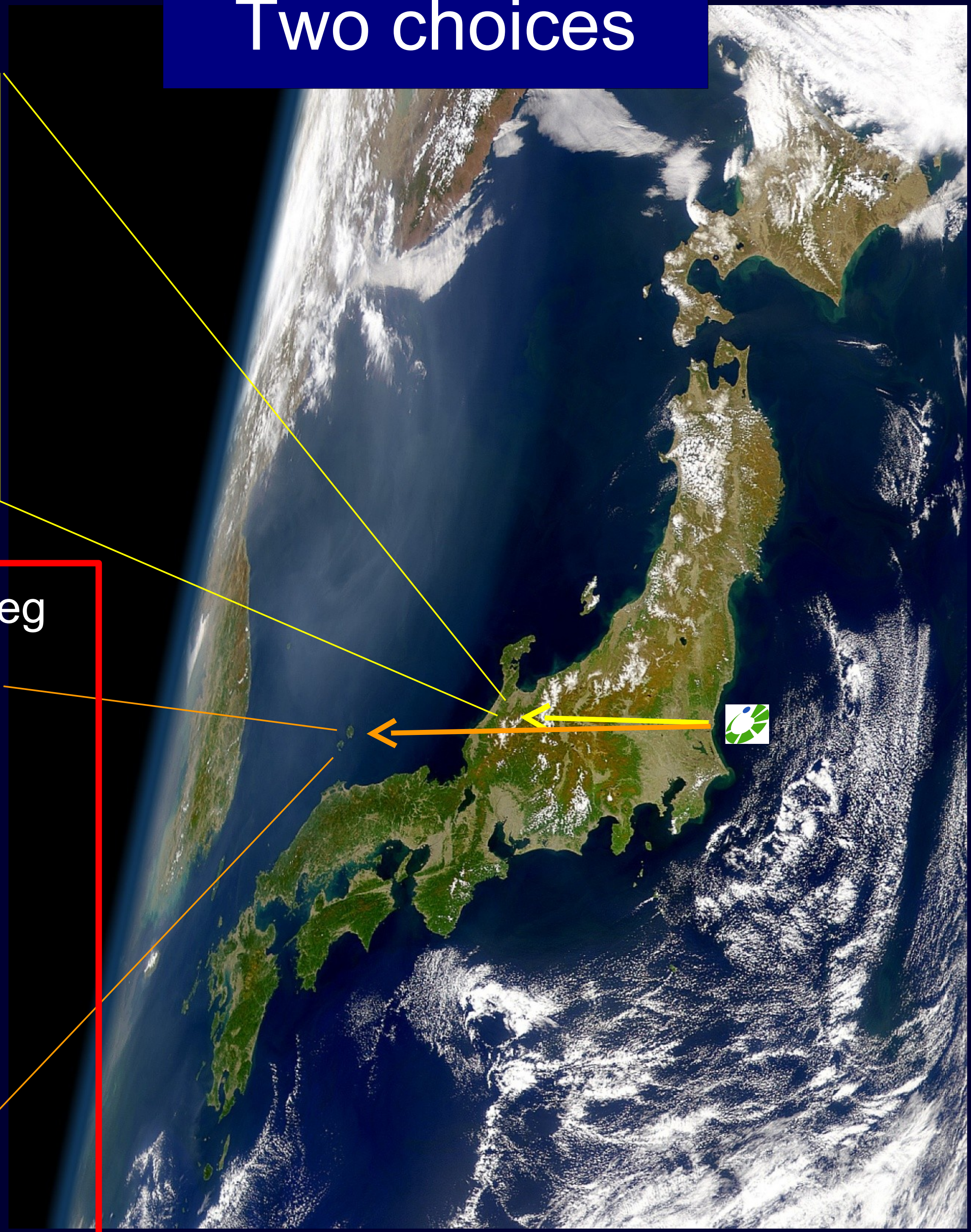

J-PARC to Okinoshima

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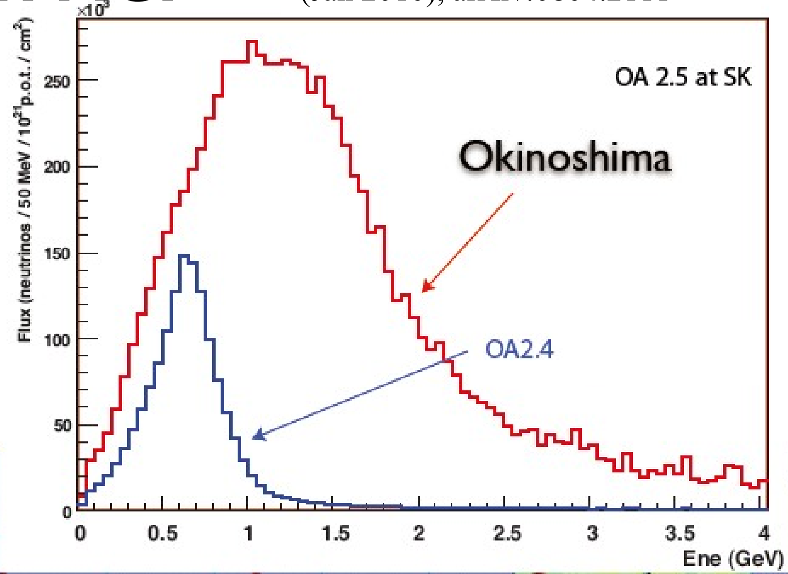
Distance = 658 km

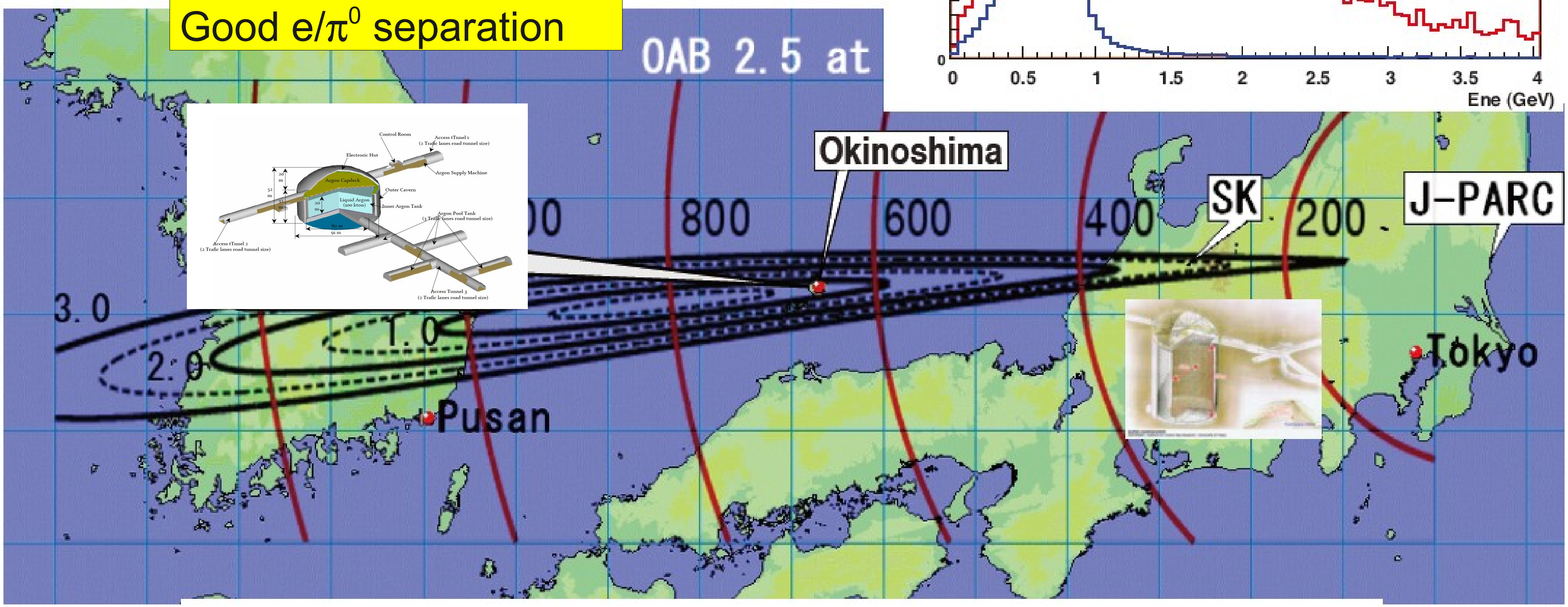
Off-axis angle = 0.76°

(2.5° @ SK)

100 kton liquid Argon

Good Energy resolution
Good e/π^0 separation





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

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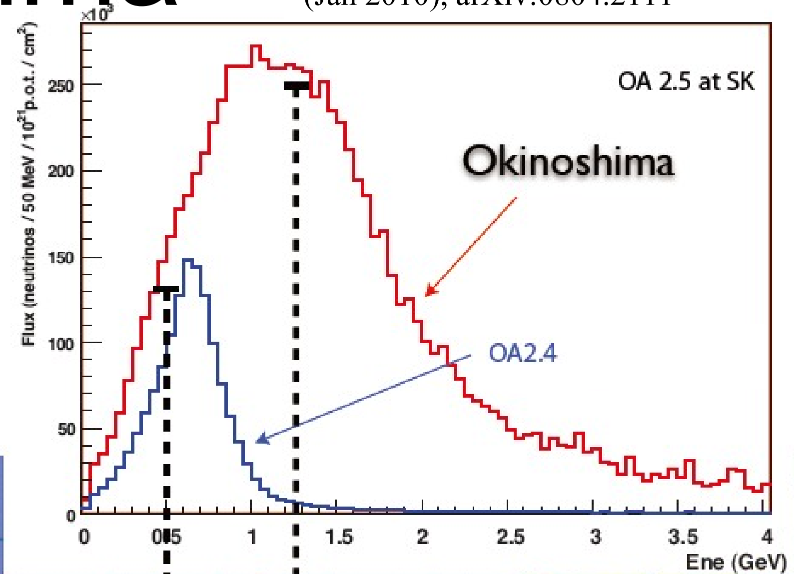
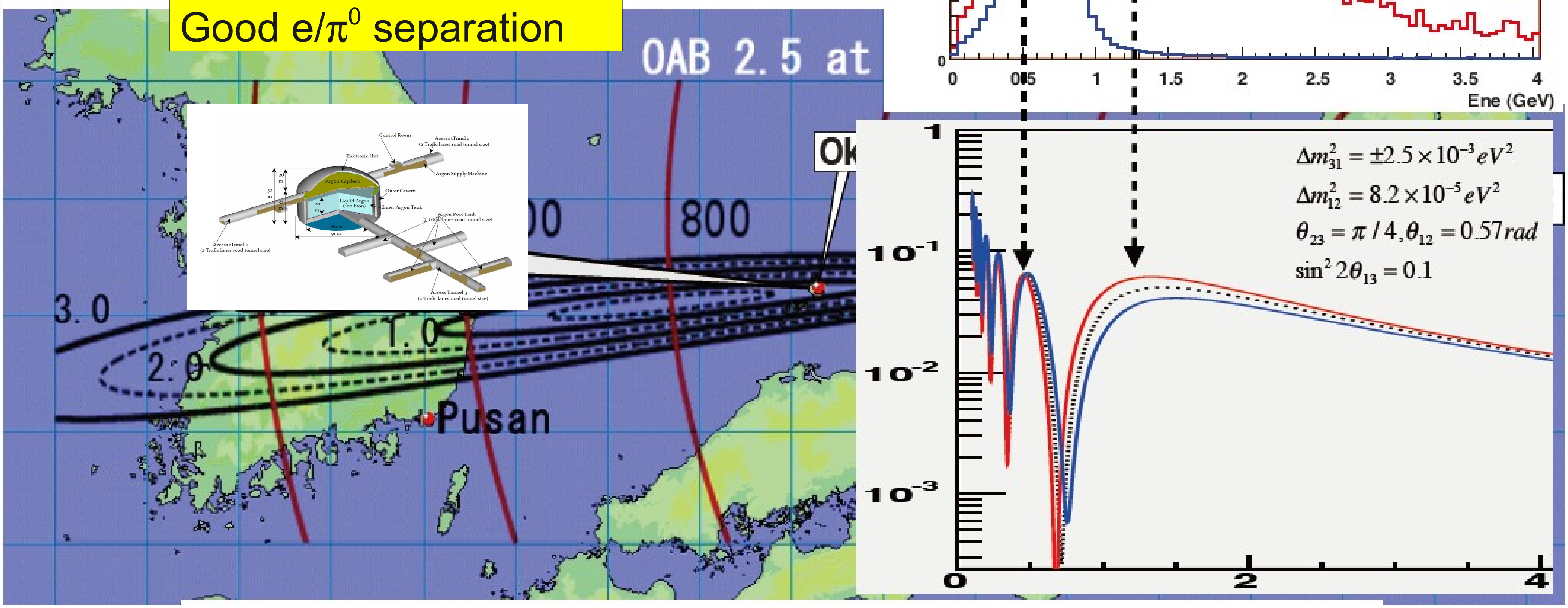




→ Extract δ_{CP} from fit of 1st & 2nd maximum

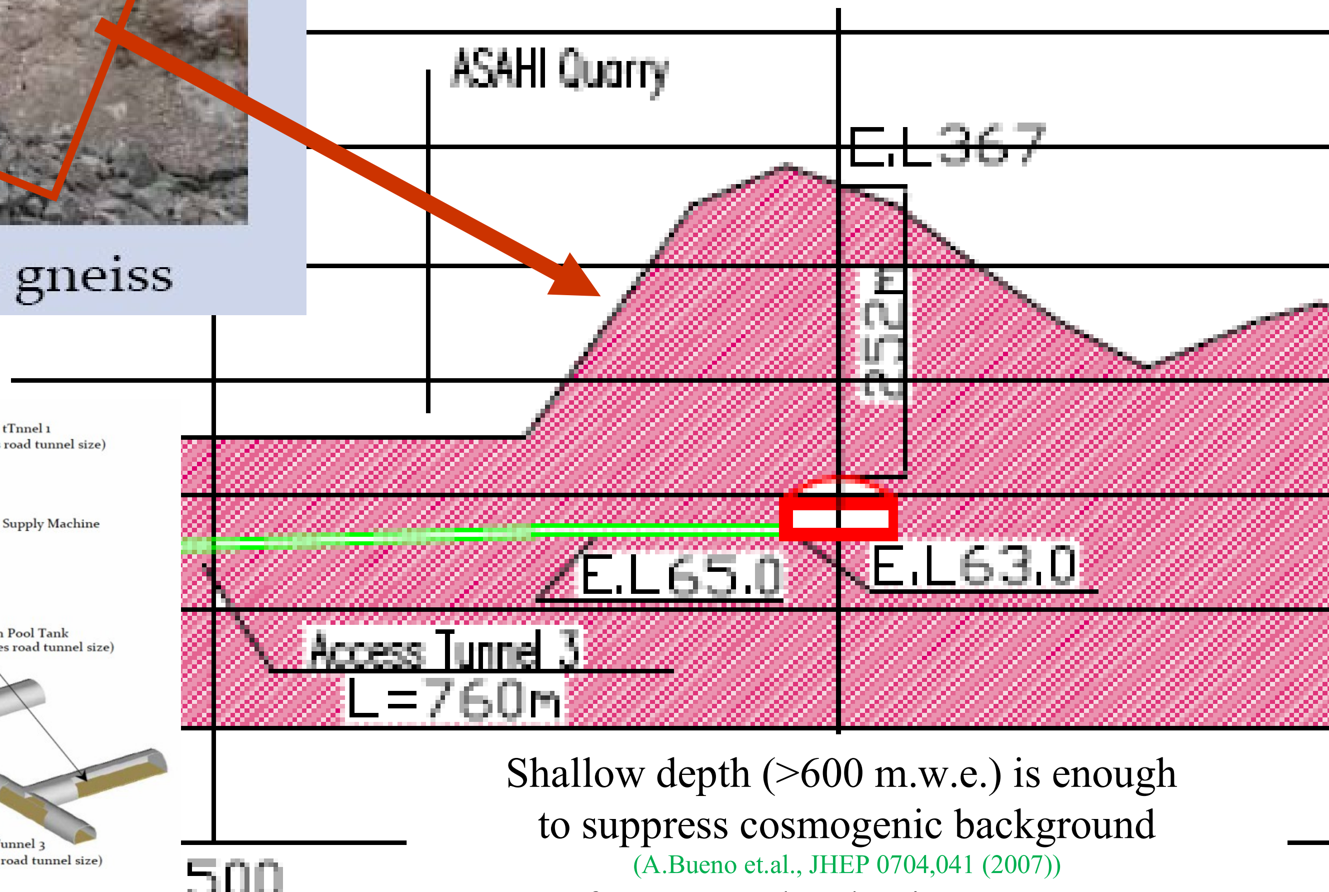
Okinoshima: Geology and Geography

A conceptual design

Site No.1

ASAHI quarry

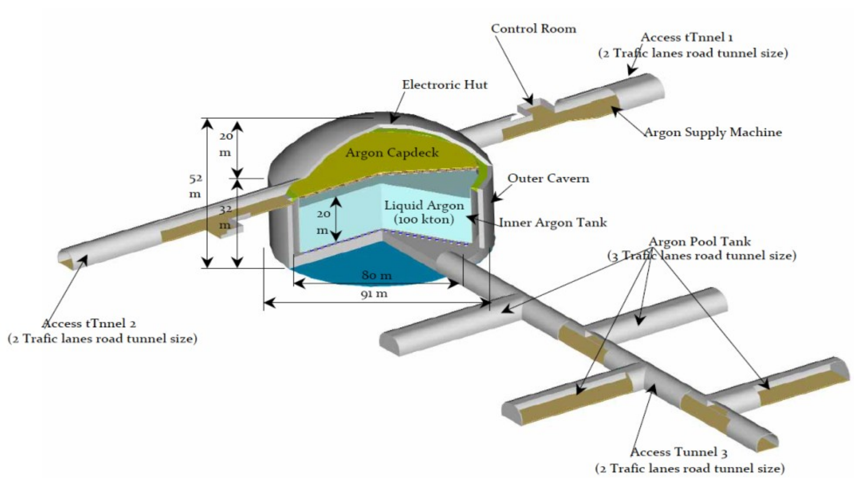
A single layer of the gneiss



Shallow depth (>600 m.w.e.) is enough to suppress cosmogenic background

(A.Bueno et.al., JHEP 0704,041 (2007))

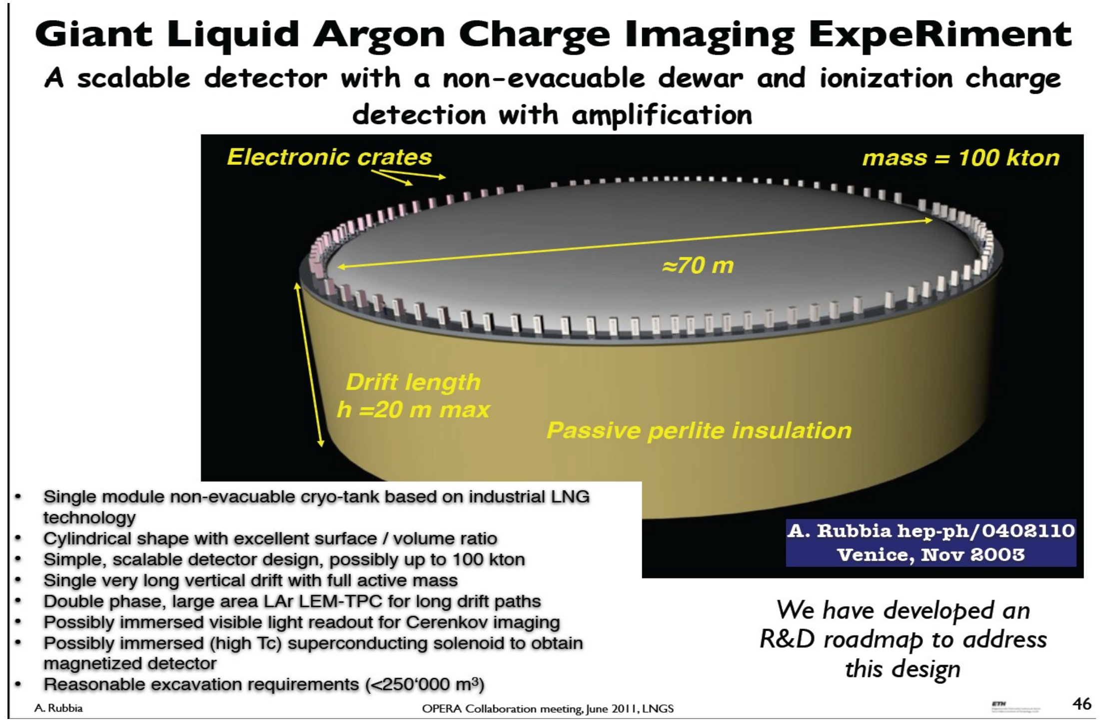
If more overburden is necessary, inclined access tunnel is also possible

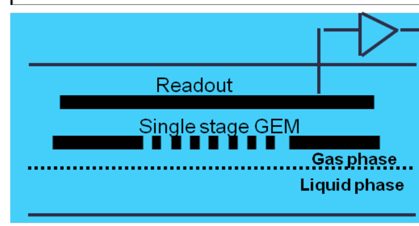


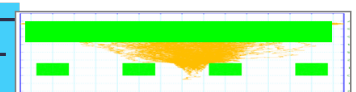
PENTA-OCEAN construction co., Ltd.,

100kt Liquid Ar TPC “GLACIER”

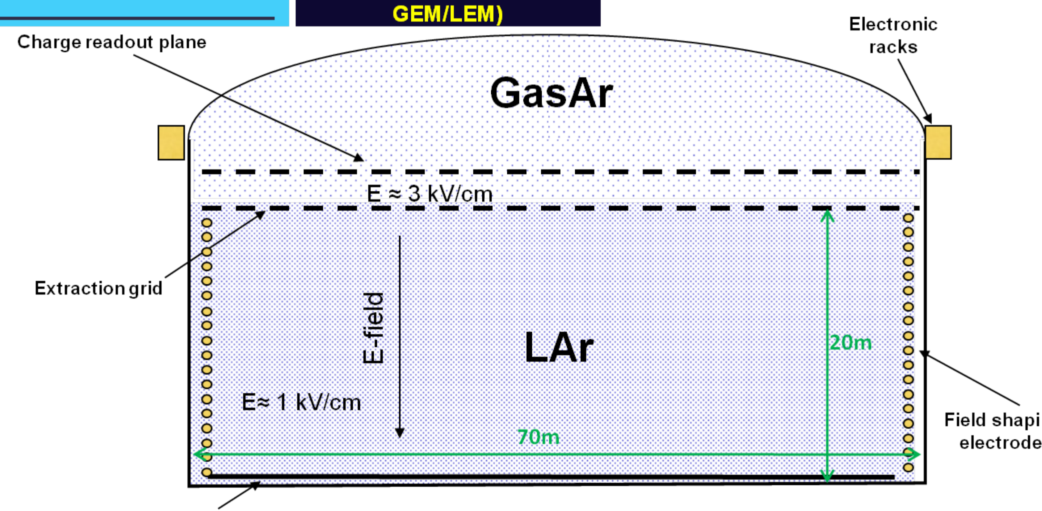
- Extremely high performance
  “Electronic Bubble Chamber”
- 3D tracking of all charged particle
  from very low energy threshold
- Precise resolution of ~mm
- Fully active homogeneous 4π
  detecotor (as WC)
- Good PID w/ dE/dx, π^0 rejection
- Double phase w/ Gas amplification
  <10ppt purity needed
- LEM readout (~106ch)
- 600ton detector realized and working



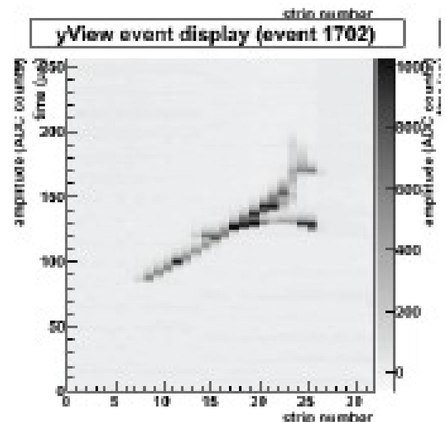




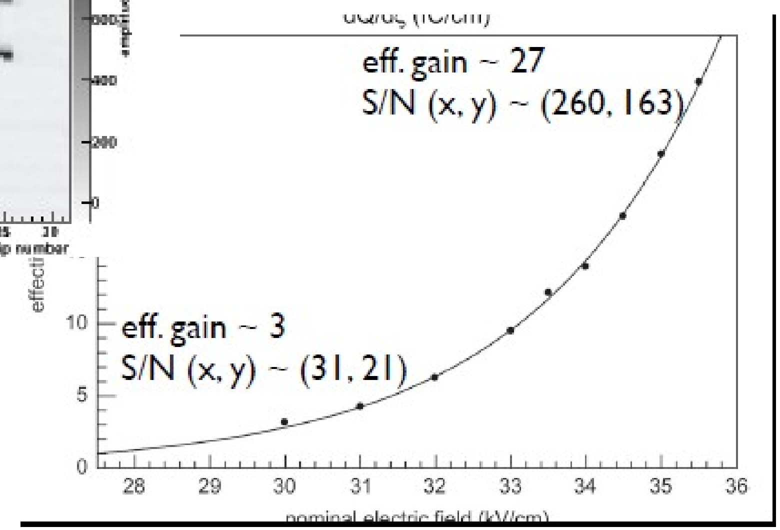
Double phase detector readout using both liquid and gas Argon phases (with GEM/LEM)

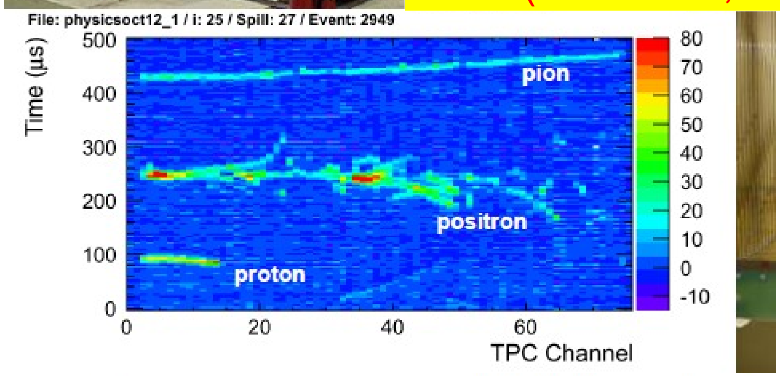


R&D toward realizing 100kt Li Ar TPC



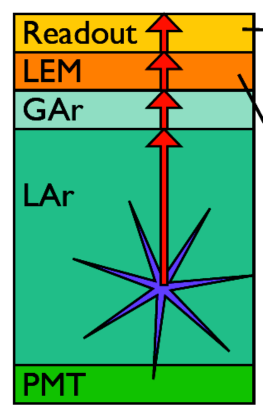
Double phase readout test @ ETHZ

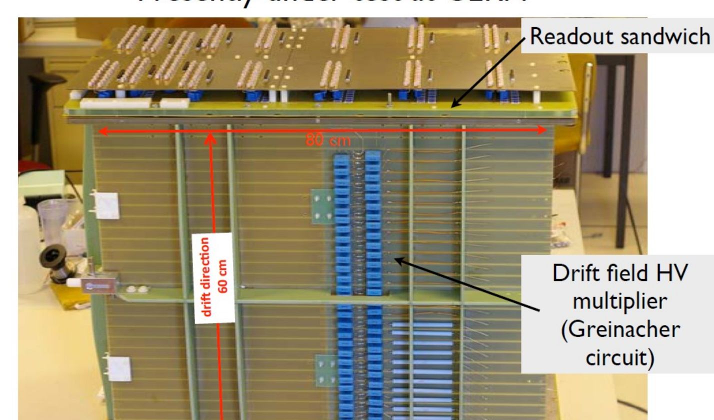


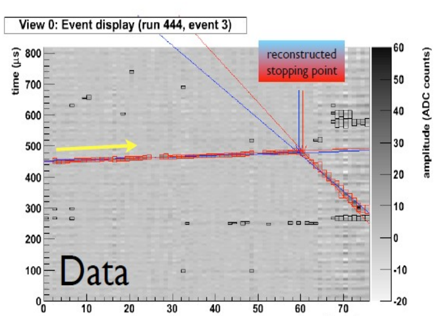


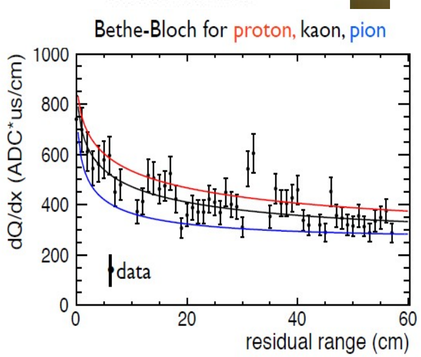
Two-phase readout w/ amplification

Presently under test at CERN





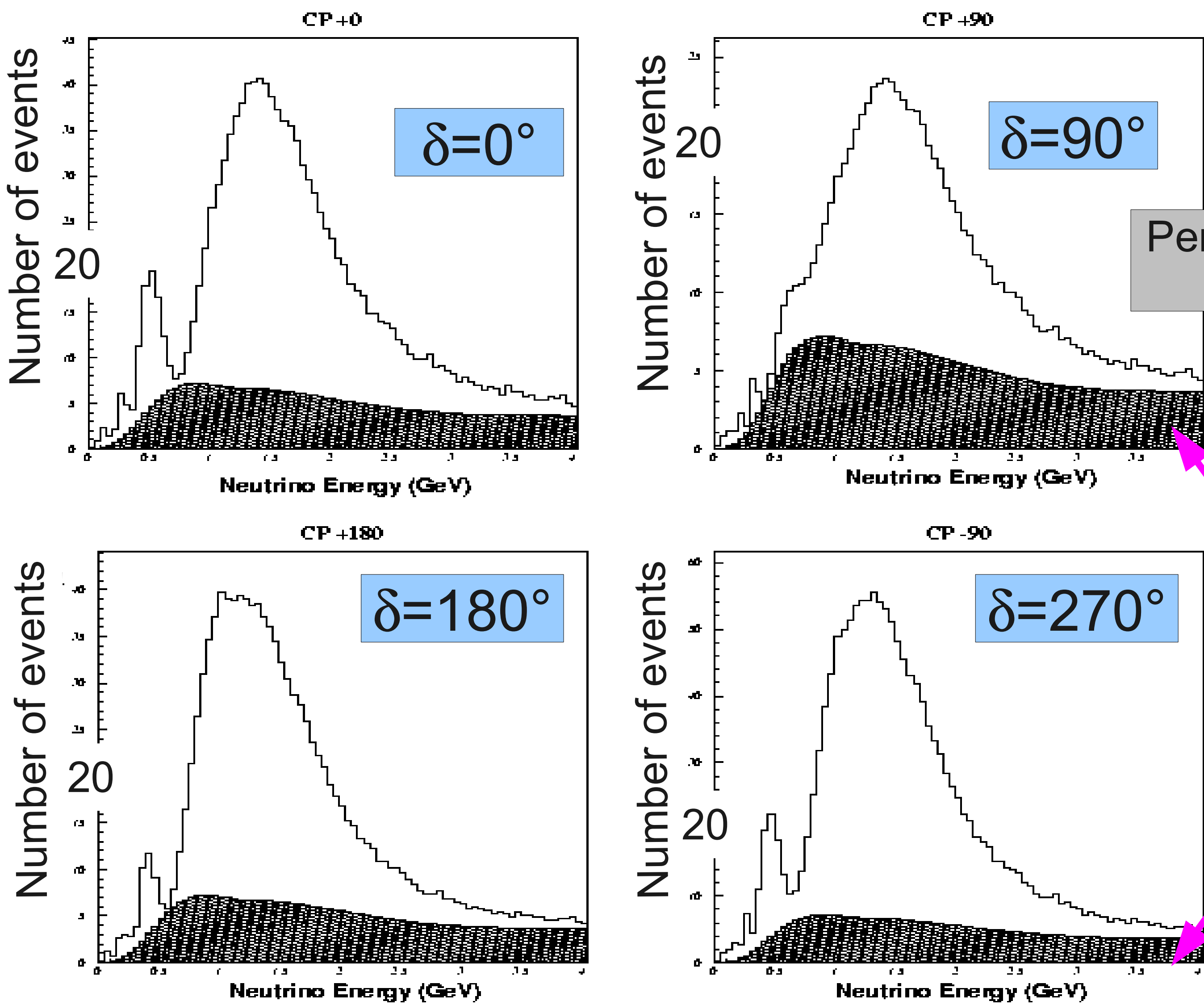




- First 250-L beam test was successful
- R&D of Two-phase readout is in progress

J-PARC to Okinoshima: ν_e Spectrum

$\sin^2 2\theta_{13}=0.03$,
Normal Hierarchy,
5 years ν run



Perfect detector resolution is assumed

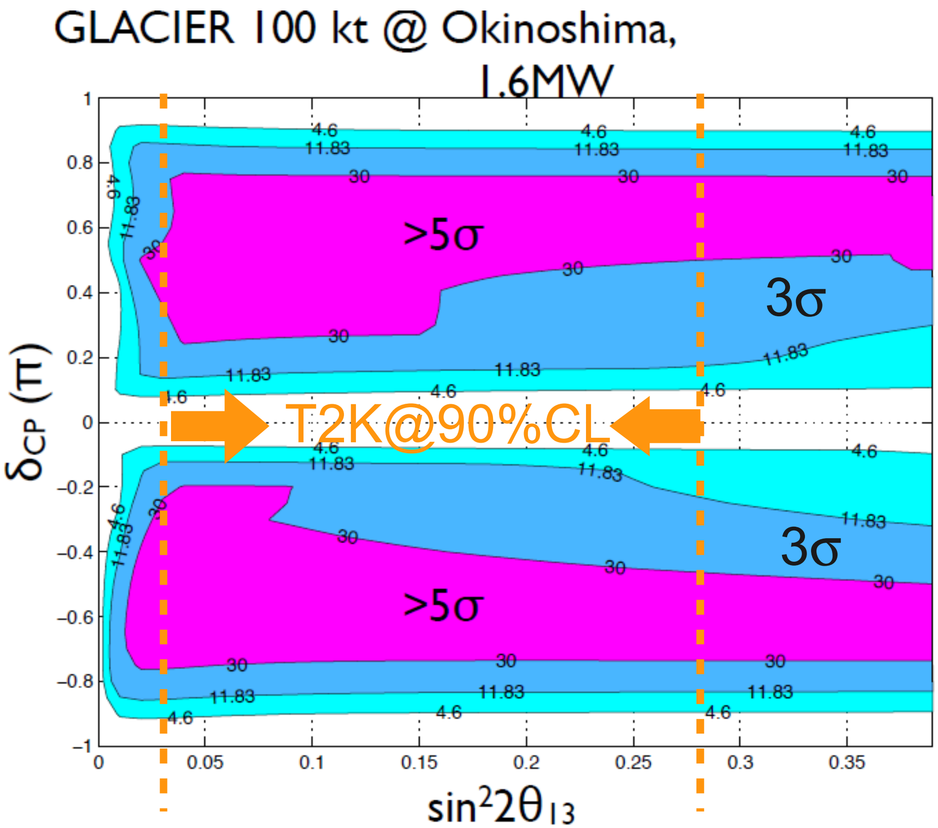
Beam ν_e background

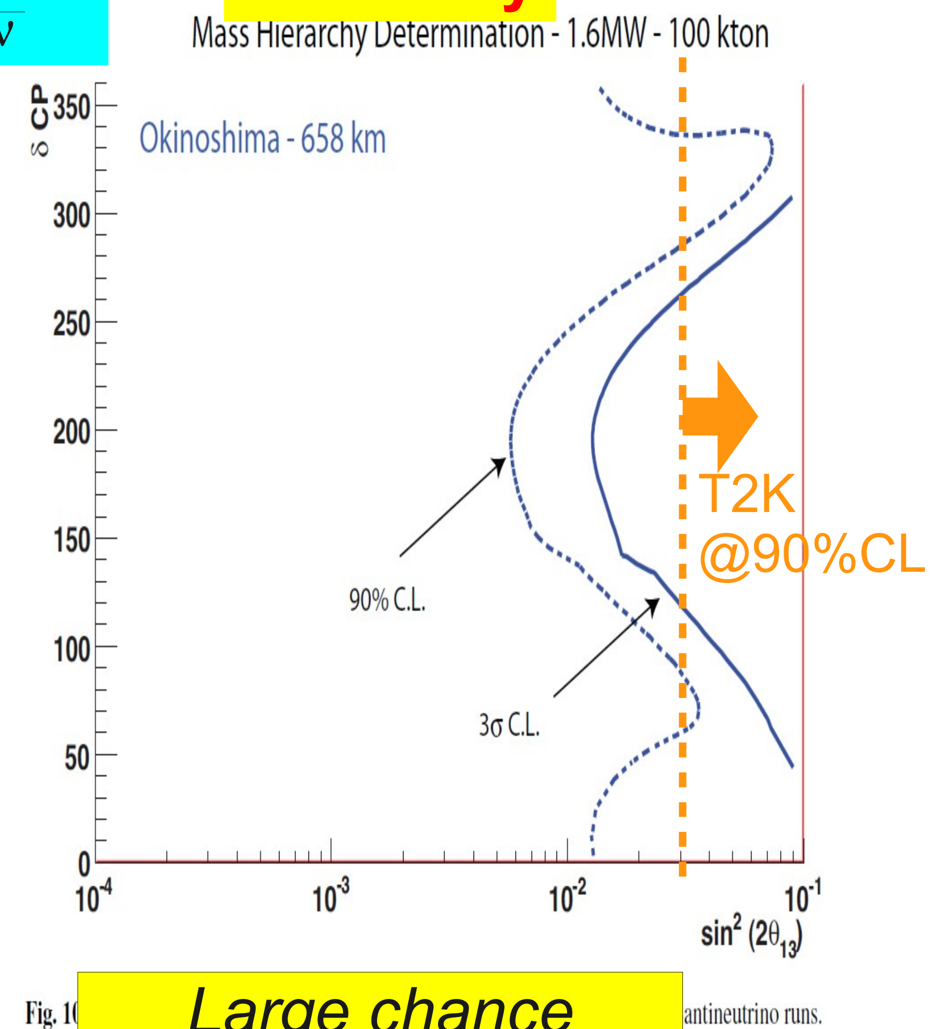
J-PARC to Okinoshima: Sensitivities

CP Violation

5 years ν +
5 years $\bar{\nu}$

Hierarchy





Mass hierarchy is assumed to be unknown
Perfect detector resolution is assumed

Large chance
to determine both δ
And mass hierarchy

Summary

Next generation LBL experiment project in Japan

- Upgrade of J-PARC accelerator (target: >1.66MW)
- Upgrade of far detector:

  Two candidate of far detector:

  - Hyper Kamiokande

    Study of CPV:

    $\nu_\mu + \overline{\nu_\mu}$ run @2.5° off-axis (optimum to 1st osc. max.)

    $\rightarrow$ measure difference b/w ν_e and $\overline{\nu_e}$ appearance

  - Liquid Ar TPC

    Study of CPV:

    ν_e appearance study @ on-axis wide band beam

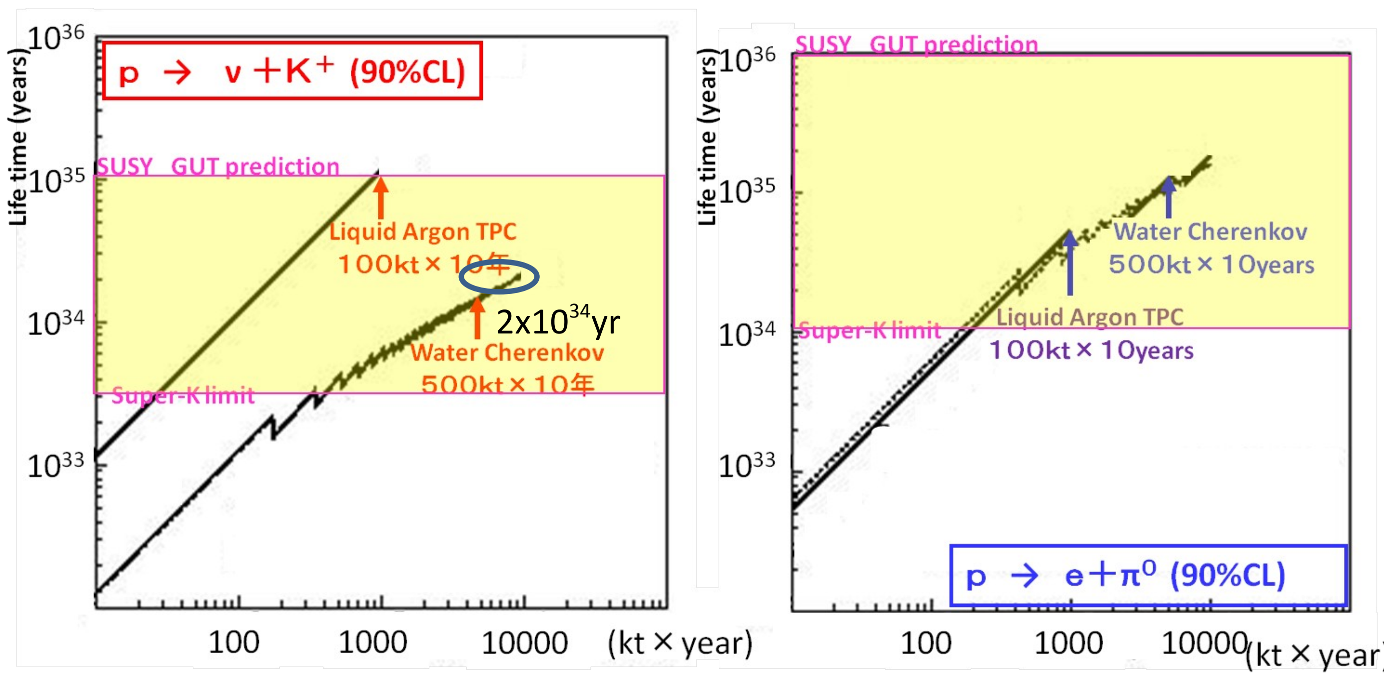
    $\rightarrow$ fit energy spectrum for both 1st & 2nd osc. max.

  - Far detector upgrade is not only for CPV but also:
    - study of neutrino mass hierarchy
    - search for nucleon decay

backup

Proton decay search

- One of the conditions needed to explain Matter-Anti-Matter Asymmetry
- High sensitivity huge detector for future ν physics should also have high sensitivit y to detect proton decay
  - LiqAr' superior efficiency for low energy particle enable drastic improvement o n sensitivity on modes such as νK
  - Water Charenkov is very good at "total absorption" modes with relatively high energy (low mass) particles, such as $e\pi^0$

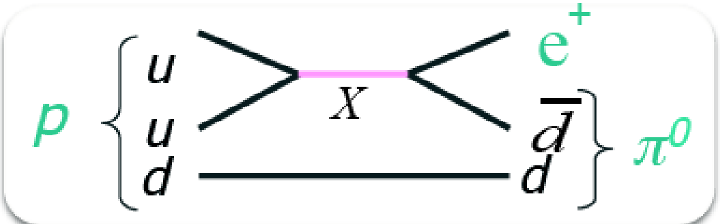


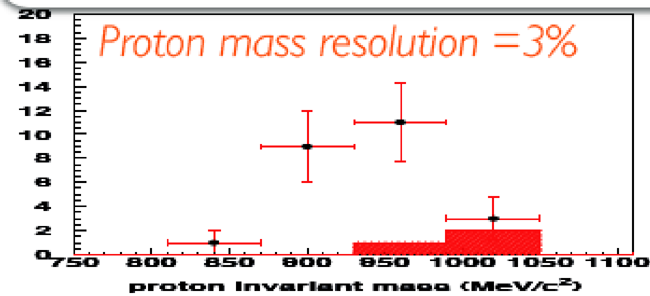
- ν ＋ K＋ mode: LAr（100kt×10years）＝～5×WC（500kt×10yeas）
- e ＋ π0 mode: LAr（100kt×10years）＝～1/2×WC（500kt×10years）

Proton Decay

Hyper-K

- explore quark/lepton unification -





p→e⁺π⁰

- 1.4 × 10^{34} years (Super-K I+II+III+IV @ 90%CL)

  → 1 x 10^{35} years (0.54Mton x 10yrs @ 90% CL)

p→νK⁺

- 4.0 × 10^{33} years (Super-K I+II+III+IV @ 90%CL)

  → 2 x 10^{34} years (0.54 Mton x 10yrs @ 90% CL)