Improving Atmospheric and Proton Decay Physics

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Feb. 8, 2006

An ‘Ultimate’ Neutrino and Proton Decay Experiment

Very personal view for

a future (10~20 years from now)

astro-particle physics detector

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An ‘Ultimate’ detector in ~2020

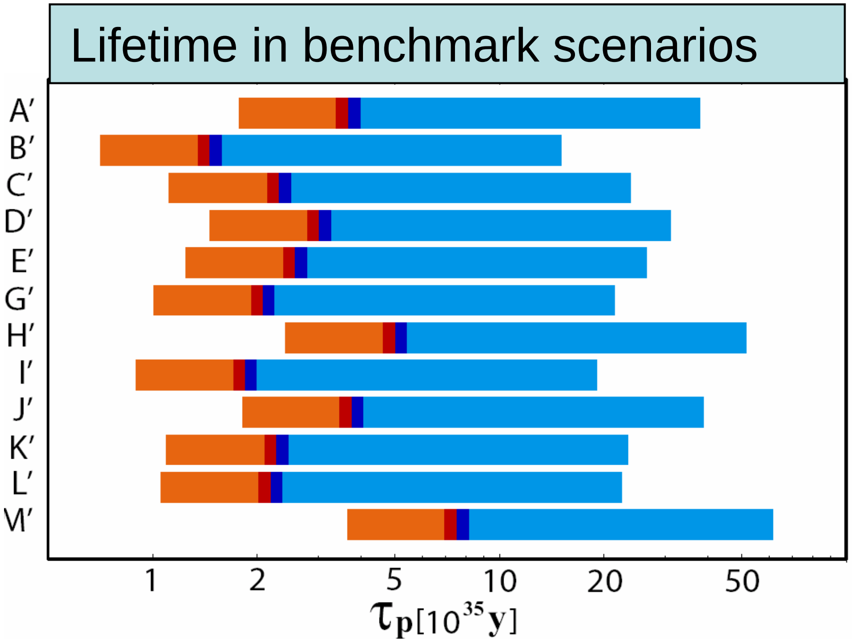
- Best sensitivity
- Scalability and flexibility

  for a situation change in future
- Shorter time to construct and shorter running time to obtain results

Proton Decay

What is the required sensitivity

J. Ellis, NNN05, April 7th, 2005
Flipped SU(5)xU(1)



Theorists do not give us any guarantee

Some theorists say

just around the corner,

and others say

1~2x 10^{35} years for $e\pi^0$,

νK is important,

νK is suppressed **and so on ….**

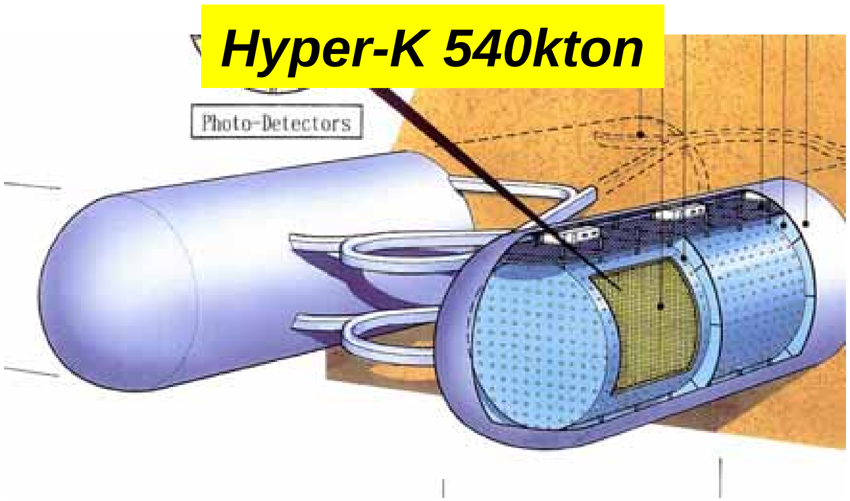
Theorists' best bets ??? :

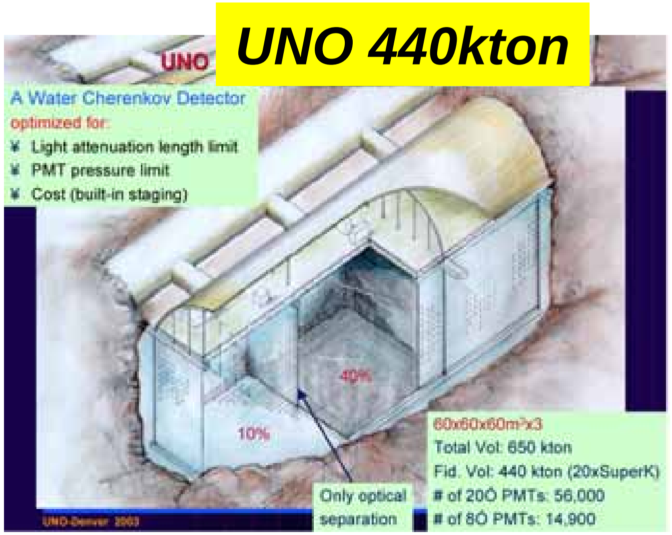
10^{35}〜10^{36} yr for $e\pi^0$: < 10^{35} yr for νK, μK

➔ Detector Size: The larger, the better ?

Proton Decay Detector

- How much of the scale up is needed.
  - Super-Kamiokande (22.5kton) untill 2020
    (~start time for UNO, HK,,,,,,)
    ➔ achieve ~0.5 Mton exposure (25yrs)
- ~ 0.5 Mt fid. detector : UNO, HK etc.

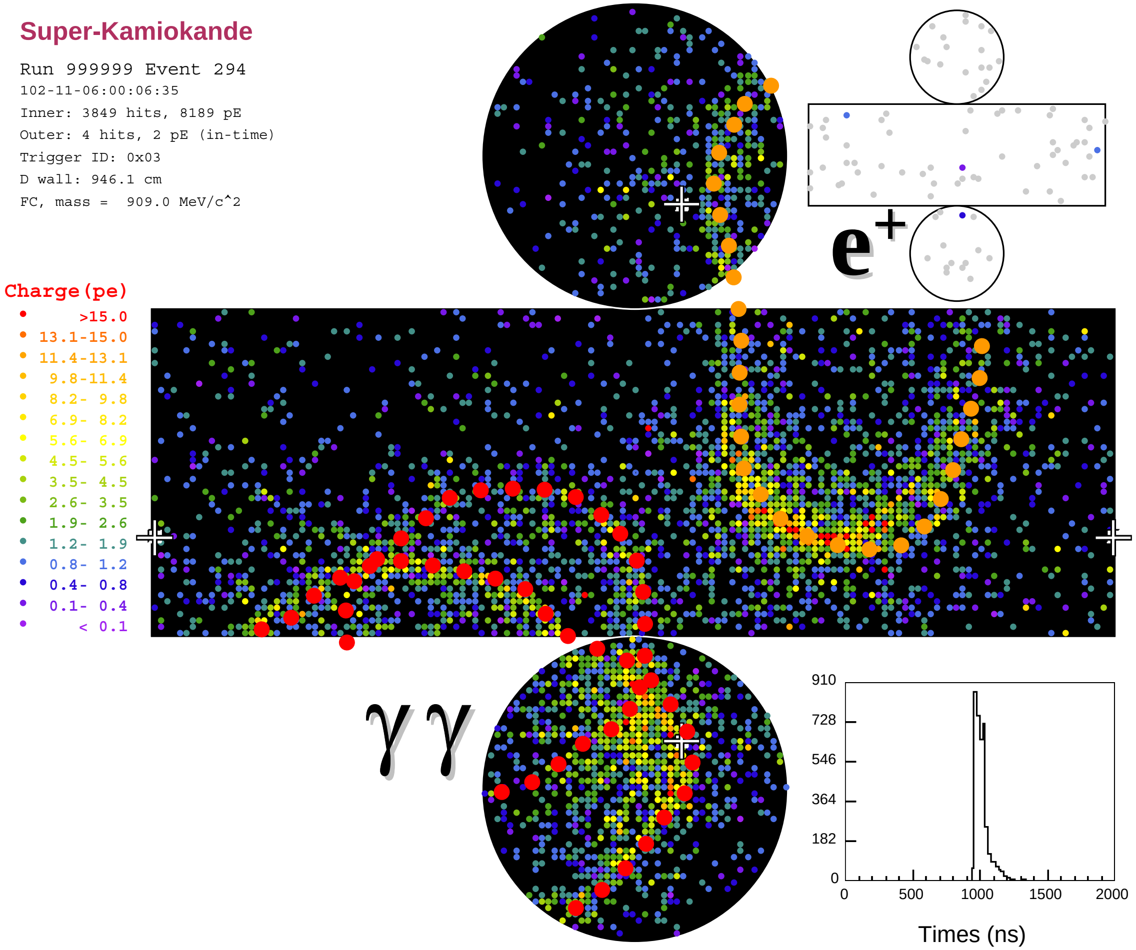




➔ Only factor 3=sqrt(10) improvement
(for 10 years operation: 2020 ~ 2030)

➔ "NEED" ~ 5 Mt fiducial mass for
factor 10=sqrt(100) improvement in 10 years

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



Criteria

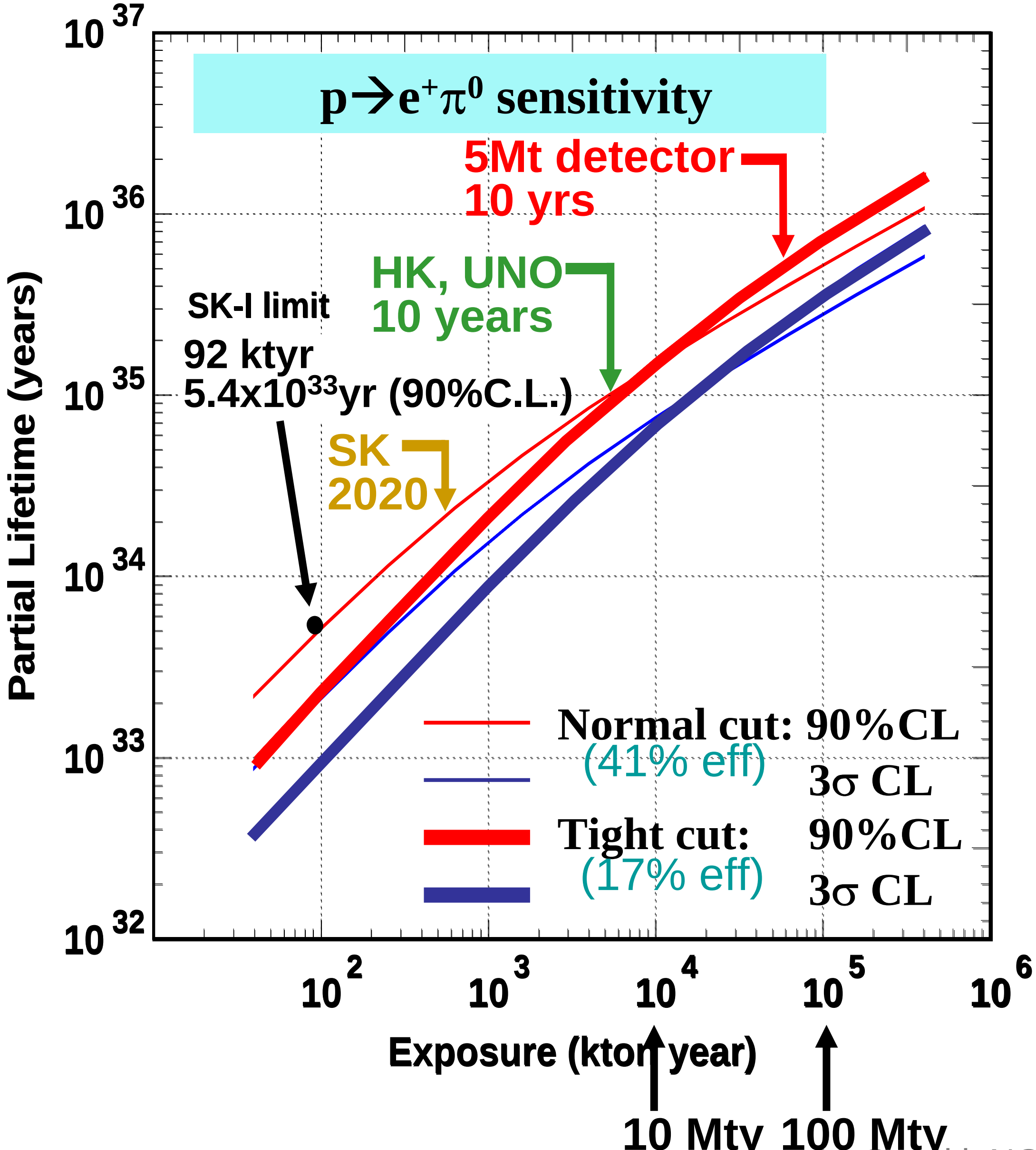
- 2 or 3 Cherenkov rings
- All rings are showering
- $85 < M_{\pi 0} < 185 MeV/c^2$ (3-ring)
- No decay electron
- $800 < M_{proton} < 1050$ MeV/c^2
  $P_{total} < 250$ MeV/c

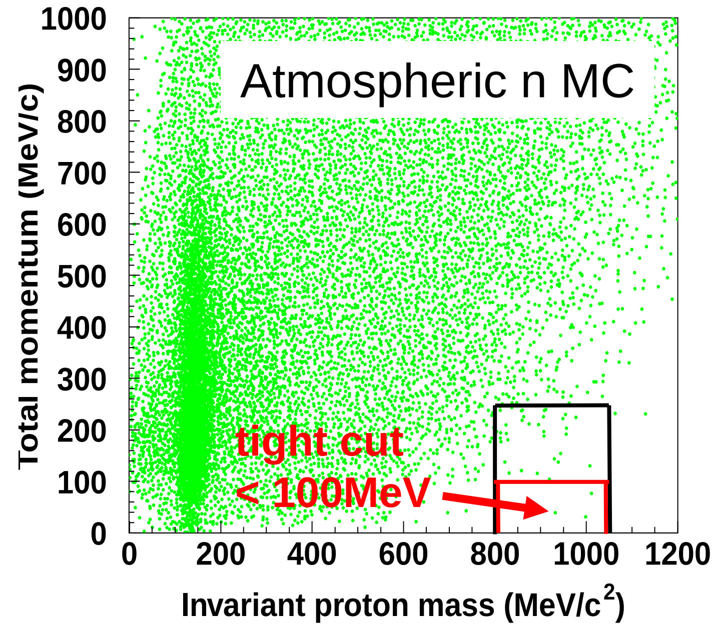
	Sig	BG	Eff %
SKI:1489d	0	0.4	40.9
SKII: 421d	0	0.2	41.1

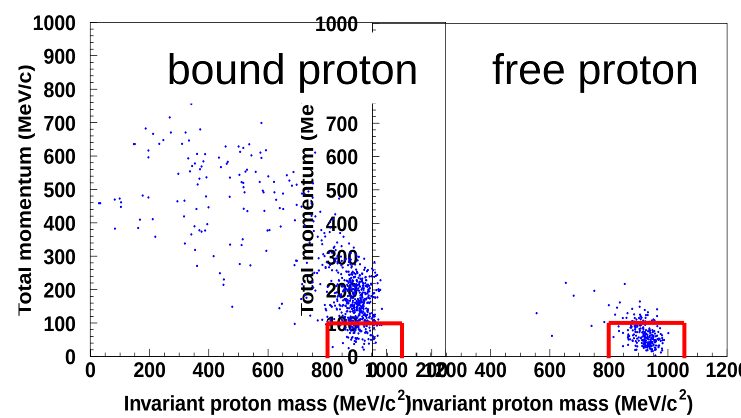
SK-I (40% cover.: 2PMT/m^2) and SK-II (20% cover.: 1PMT/m^2) give similar efficiency and BG. [SK-PMT: 50cm in diameter]

SK-I+SK-II(421d): 118 ktyr → 6.9x10^{33}yr 90%CL

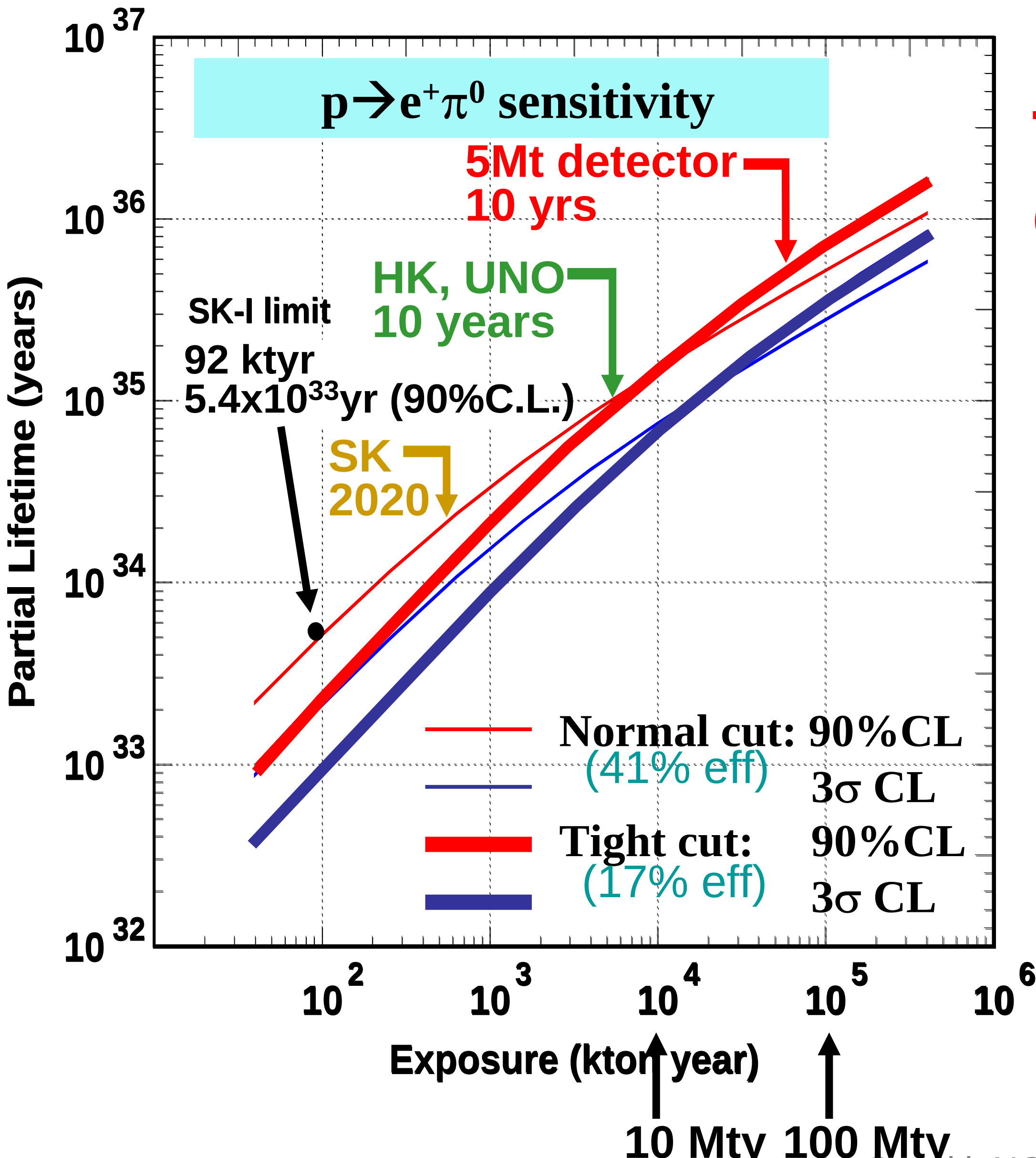
Sensitivity for $p \rightarrow e^+ \pi^0$







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



Tight cut is effective
Only for > 1Mt detector

HK, UNO: 10yrs
➔
~ 10^{35} yrs @90% C.L.

5 Mt detector: 10 yrs
➔
~ 6 x 10^{35} yrs @90% C.L.

$p \rightarrow \bar{\nu} K^+$

$p \rightarrow \nu K^+$

$K^+ \rightarrow \pi^+ + \pi^0(\gamma\gamma)$

back to back

205 MeV/c

$^{15}N^* \rightarrow \sim 6$ MeV γ (1/2p, 3/2p)

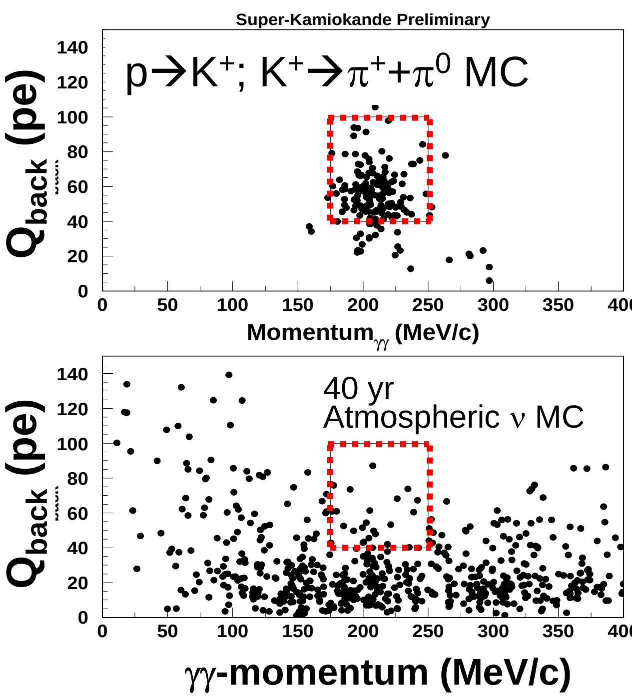
$^{16}O(p) \rightarrow \nu K^+$

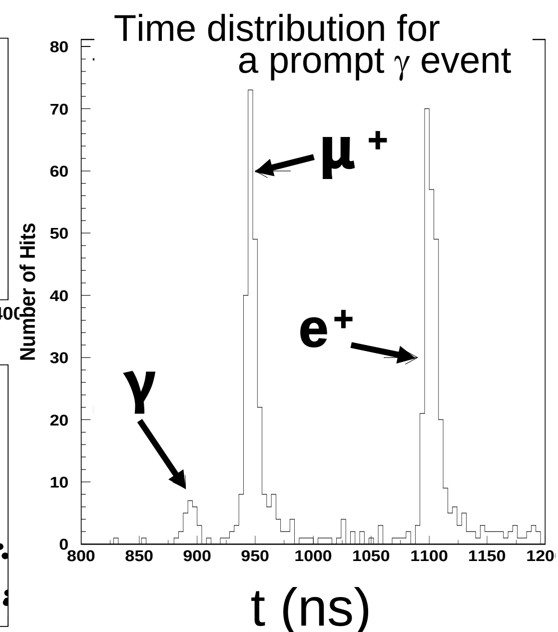
$K^+ \rightarrow \mu^+ \nu$

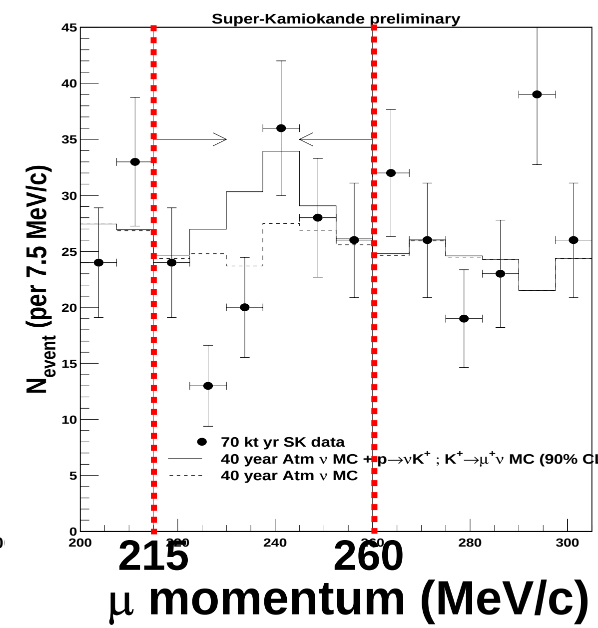
12.4ns

$\mu^+ \rightarrow e\nu\nu$

	$\pi^+\pi^0$(21.1%)			prompt-γ + $\mu^+\nu$			$\mu^+\nu$ (63.4%)		
	eff.	sig.	BG	eff.	sig.	BG	eff.	sig.	BG
SK-I (1489d) 40% cov.	5.7	0	0.65	8.5	0	0.73	33	---	---
SK-II(627d) 20% cov.	5.4	1	0.52	4.7	2	0.54	37	---	---



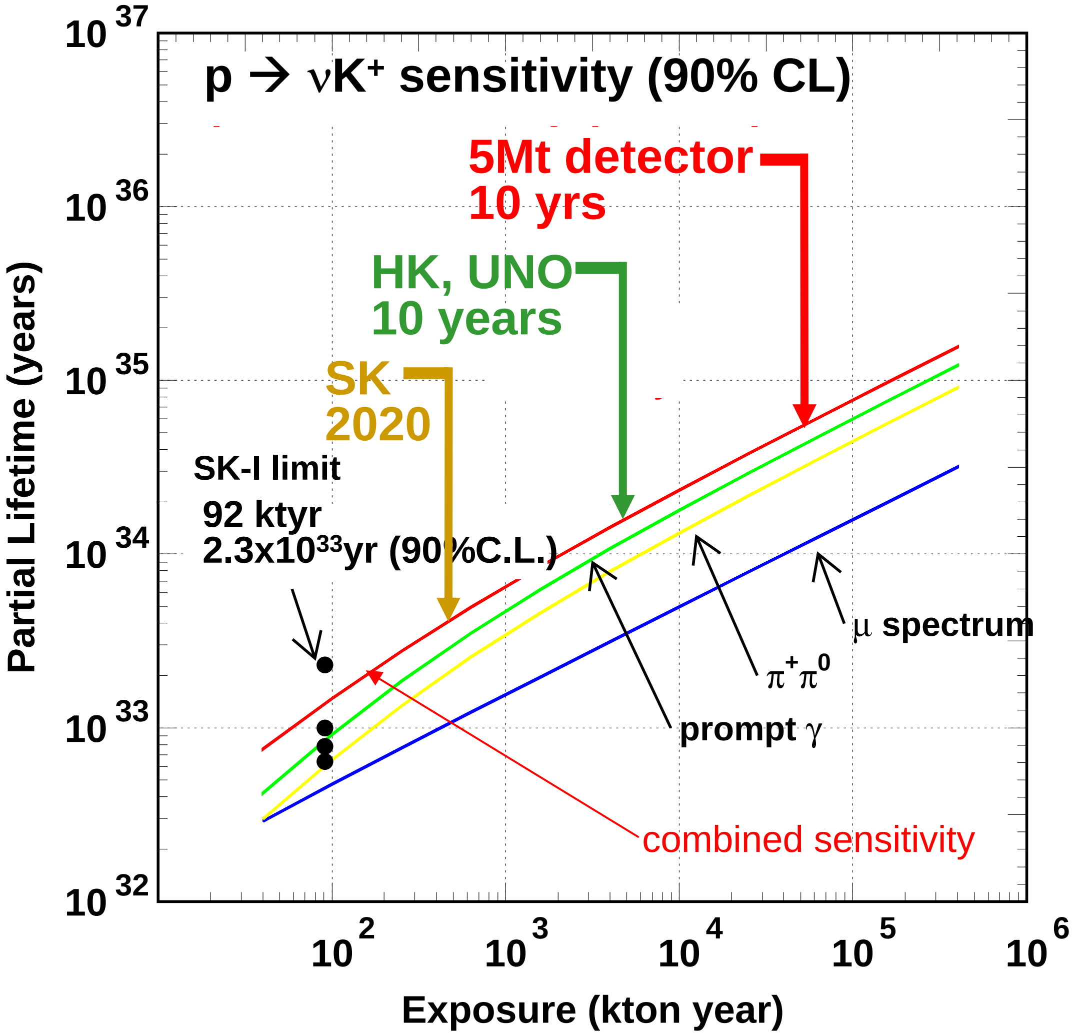




Sensitivity for p→νK$^+$

- Assume; 40% coverage:

Need more study for the 20% coverage



HK, UNO: 10yrs

~ 2 x 10^{34} yrs @90% C.L.

5 Mt detector: 10 yrs

~ 7 x 10^{34} yrs @90% C.L.

How a ~5 Mt detector looks like

Super-UNO
Super-HK
Super- ???

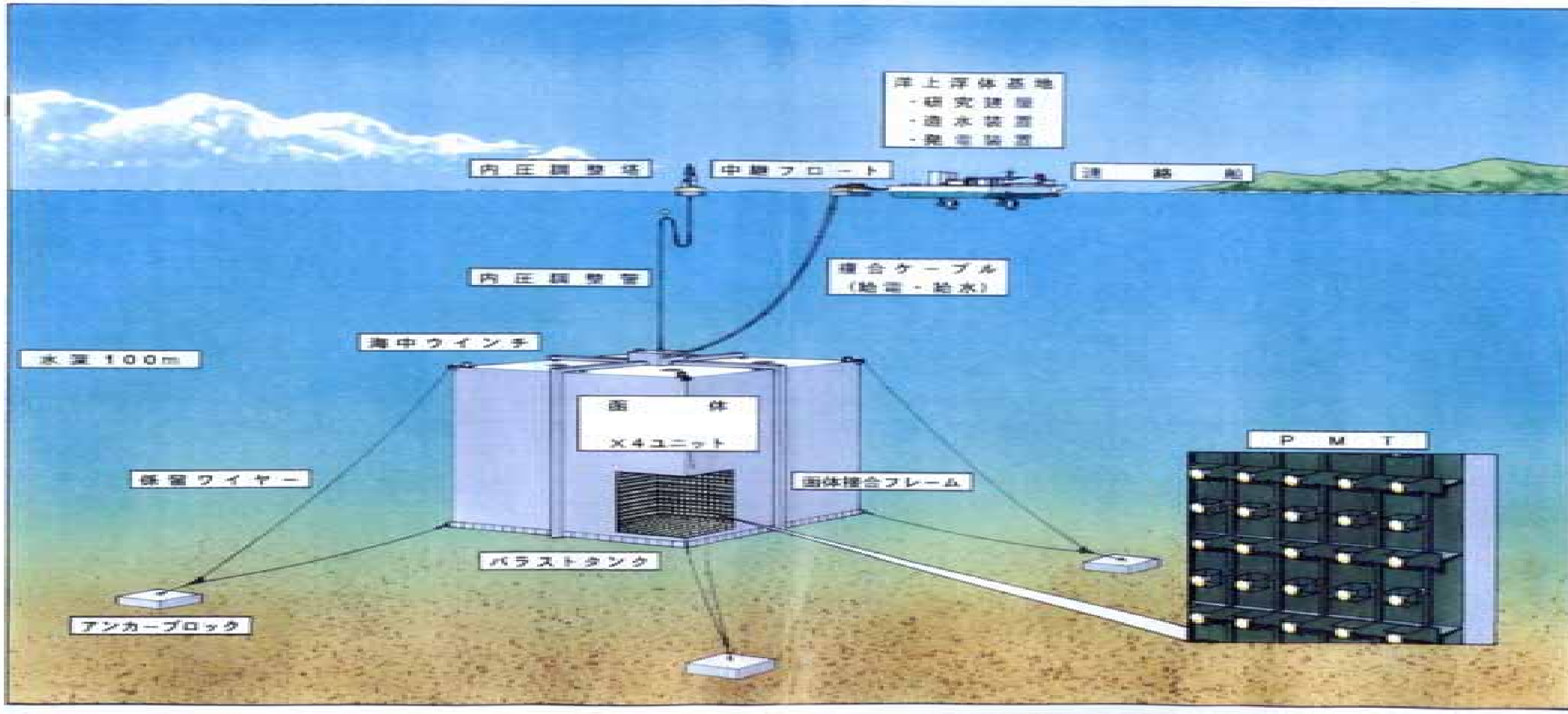
Requirements for the detector

1) Scalability: May start with 1 Mt
but can be expandable
2) Low cost
3) Short construction time

TITAND

Totally Immersible Tank Assaying Nucleon Decay

Y. Suzuki
hep-ex/0110005 (in 2001)
Multi-Megaton Water Cherenkov Detector for a Proton Decay Search -- TITAND



浮沈式陽子崩壊実験装置イメージ図

TITAND-I

85m x 85m x 105m x 4 units = 3.03 Mt

(2.22 Mt fiducial : ~ SK x 100)

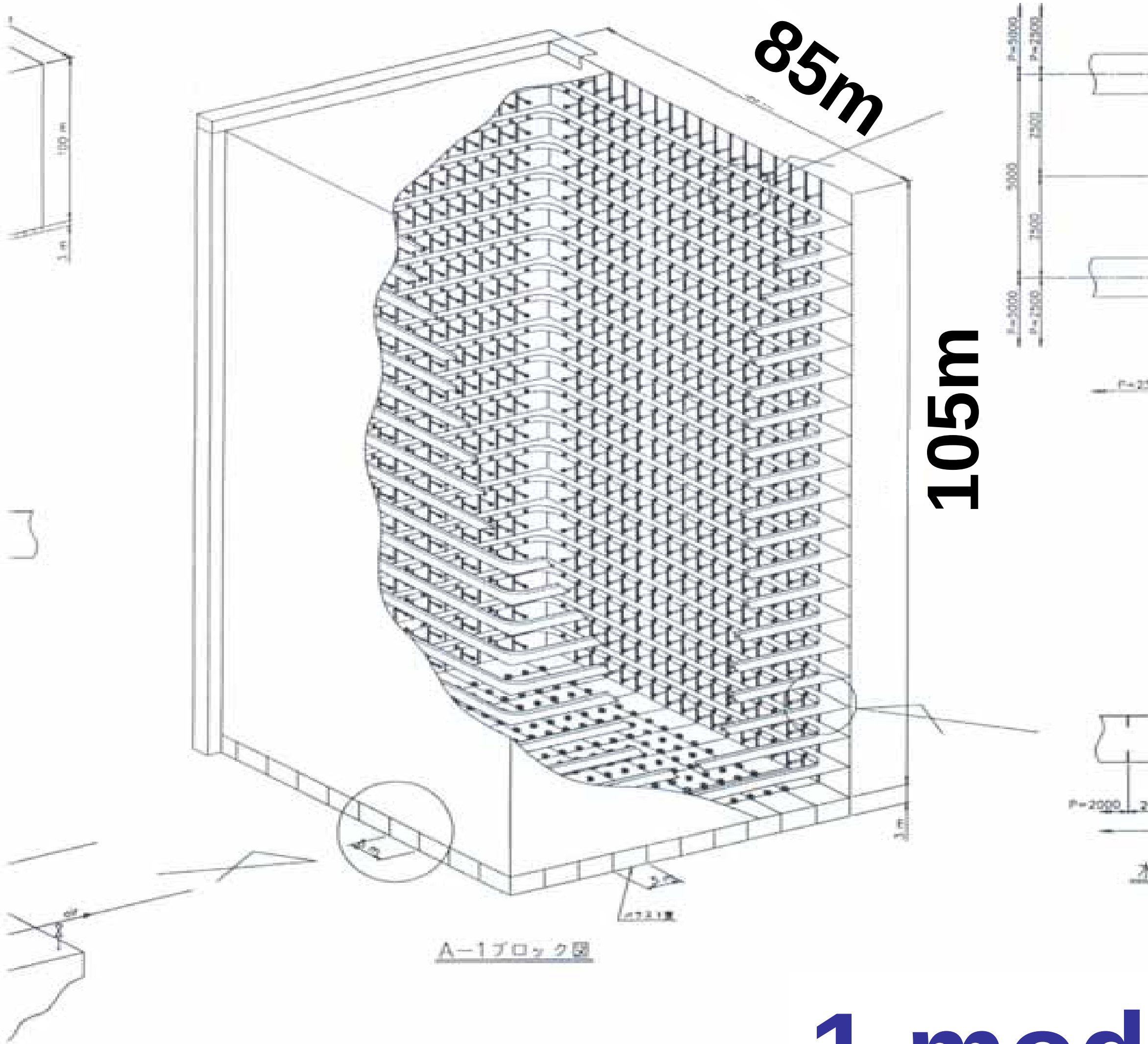
TITAND-II

2 module ➔ 4.4 Mt f.v. (SK x 200)

For 3.03 Mt module
Steel + epoxy lining
69,600 tons + α

➔ **Balance to buoyancy force (salt water <-> pure water) (78,000 tons)**

Structure (1 unit)



Semi-Pressure Vessel

1 module = 4 units

How to construct

1. Construct steel container (unit)

   85m x 85m x 105m

   Maximum size of DOCK in the world

   ➔ width:108m x length: 480m

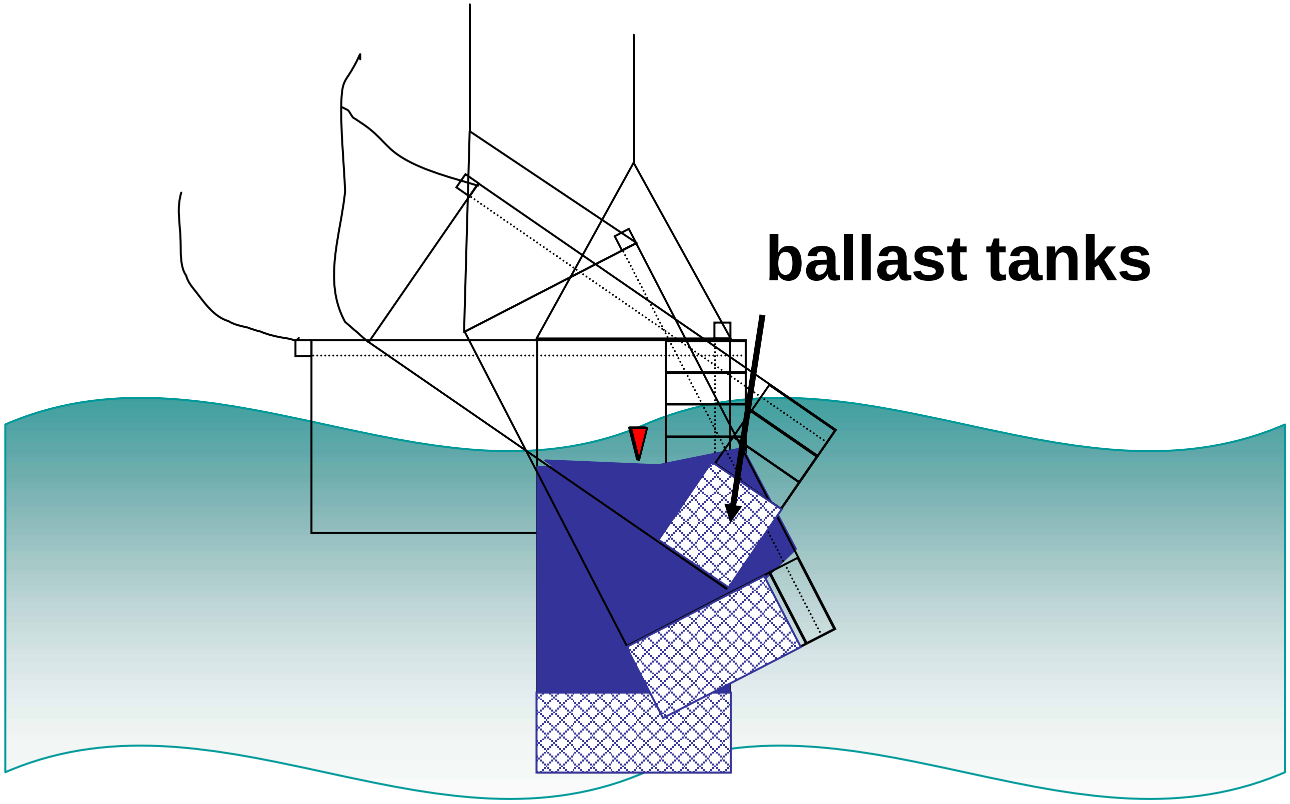
2. Install PMTs at the DOCK

   Number of PMTs
   (or any equivalent light sensors):

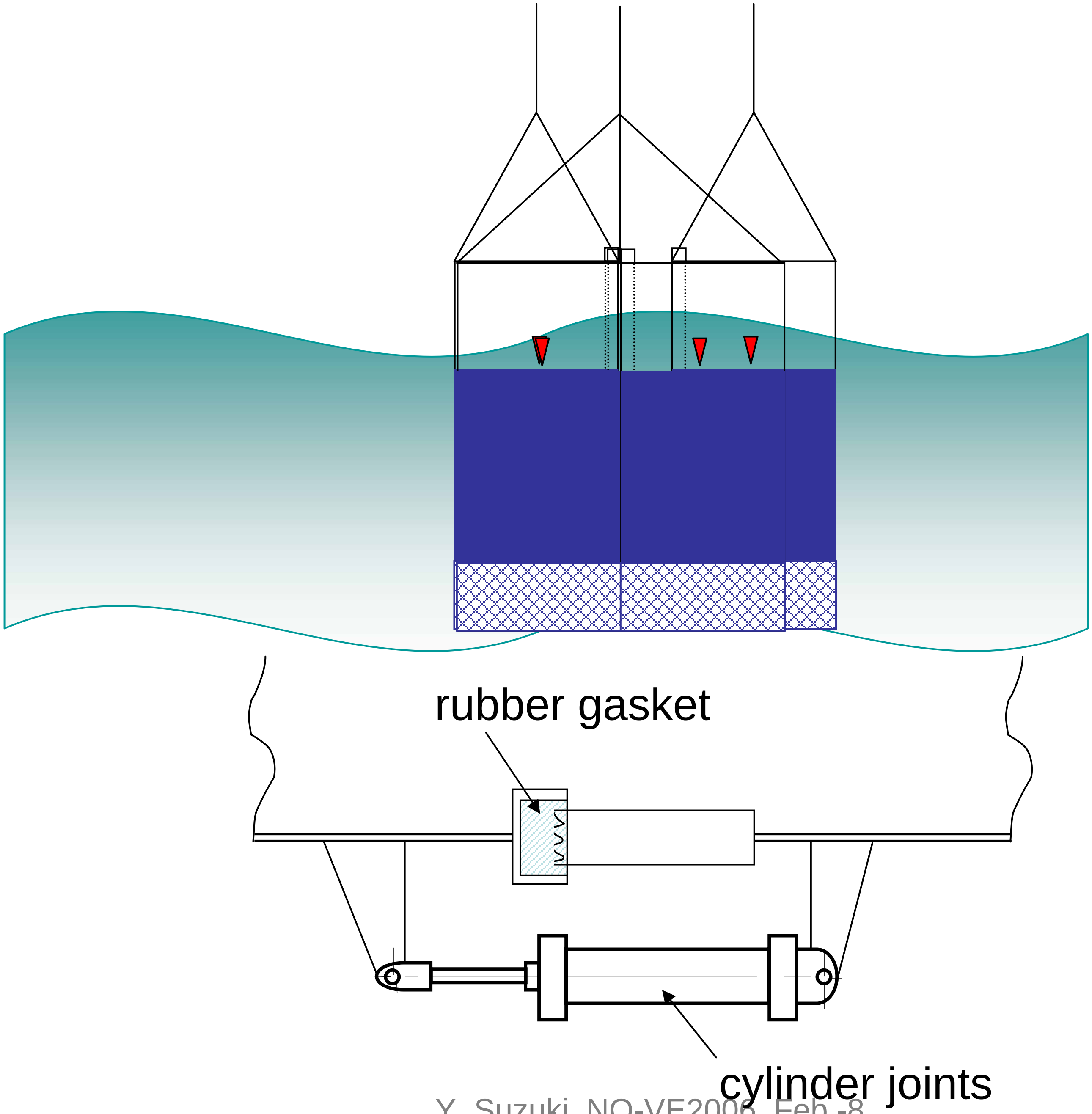
   179,200 PMTs (1/2 SK density)

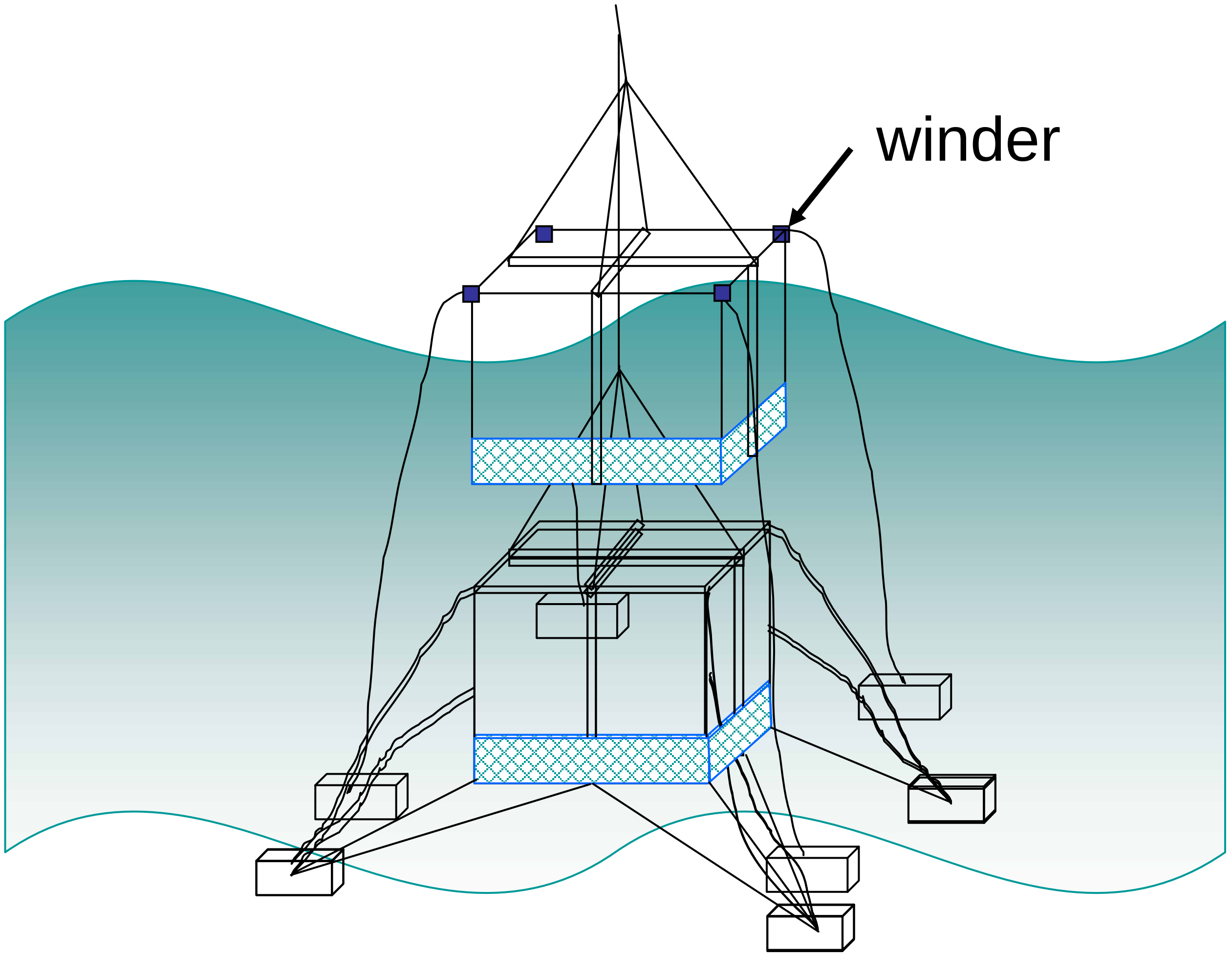
   for TITAND-I

3. Tow units to the site



ballast tanks


rubber gasket
cylinder joints



If we remove the water in the ballast tanks, the detector can be brought up to the surface.

Surface Floating Plat Form

sub-merging floating object

May be 30m x 40m
(steel + epoxy lining) is enough

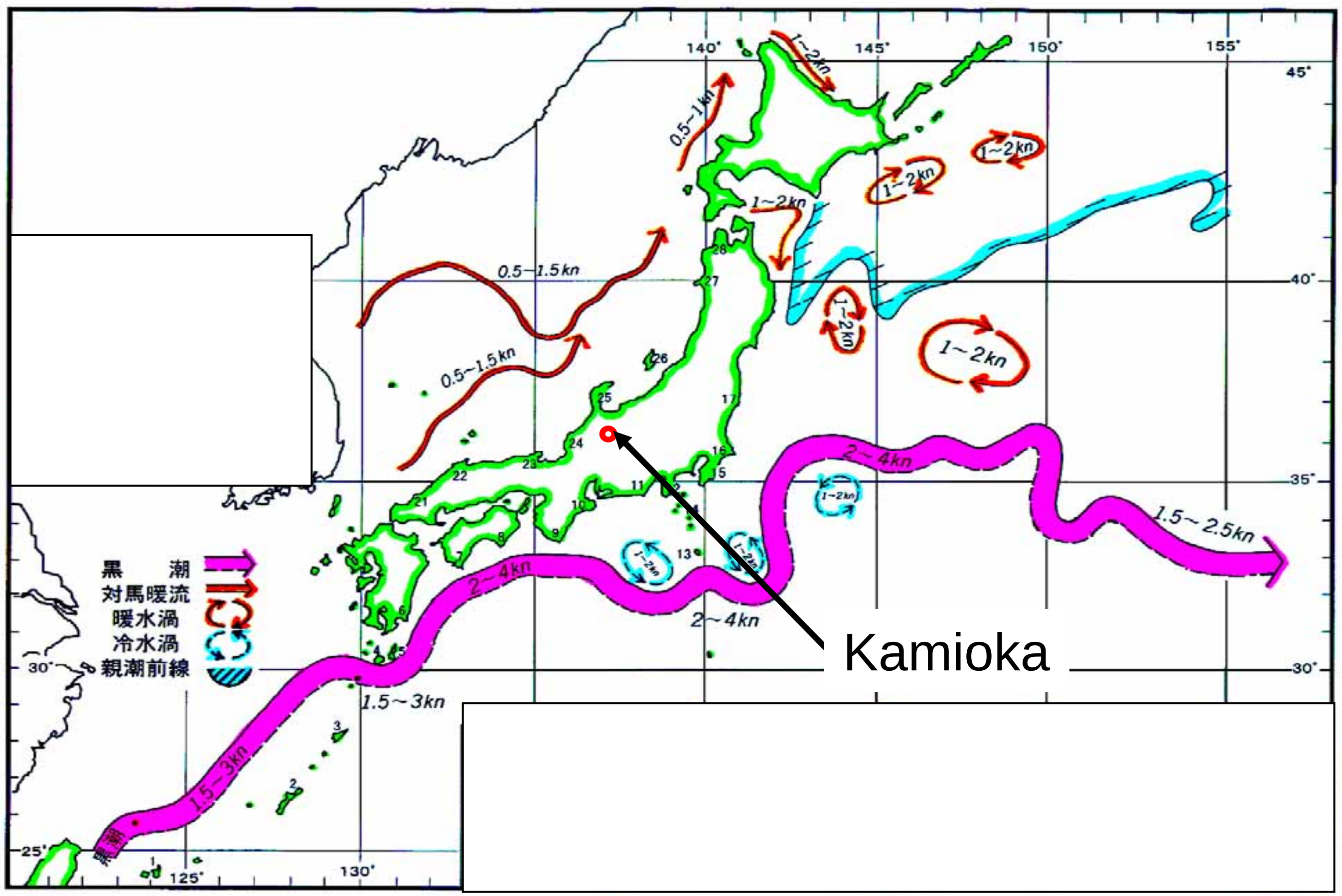
10 ktons /day (2 system)
100 days for 2 Mton

- Generator → 1.5 MW
- Desalination system
- Water purification system
- Research buildings
  - Electronics & computer
  - Dormitory
  - Restrant & Caffe

Where we can place the detector?

Tidal current < 3 knot ~ 5.6km /hour

In order to keep the detector in place



Construction periods

		1st yr	2nd yr	3rd yr
	Design			
	Preparation			
	Construction			
	Set up			

Total 3 years construction time:

very short

But the manufacturing time for the light sensors is not included.

Crude cost estimate

TITAND-I 2.22 Mt (~100xSK) fiducial volume

Container	$ 141 M	
Install	25	
Light sensors	179.2	1k$ /channel (20% coverage)
Electronics	17.9	100$ /channel
Floating Plat form	8.6	
Generator	5.0	
Desalination Plant	32.0	
Others	10.0	
Total	$ 418.7M	

$211.6 M (2.2Mton fid.)

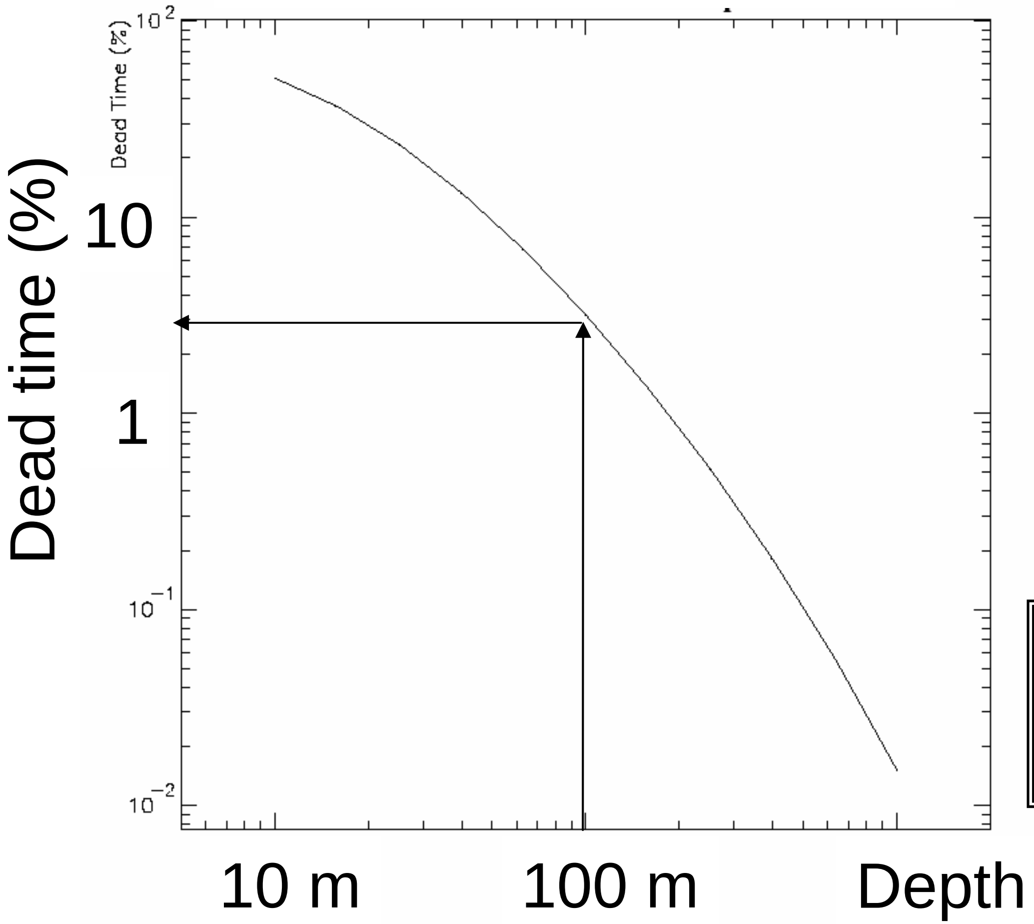
Underground
Cavity
Tank and structure

Cost: TITAND-II 4.44 M ton (~200xSK) < (TITAND-I x 2)

Depth requirement

Assumption: 1μsec dead time for CR events

Dead time for a
100mx100mx100m detector



Dead time < a few %

Deeper than 100 m

If shallow depth,
dedicated to high energy experiments,
due to many spallation products

Depend on the segmentation:
TITAND 85mx85mx105m is better

Improvement of the Atmospheric Neutrino Data by TITAND-II

- Full SK detector MC and SK reconstruction tools.
  - w/ same systematic errors
- Fixed Parameters
  - $\Delta m^2_{23} = 2.5\times10^{-3}eV^2$ (positive)
  - $\Delta m^2_{12} = 8.3\times10^{-5}eV^2$ and $\sin^2 2\theta_{12} = 0.825$
- Created for the combinations of various 3 parameter sets (test points)
  - $\sin^2\theta_{23}$ = 0.40, 0.45, 0.50, 0.55, 0.60
  - $\sin^2\theta_{13}$ = 0.04, 0.02, 0.006, 0.00
  - $\delta_{CP} = 45^o, 135^o, 225^o, 315^o$

Mass Hierarchy:
Our future home work

Small θ_{13} case:
Our future home work

Data sets

- Created data sets for 100 yrs full simulation
- Statistically scaled to 800 yrs

- 800 yrs of SK: 18 Mtyr

  = 4 years of TITAND-II(4.4Mt)

  36 years of UNO or HK

  - Compared to 80yrs of SK = 4 yrs of UNO or HK

    5 months of TITAND-II

  - Compared to 20yrs of SK = SK by 2020

Oscillation effects in electron appearance

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

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

Solar term

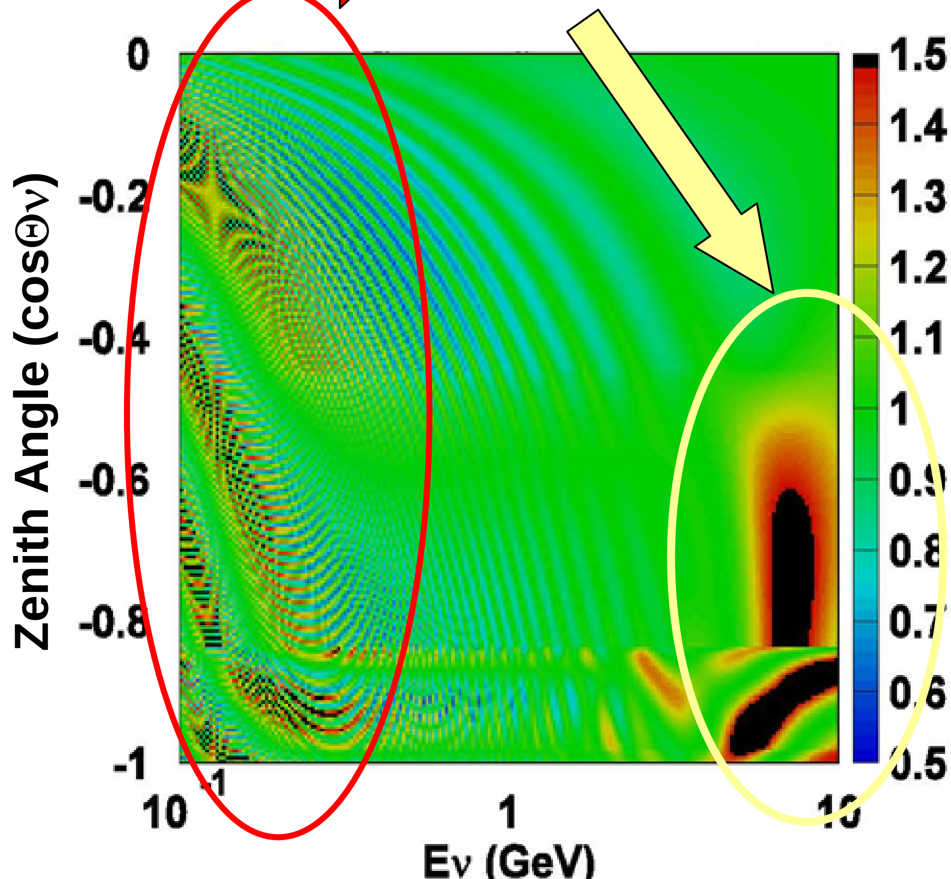
Interference CP-phase

θ_{13} term

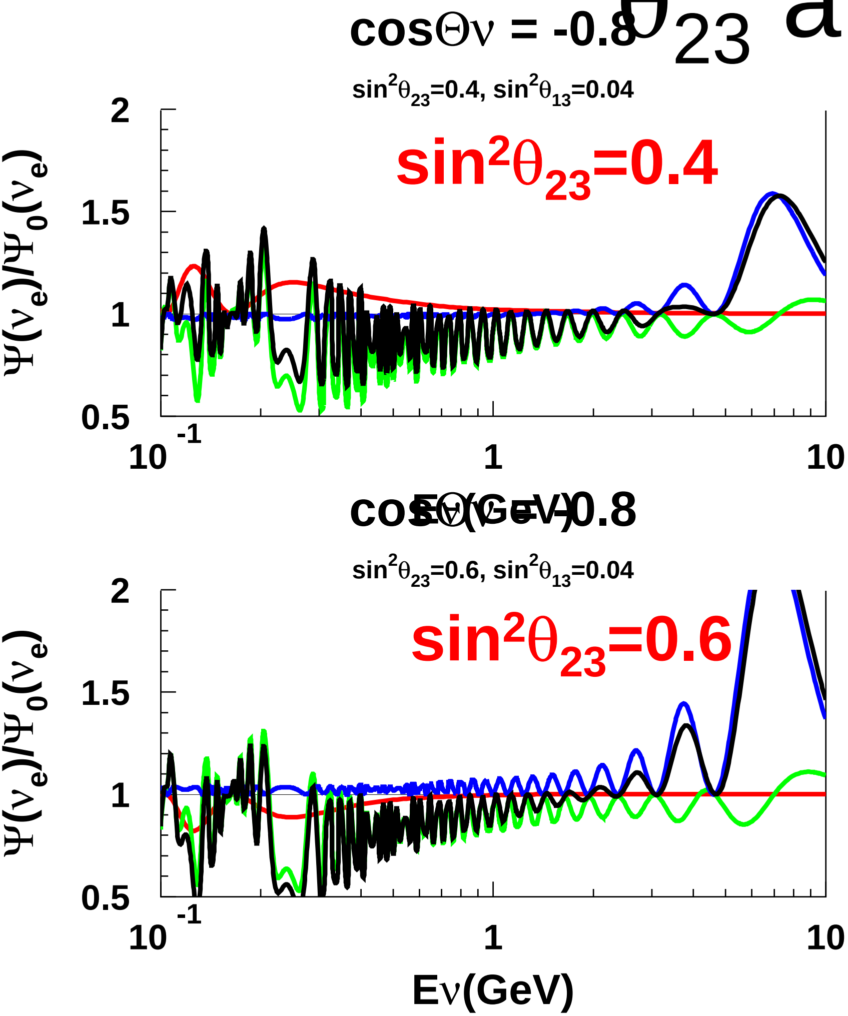
r : μ/e flux ratio (~2 at low energy)
~ : mixing angle in matter
$P_2 = |A_{e\mu}|^2$: $\nu_e \rightarrow \nu_{\mu\tau}$ in matter
$R_2 = \mathrm{Re}(A^*_{ee}A_{e\mu})$
$I_2 = \mathrm{Im}(A^*_{ee}A_{e\mu})$

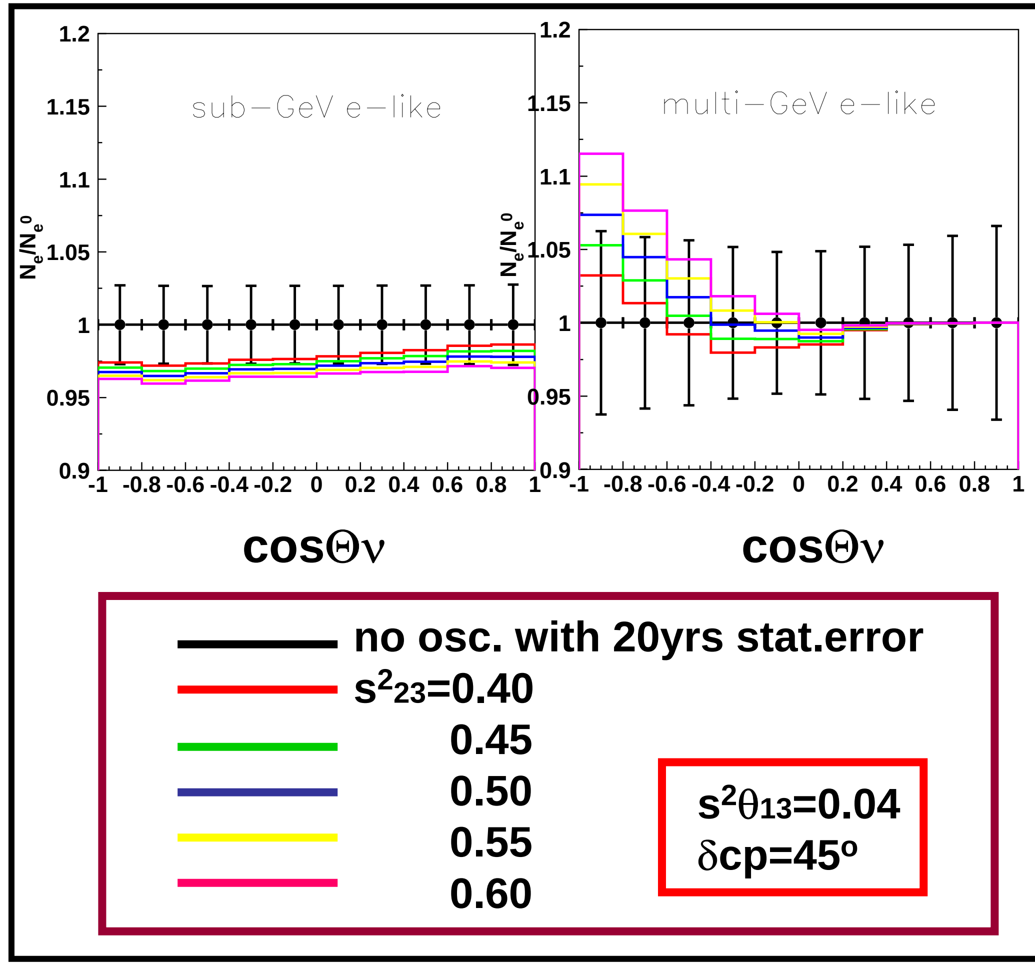
See for example:
Parse and Smirnov
hep-ph/0309312

$s^2 2\theta_{12}=0.825$
$s^2\theta_{23}=0.4$
$s^2\theta_{13}=0.04$
$\delta cp=45^o$
$\Delta m^2_{12}=8.3\times10^{-5}$
$\Delta m^2_{23}=2.5\times10^{-3}$



θ_{23} and Octant



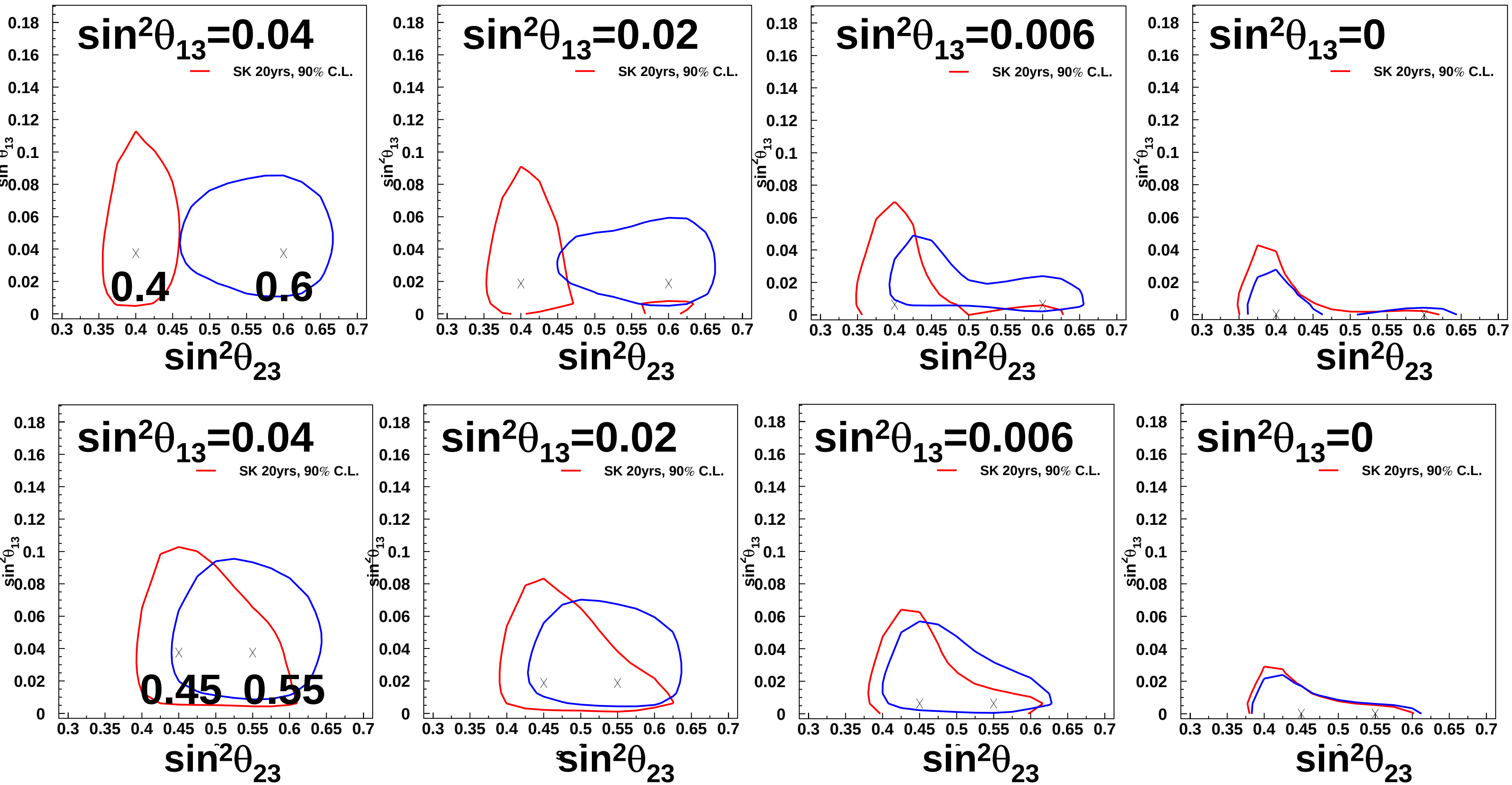


$s^2\theta_{13}$=0.04
δcp=45º
cos$\Theta\nu$=-0.8

Total
Solar term
θ_{13} term
Interference

Fixed
Δm^2_{23} = 2.5x10^{-3}eV^2 (positive)
Δm^2_{12} = 8.3x10^{-5}eV^2
$\sin^2 2\theta_{12}$ = 0.825

20 year of SK (SK 'final' results!)

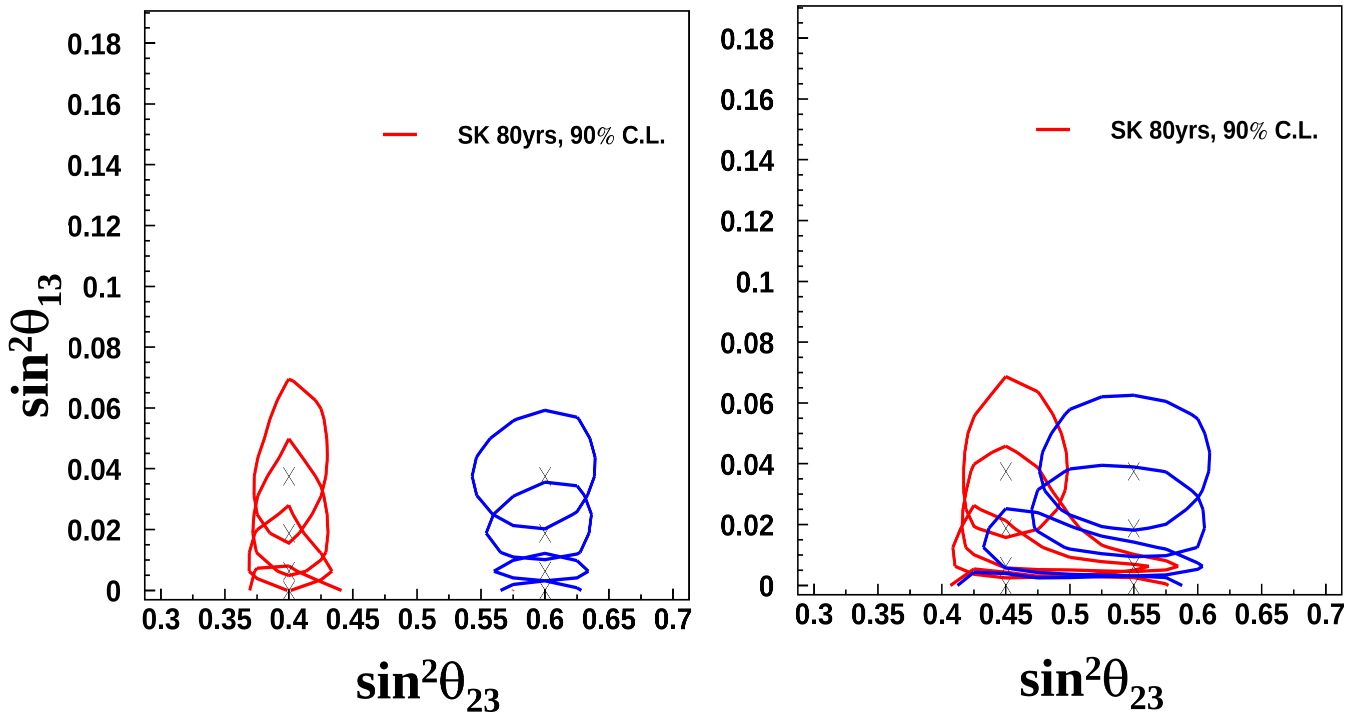


$\sin^2\theta_{23}$ = 0.40 or 0.60 ($\sin^2 2\theta_{23}$=0.96) : Possible for larger $\sin^2\theta_{13}$ for SK 20 yrs

$\sin^2\theta_{23}$ = 0.45 or 0.55 ($\sin^2 2\theta_{23}$=0.99) : Difficult for SK 20 yrs

80yrs SK ~ 3.6yrs of UNO or HK

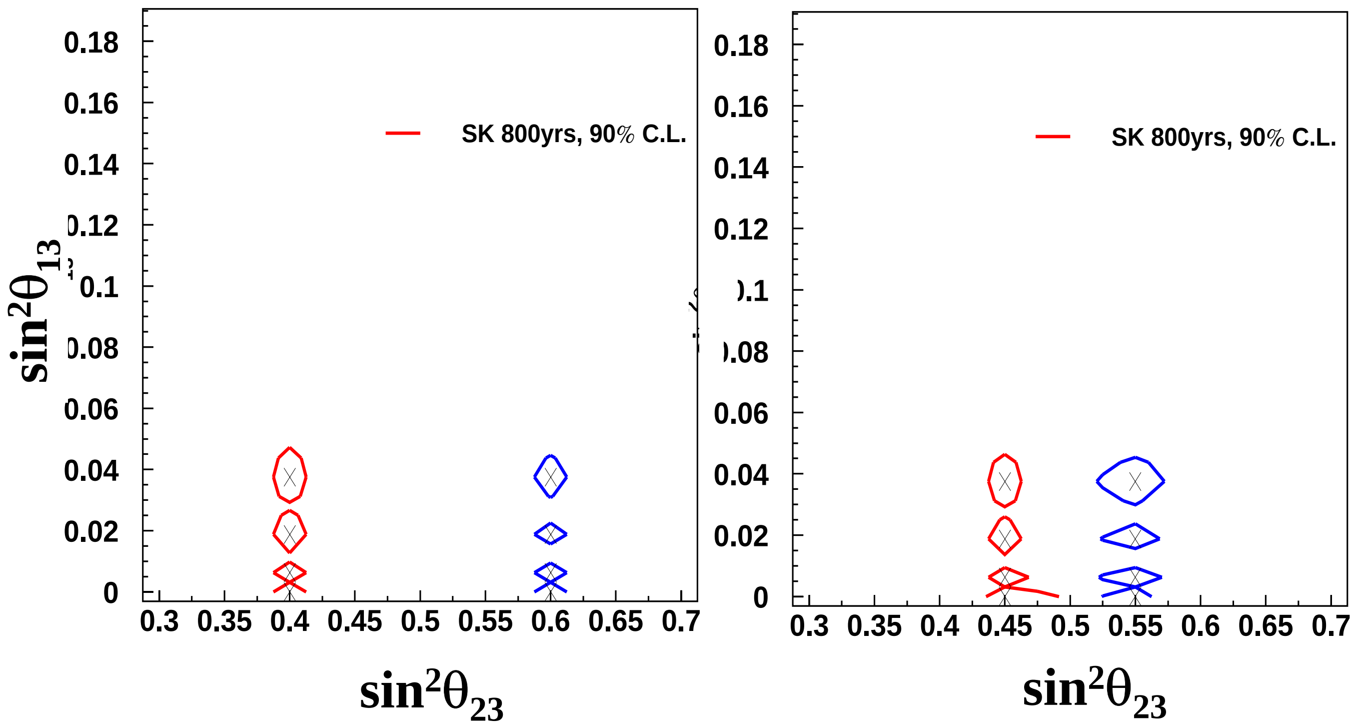
$s^2 2\theta_{12}$=0.825
$s^2\theta_{23}$=0.40 ~ 0.60
$s^2\theta_{13}$=0.00~0.04
δcp=45°
Δm^2_{12}=8.3x10^-5^
Δm^2_{23}=2.5x10^-3^



For UNO or HK, discrimination is possible for $\sin^2\theta_{23}$ = 0.40 or 0.60 ($\sin^2 2\theta_{23}$=0.96)

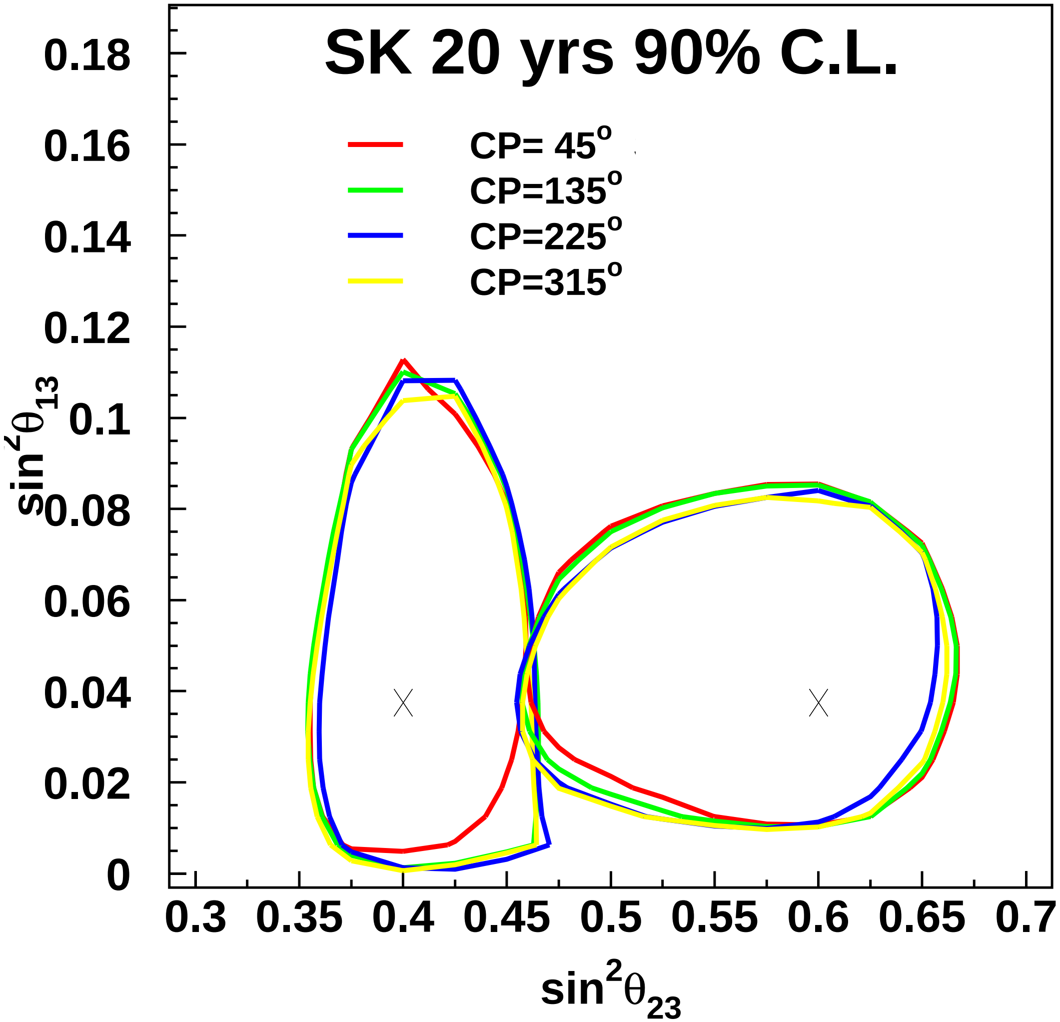
800yrs SK ~ 4yrs of TITAND-II

$s^2 2\theta_{12}$=0.825
$s^2\theta_{23}$=0.40 ~ 0.60
$s^2\theta_{13}$=0.00~0.04
δcp=45°
Δm^2_{12}=8.3x10^{-5}
Δm^2_{23}=2.5x10^{-3}

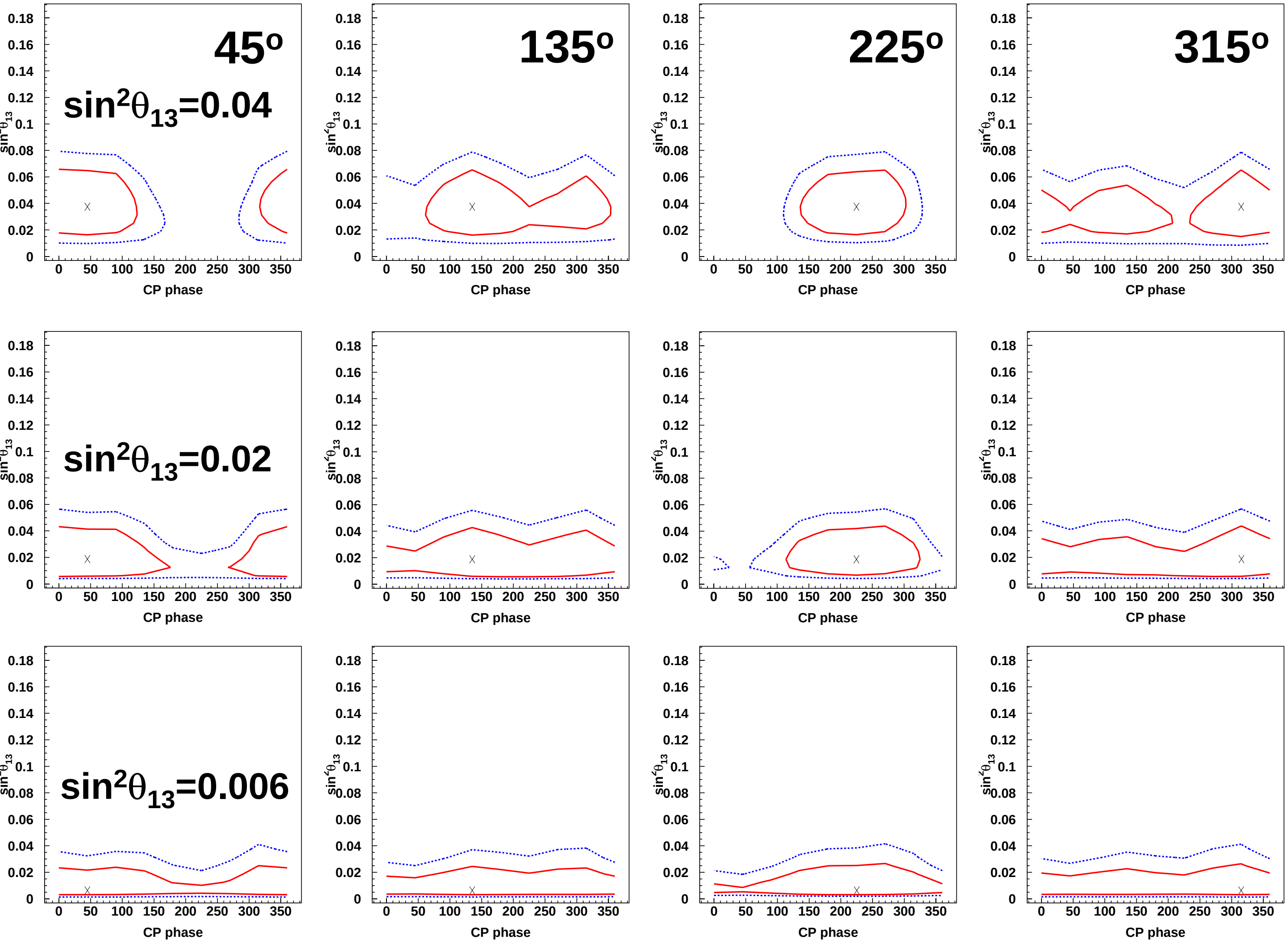


For TITAN-II, octant can be resolved for $\sin^2\theta_{23}$ > 0.45 or < 0.55 ($\sin^2 2\theta_{23}$ > 0.99)

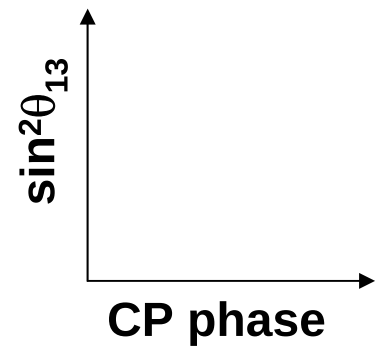
No strong CP phase dependence for Octant search



CP phase (80yrs SK = 3.6yrs of UNO or HK)

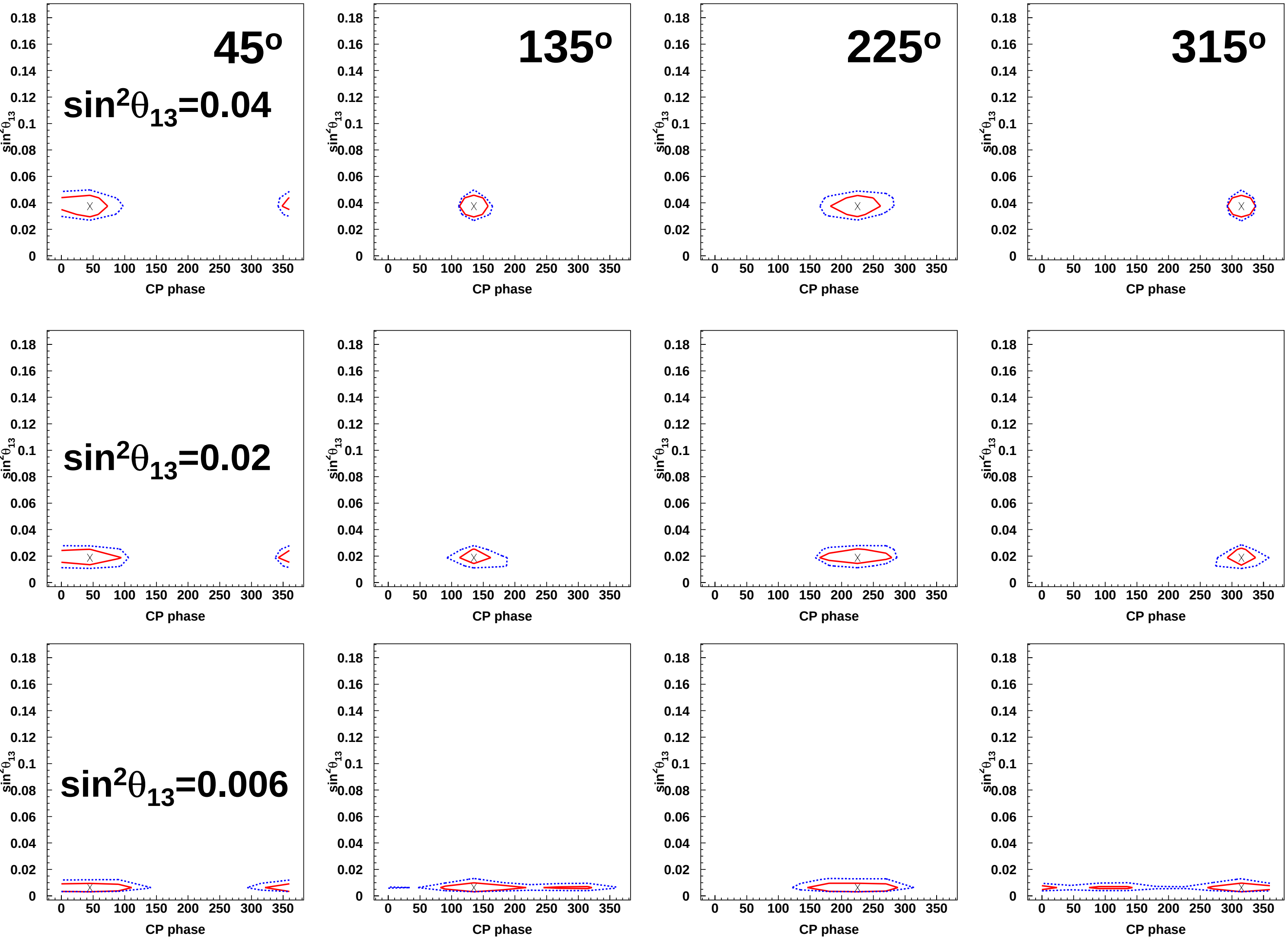


$s^2 2\theta_{12}=0.825$
$s^2\theta_{23}=0.5$
$s^2\theta_{13}=0.006\sim0.04$
$\delta cp=0^o\sim360^o$
$\Delta m^2_{12}=8.3\times10^{-5}$
$\Delta m^2_{23}=2.5\times10^{-3}$

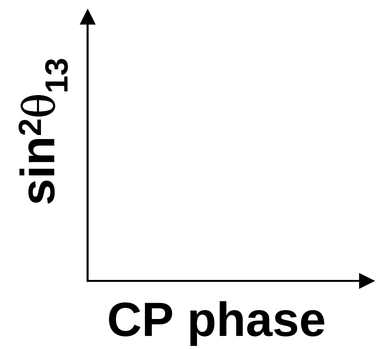


For UNO or HK, CP phase may be seen if θ_{13} is close to the CHOOZ limit

CP phase (800yrs SK = 4 yrs of TINTAND-II)

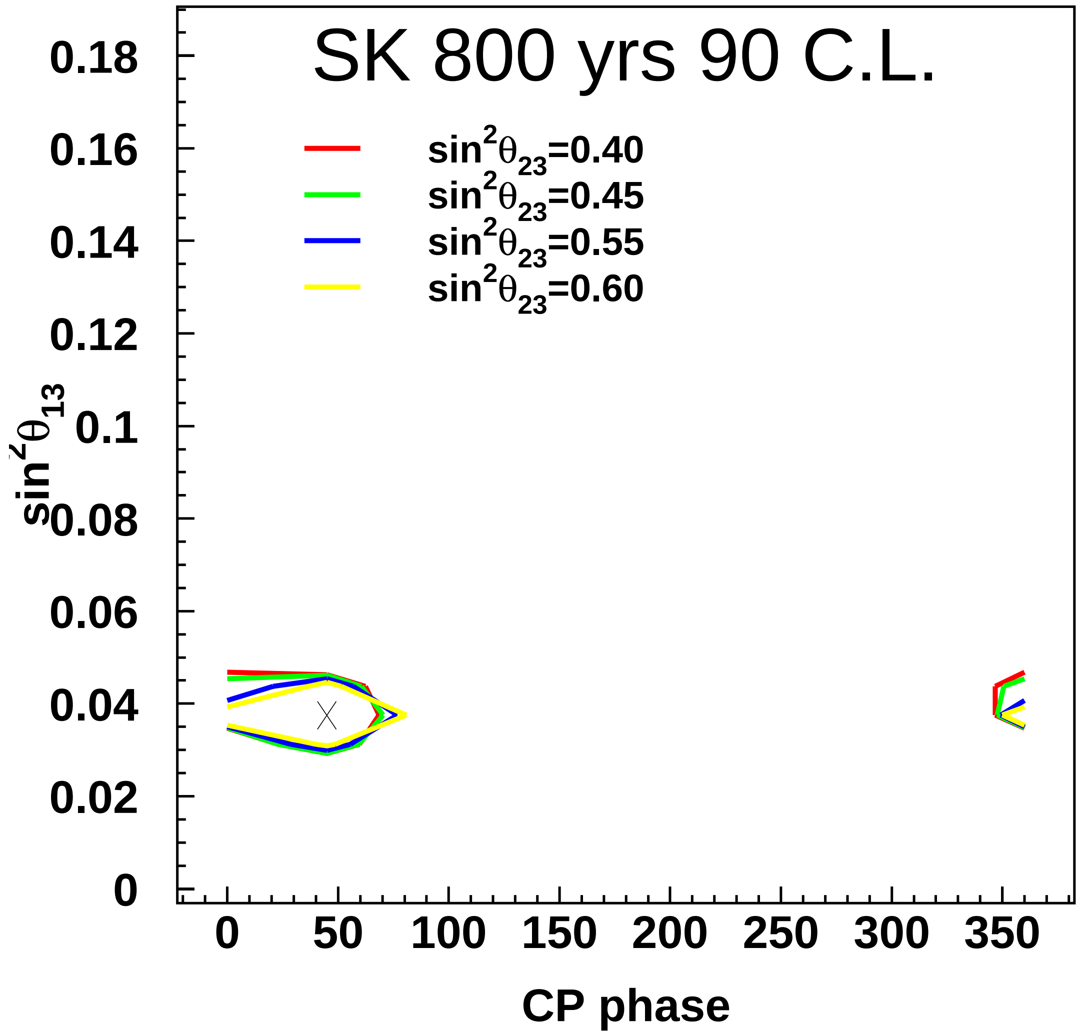


$s^2 2\theta_{12}=0.825$
$s^2\theta_{23}=0.5$
$s^2\theta_{13}=0.006\sim0.04$
$\delta cp=0^o\sim360^o$
$\Delta m^2_{12}=8.3\times10^{-5}$
$\Delta m^2_{23}=2.5\times10^{-3}$

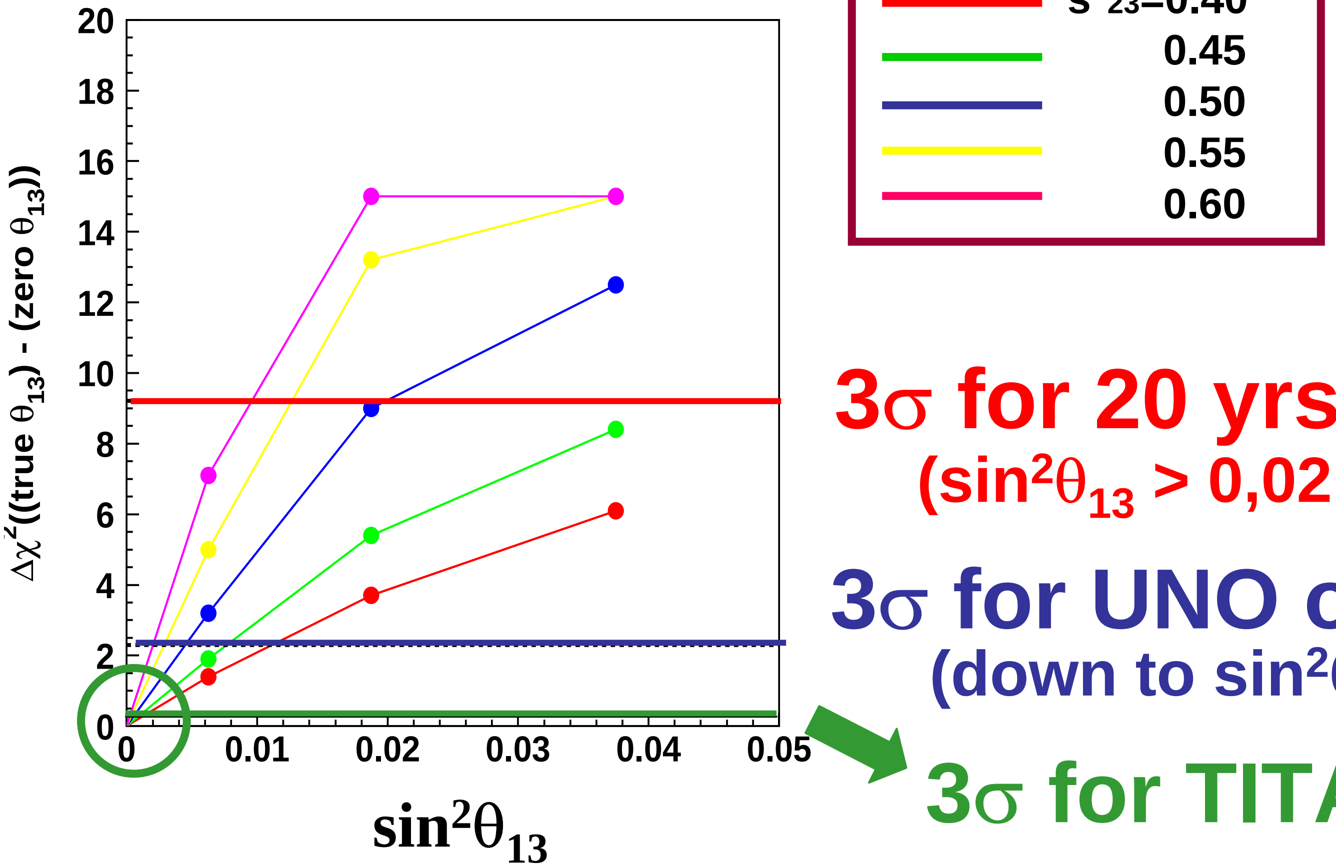


For TITAND-II, CP phase could be determined if θ_{13} is larger than $\sin^2\theta_{13}\sim 0.006$

No strong θ_{23} dependence for CP phase search



Non-zero θ_{13}



$s^2 2\theta_{12}$=0.825
$s^2\theta_{23}$=0.40 ~ 0.60
$s^2\theta_{13}$=0.00~0.04
δcp=45°
$\Delta m^2_{12}=8.3\times10^{-5}$
$\Delta m^2_{23}=2.5\times10^{-3}$

3σ for 20 yrs SK

($\sin^2\theta_{13}$ > 0,02 & $\sin^2\theta_{23} \geq$ 0.5)

3σ for UNO or HK

(down to $\sin^2\theta_{13} \geq$ 0,006)

3σ for TITAND-II ??

Need more test points

→ Our future Home Work

Other physics with TITAND

- Serve as a movable far detector for LBLE at any distance
- Supernovae
- Can be added magnetic detector for neutrino factory
- May be more

Conclusion

Astroparticle Physicists in the 21st Century

would travel

on the sea