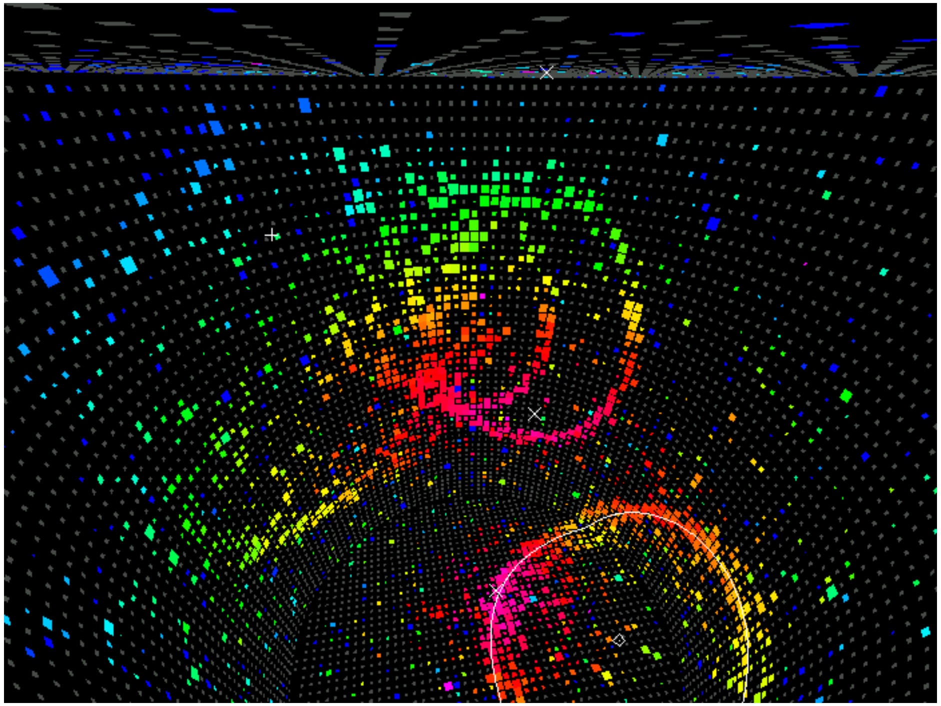


Hyper-Kamiokande

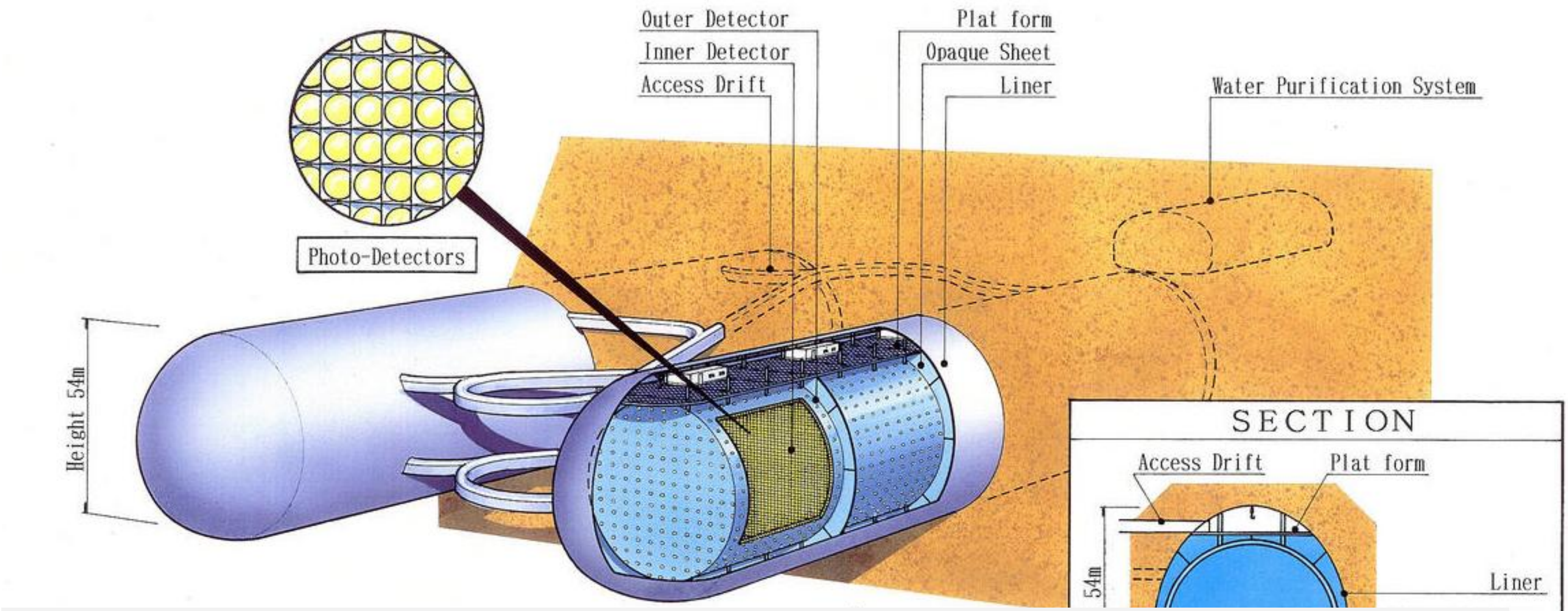
K. Okumura (ICRR Univ. of Tokyo)

NNN07 @ Hamamtsu, Oct 4. 2007

Outline

- Introduction
- Physics of HK
- Prospect for HK electronics
- Summary

Introduction



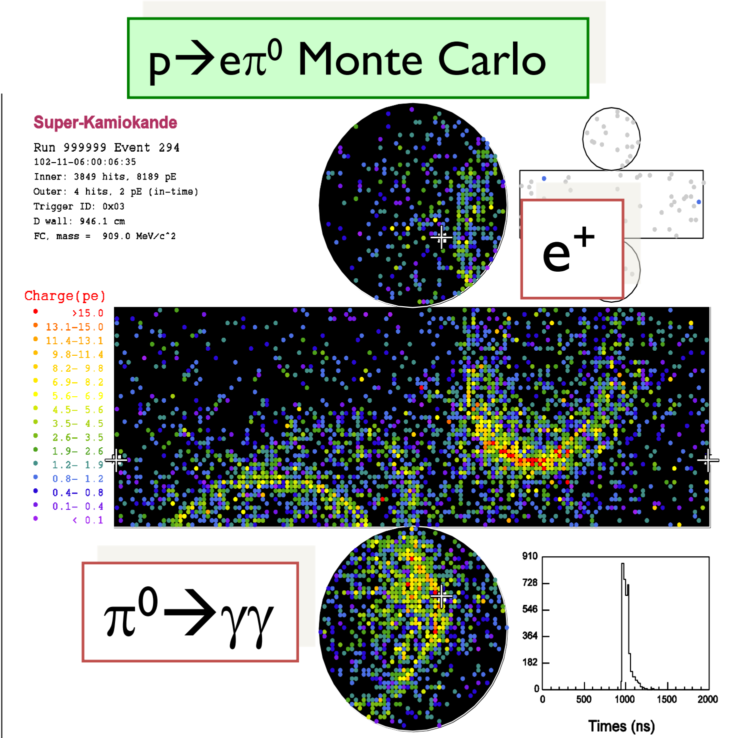
- total ~1 Mton (2 x 0.5 Mton) water Cherenkov detector at Kamioka site
- fiducial mass 0.54 Mton in total
- Number of 20-inch PMTs : ~100,000 for 1 PMT / m2 (20% photo coverage)
  ~200,000 for 2 PMT / m 2 (40% photo coverage)
- Overburden : 600~700 m of rock (2.7 g/cm^3 density, 1600~1900 m.w.e.)

Physics of HK

- Nucleon decay
  - $p \rightarrow e+ \pi^0$, $p \rightarrow \nu K+$, other decay mode
- Long baseline oscillation experiments
  - θ_{13}, CP violation, mass hierarchy
- Atmospheric neutrinos
- Super nova neutrinos
- Relic super nova neutrinos

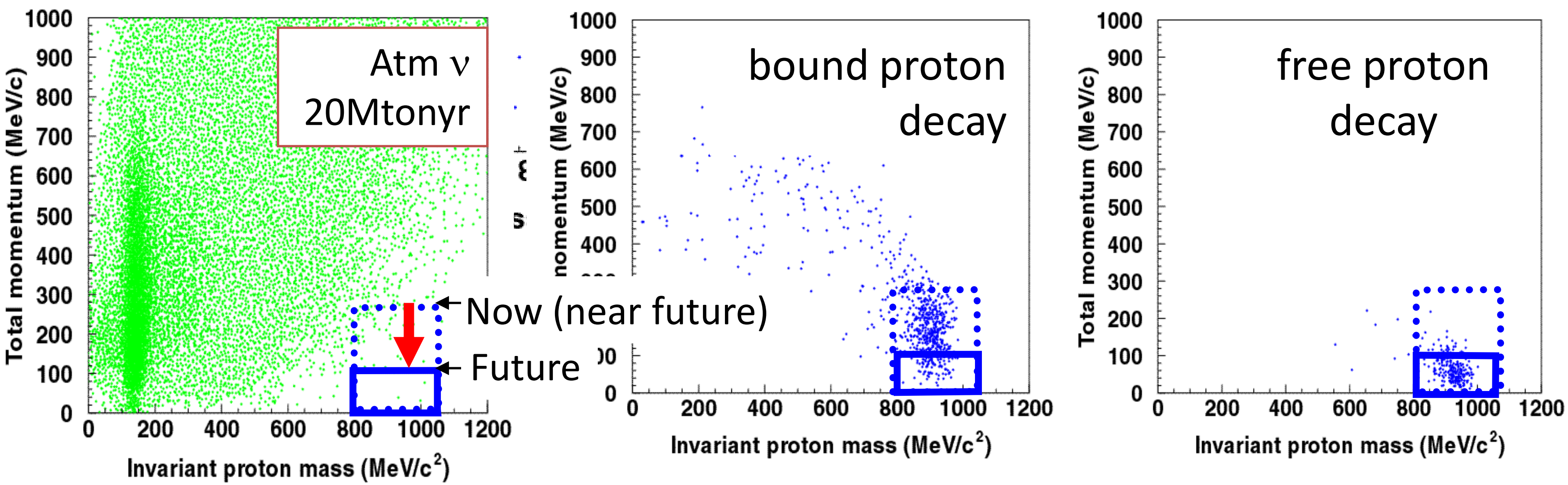
Search for p→$e^+\pi^0$

M.Shiozawa NNN05

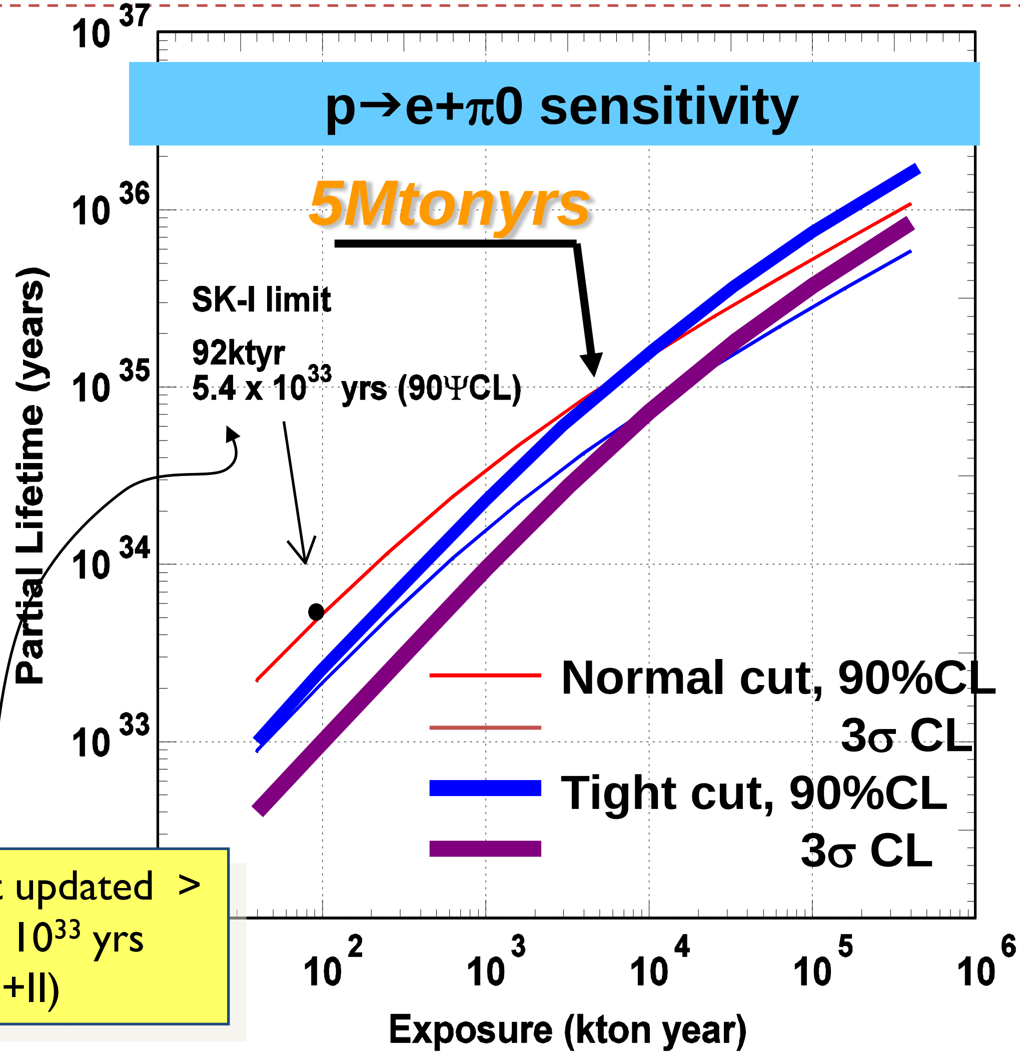


- P_{tot} < 250 MeV/c,
  BG 2.2ev/Mtyr, eff=40%
- P_{tot} < 100 MeV/c,
  BG 0.15ev/Mtyr, eff=17%

Main target is free proton decays for the tight cut.



Lifetime sensitivity for p→$e^+\pi^0$



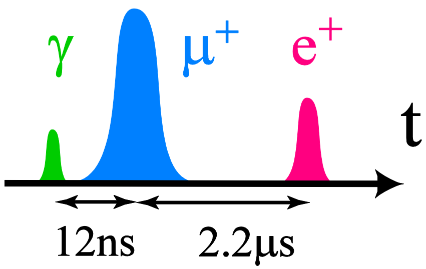
Most updated > 8.4×10^{33} yrs (SK-I+II)

5Mtonyrs ➔
~10^{35} years@90%CL
~$4\text{x}10^{34}$ years@3σCL

$p \to \nu K^+$

(1) $^{16}O \to \nu K^{+}\,^{15}N\,\gamma$, $K^+ \to \mu^+\nu$ ($\mu^+ \to e^+\nu\nu$)

6 – 10 MeV (γ)   236MeV/c (μ⁺)



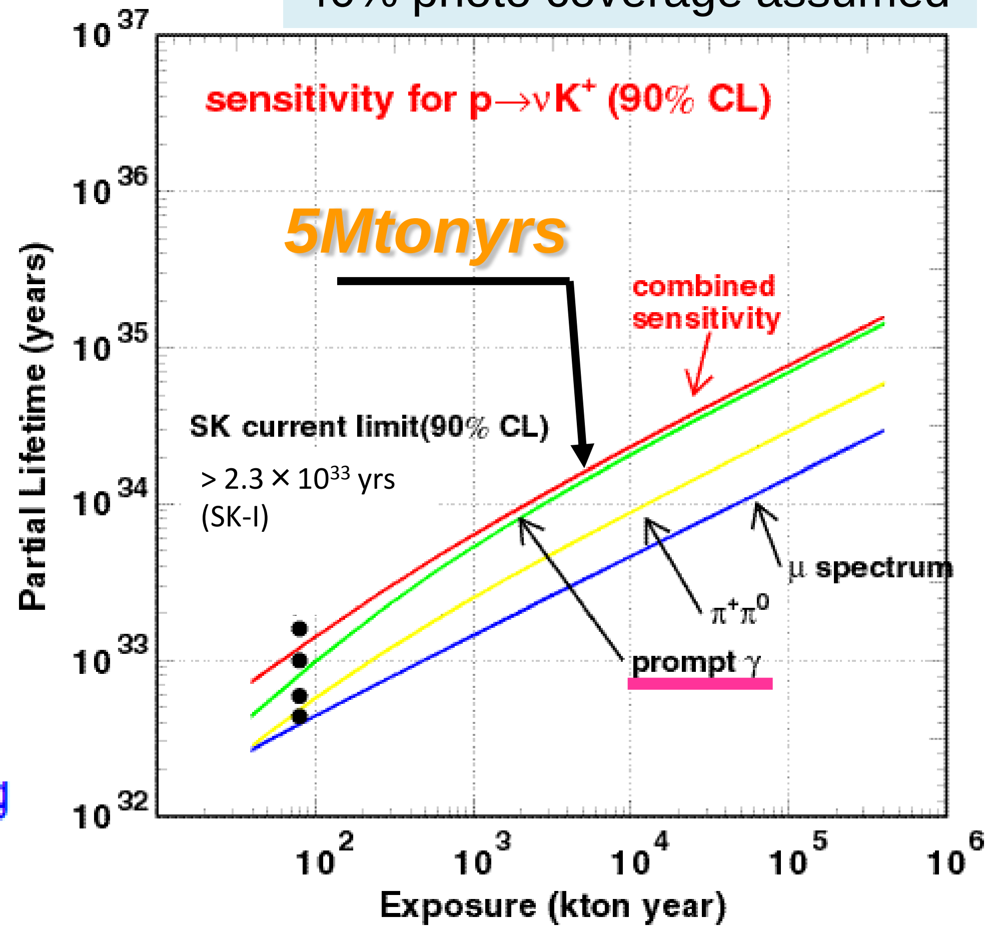
- 1 μ and 1 decay electron
- $215 < P_\mu < 260$ MeV/c
- no proton
- maximize NHIT in the 12 ns sliding time window, $7 \leq NHIT_\gamma \leq 60$

(Also, searches for

(2) $p \to \nu K^+$ ($K^+ \to \pi^+\pi^0$)

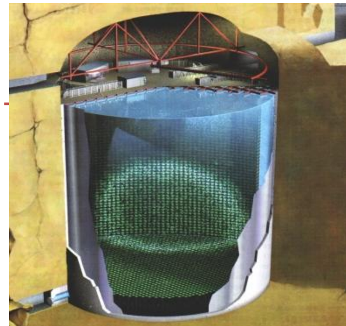
(3) $P \to \nu K^+$($K^+ \to \mu^+\nu$, without γ))

40% photo coverage assumed



5Mtonyrs →
~2x10^{34} years@90%CL
~0.8x10^{34} years@3σCL

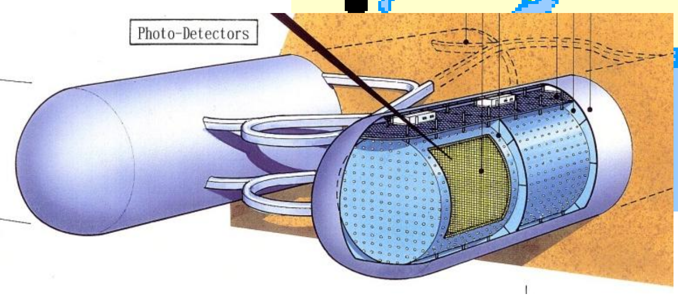
T2K



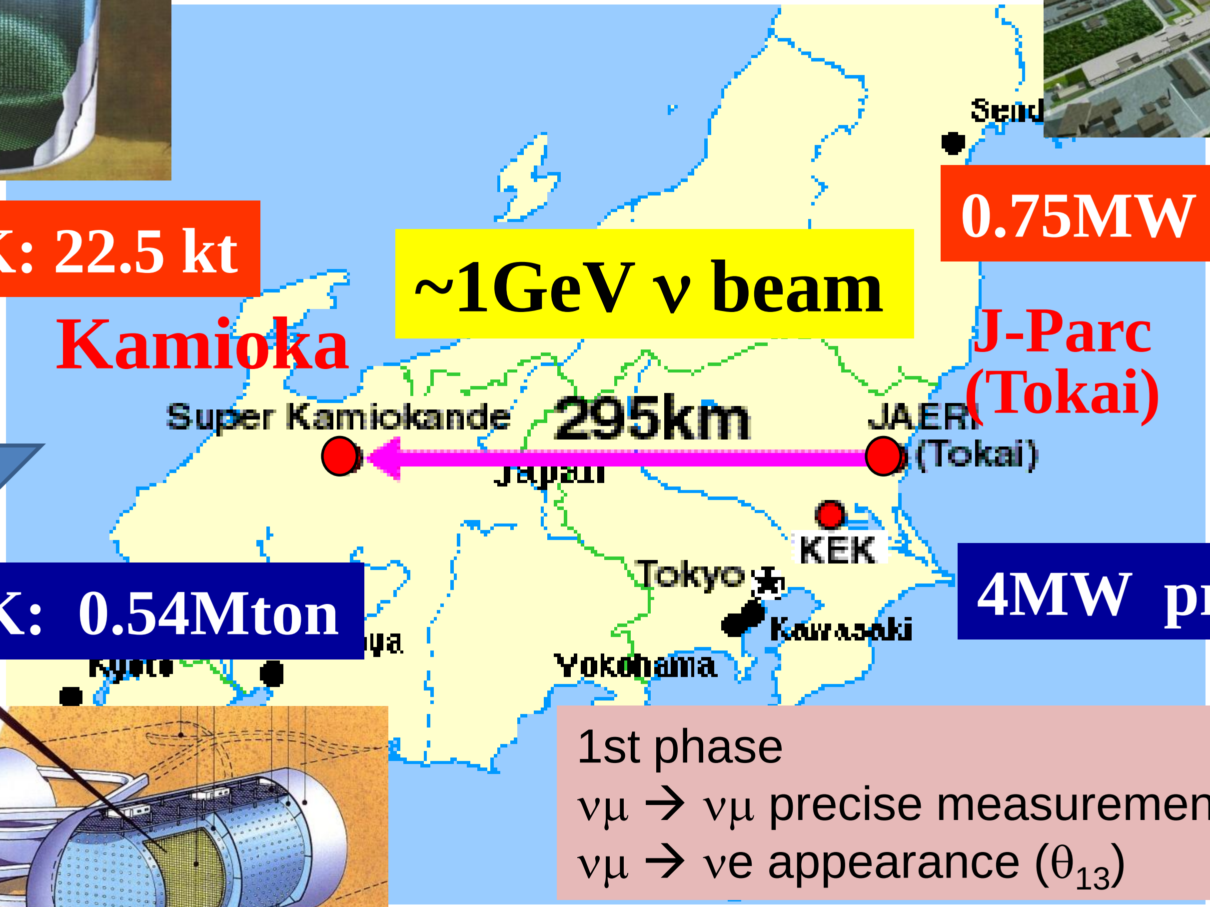
Super-K: 22.5 kt

Kamioka

Hyper-K: 0.54Mton



~1GeV ν beam



0.75MW proton beam

J-Parc (Tokai)

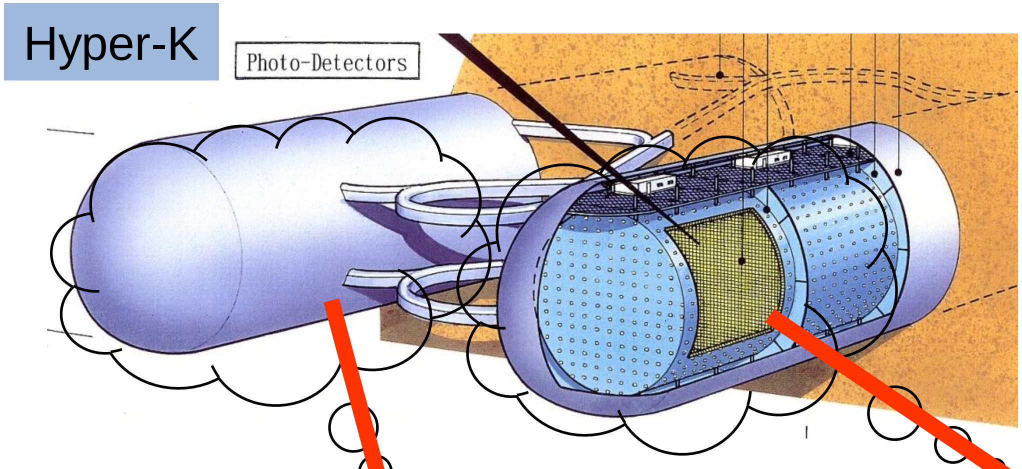
4MW proton beam

1st phase
νμ → νμ precise measurement (Δm_{23}^2, θ_{23})
νμ → νe appearance (θ_{13})

2nd phase (T2K-II)
CP violation
mass hierarchy

T2KK

Recently T2KK extension is extensively discussed ….



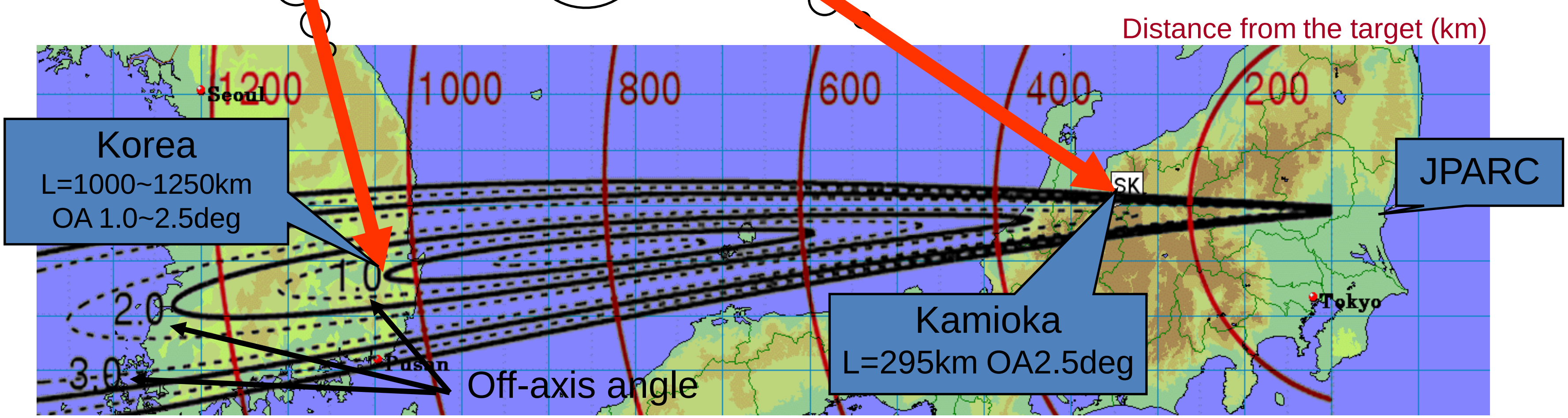
two identical detector at different baseline length

L = 295km → 1000~1250km

CP phase effect enhanced by L

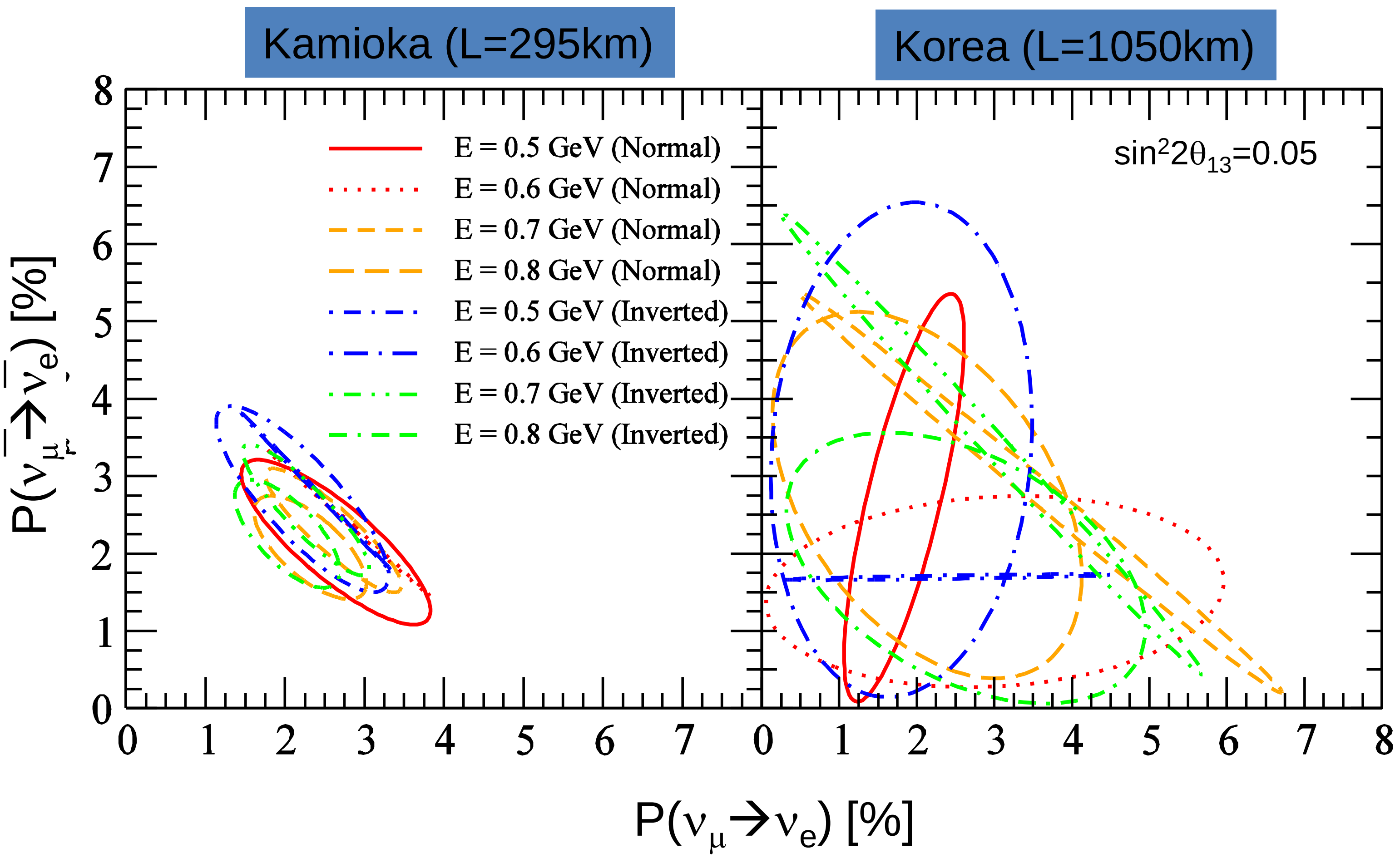
event rate decrease to ~1/10

same detector → reduce systematic errors



K. Hagiwara Nucl. Phys. Proc. Suppl. 137 84 (2004)

Oscillation Probabilities at Kamioka and Korea



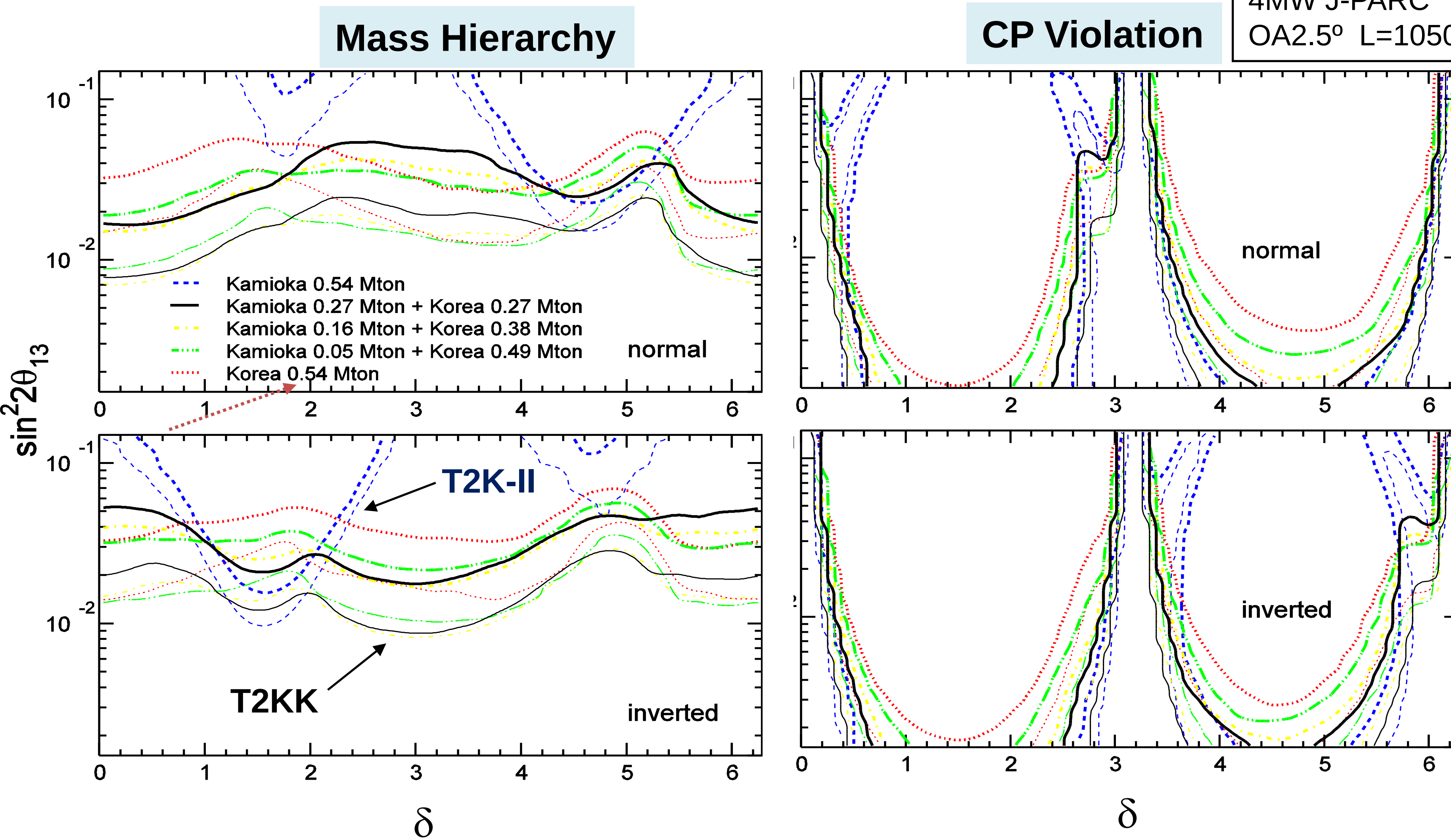
large energy dependence of bi-probabilities

sensitive to mass hierarchy

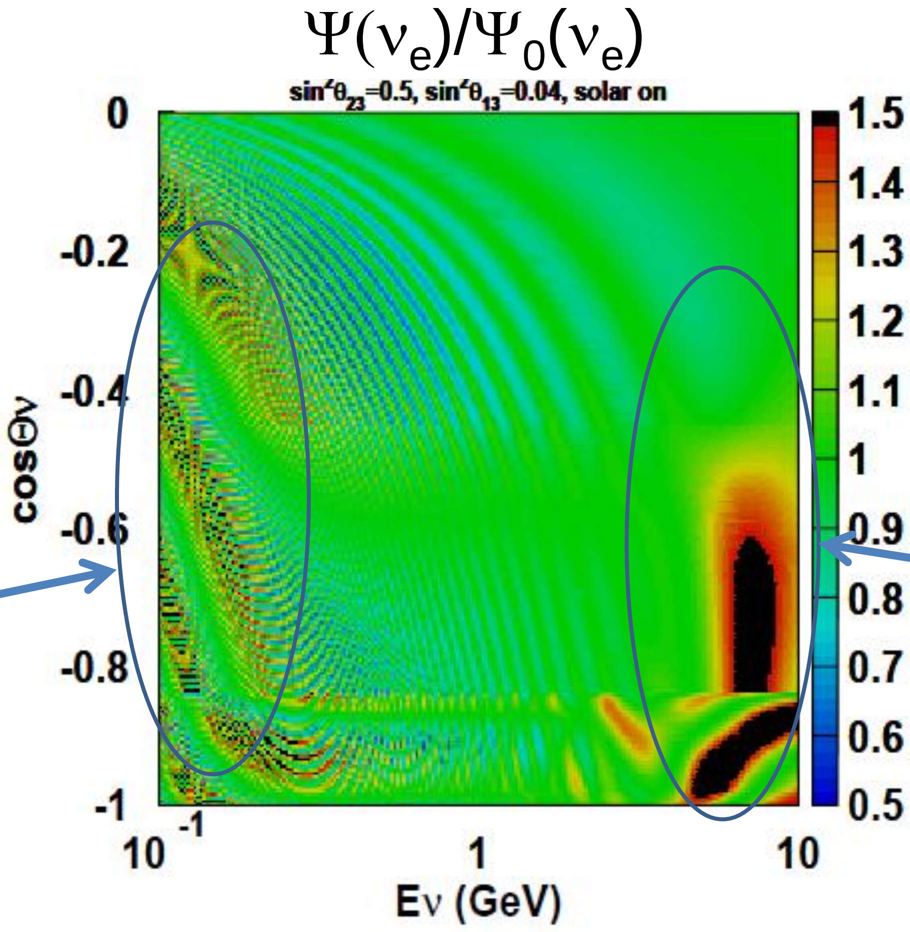
Ishitsuka et al. PRD 72 (2005) 033003

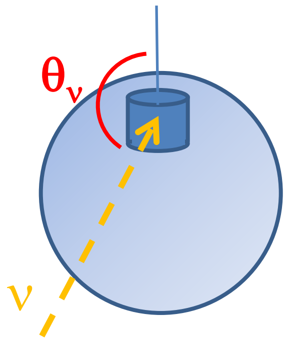
T2K-II and T2KK sensitivities

4yr ν + 4yr $\overline{\nu}$
4MW J-PARC
OA2.5º L=1050km



Matter effect of atm. ν in Earth





Sub-GeV region

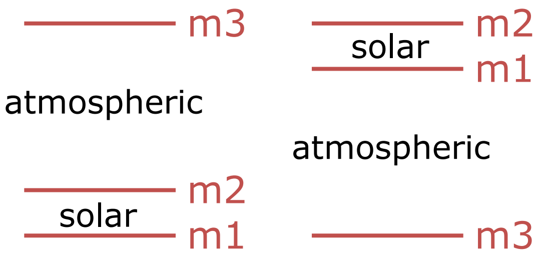
solar term effect (Δm_{12}^2):

Multi-GeV region

ν_e enhancement due to non-zero θ_{13}

Probing sign of Δm^2_{23} with atm. ν

Δm^2_{23} = 0.0025 eV^2
$s^2 23$ = 0.5
$s^2 13$ ~ 0.04
4.5 Mton·yr

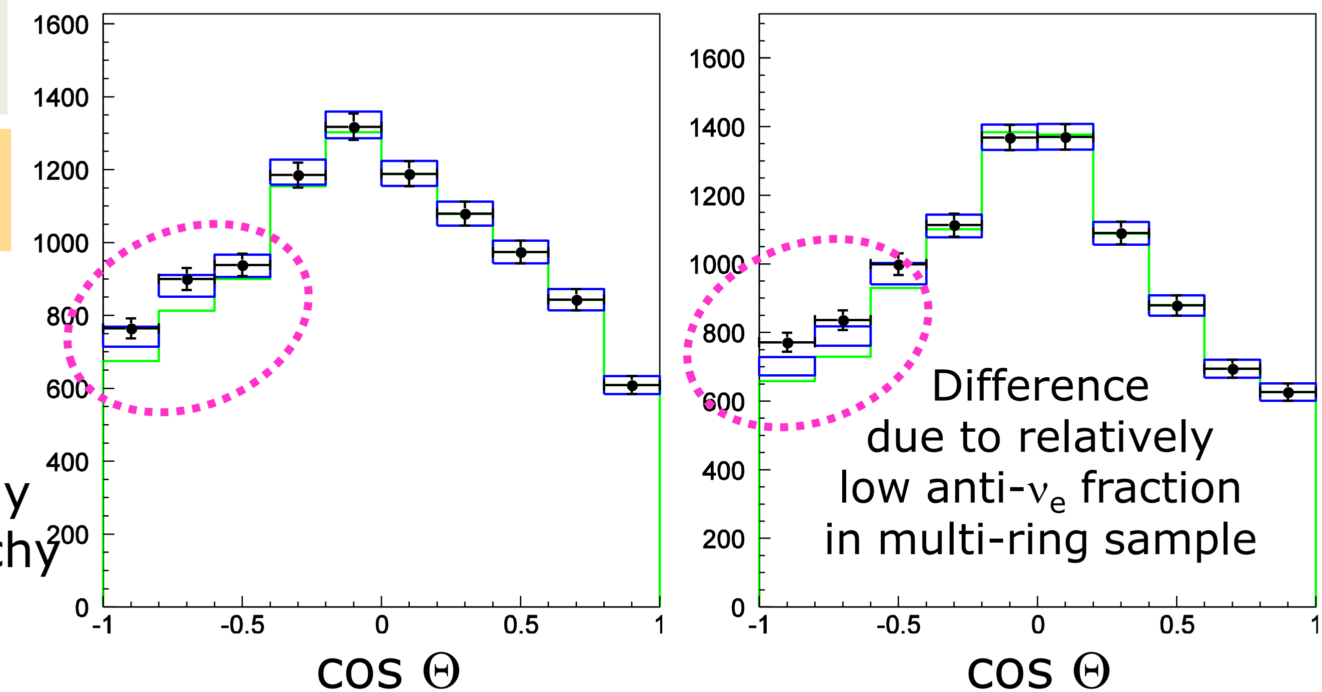


Normal Hierarchy ($\Delta m^2>0$)	Inverted Hierarchy ($\Delta m^2<0$)
resonance only for ν_e	resonance only for $\overline{\nu_e}$

2.5~5 GeV/c

single-ring e-like

multi-ring e-like

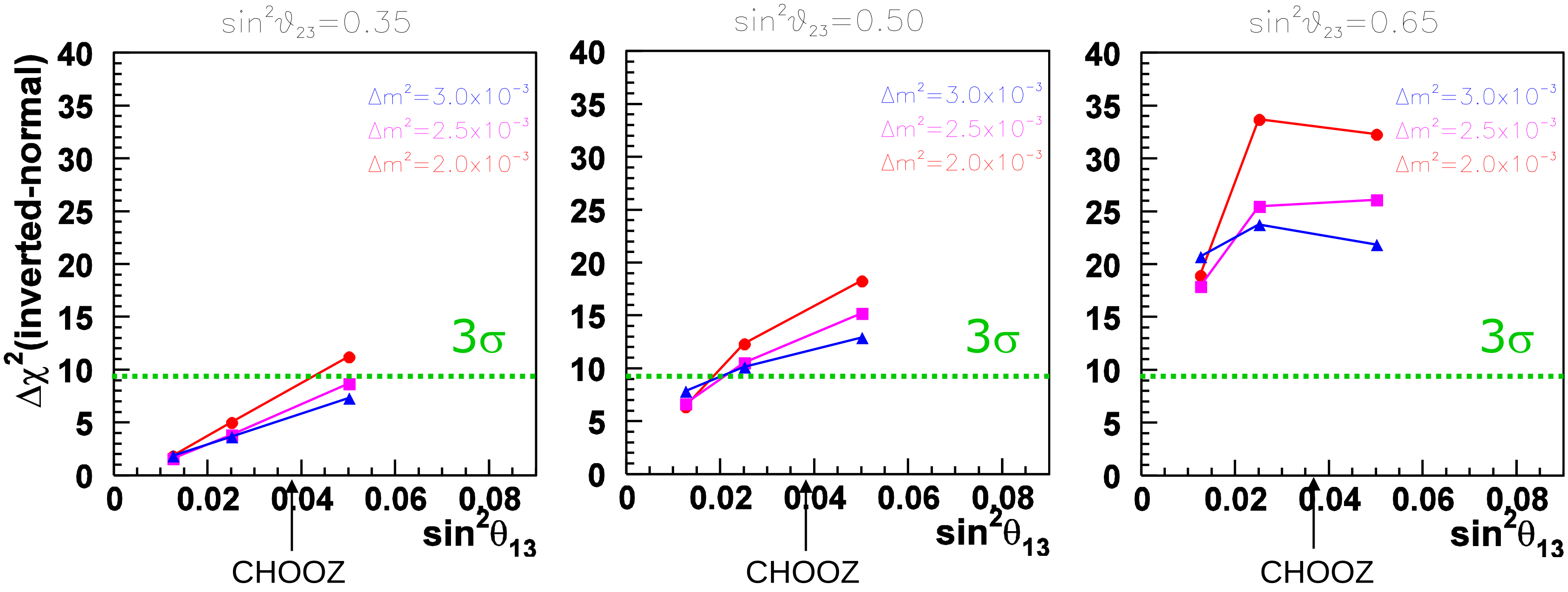


Normal hierarchy
Inverted hierarchy
Null oscillation

χ^2 difference (inverted – normal)

1.8 Mton·yr

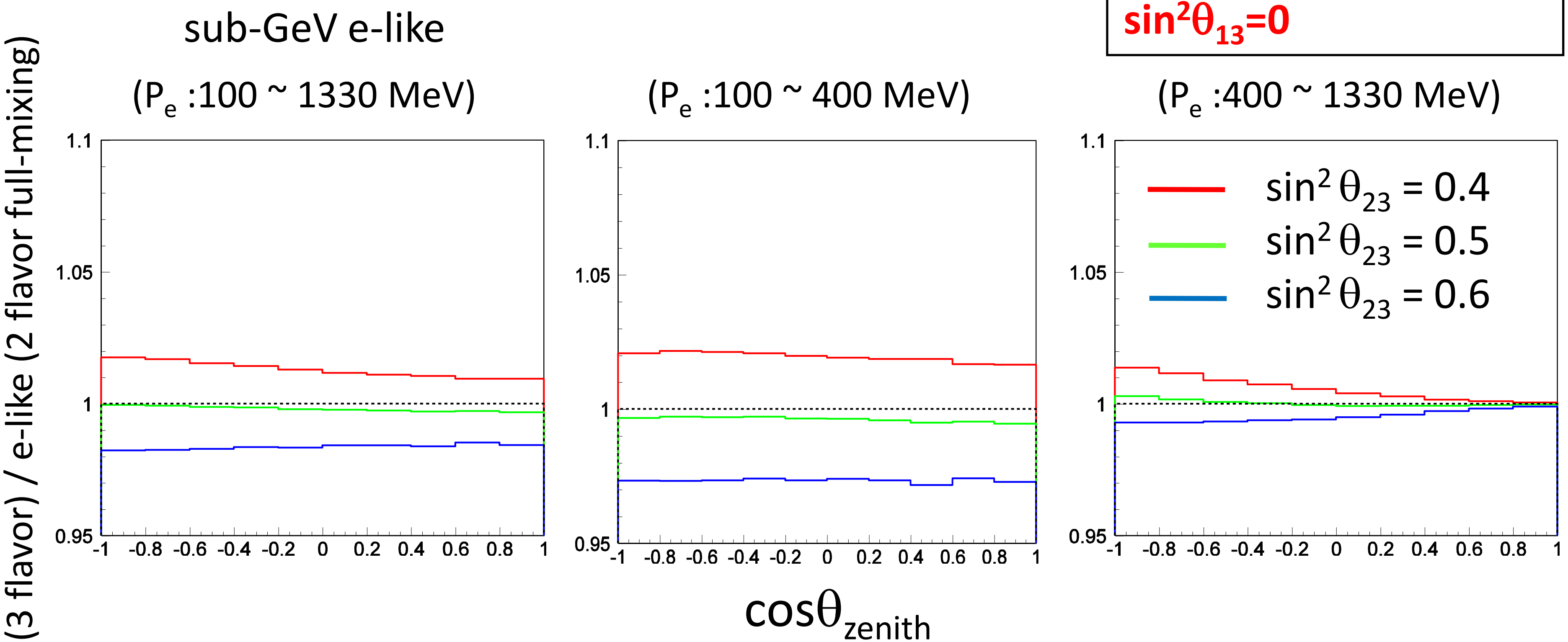
True : normal mass hierarchy



θ23 octant

$\sin^2 2\theta_{23}=0.96$ → $\sin^2\theta_{23}=0.4$ or 0.6

$\Delta m^2_{12} = 8.3 \times 10^{-5}\ eV^2$
$\Delta m^2_{23} = 2.5 \times 10^{-3}\ eV^2$
$\sin^2 2\theta_{12} = 0.82$
$\sin^2\theta_{13}=0$



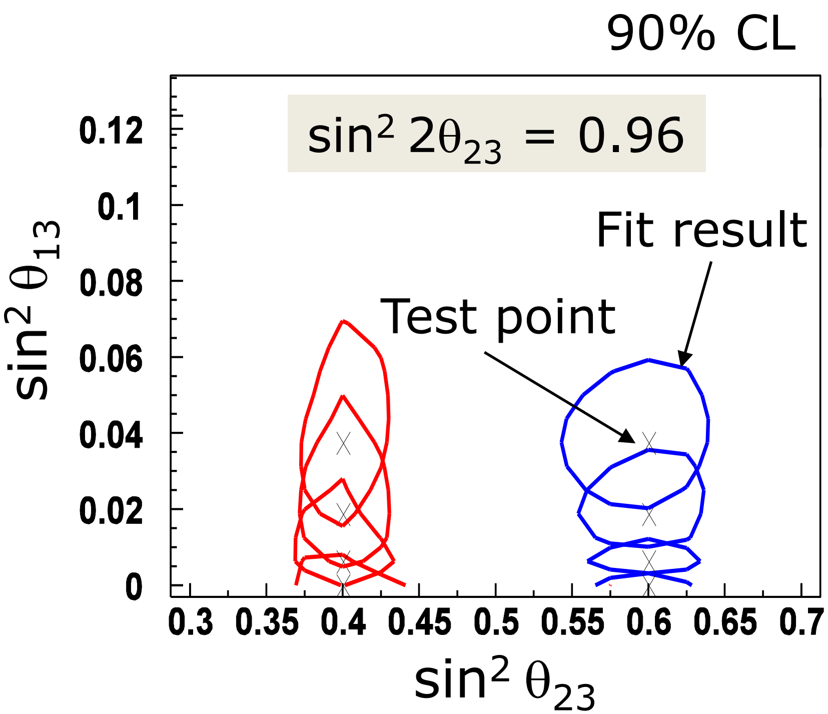
(some opposite effect for μ-like events.)

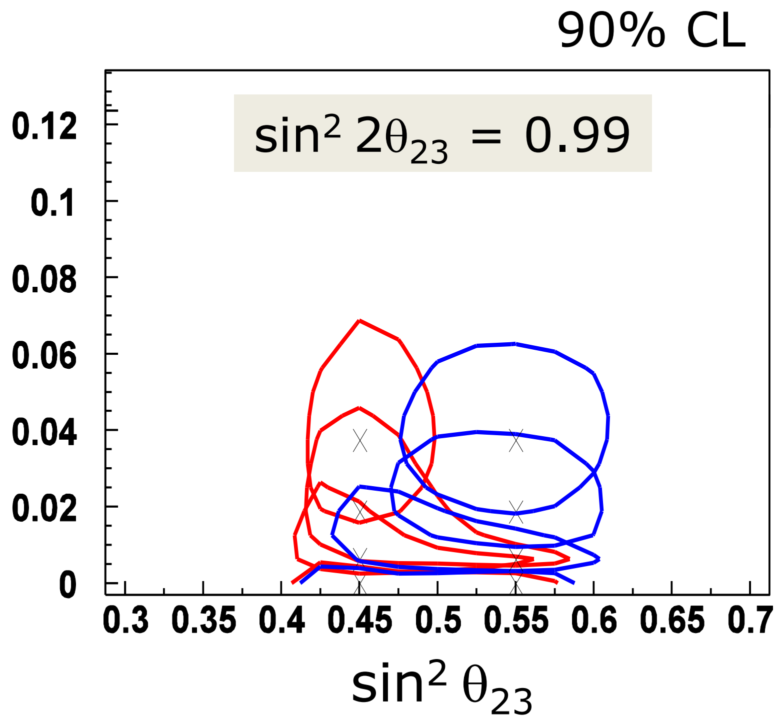
μ/e ratio @low energy is useful to discriminate $\theta_{23}>\pi/4$ and $<\pi/4$.

Discrimination between $\theta_{23} > \pi/4$ and $< \pi/4$ with the (12) and (13) terms

$\sin^2\theta_{23} = 0.40 \sim 0.60$
$\sin^2\theta_{13} = 0.00 \sim 0.04$
$\delta_{cp} = 45^\circ$

1.8 Mton·yr





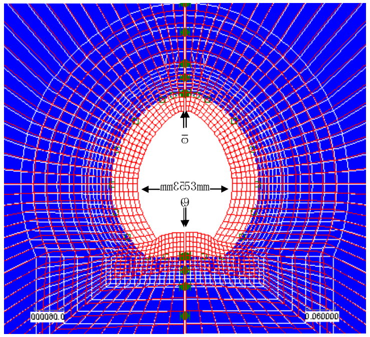
Discrimination between $\theta_{23} > \pi/4$ and $< \pi/4$ is possible for all θ_{13}.

Discrimination between $\theta_{23} > \pi/4$ and $< \pi/4$ is marginally possible only for $\theta_{13} > 0.04$.

Physics summary

- Proton decay
  - p → $e\pi^0$: ~1×10^{35} yr @ 5Mton (90% C.L.)
  - p → νK^+ : ~2×10^{34} yr @ 5Mton (90% C.L.)
- Accelerator oscillation experiments
  - T2K 2nd phase will be able to probe CP violation, and mass hierarchy partially
  - T2KK will extend mass hierarchy sensitivities significantly for any CP phase
- Atmospheric neutrino
  - mass hierarchy and θ_{23} octant can be probed due to matter effect in Earth. it will be complementary measurement with long baseline experiment

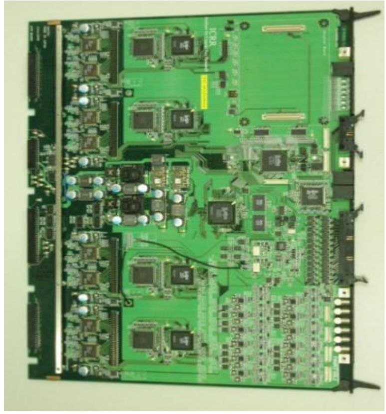
R&D status of HK



Kamioka Site study and detector structural

→ N. Wakabayashi

Photo sensor (HPD)
→ T. Tanaka



Recently we are developing new electronics for Super-K which are also considering future Mton detector use. I will discuss about the prospect.

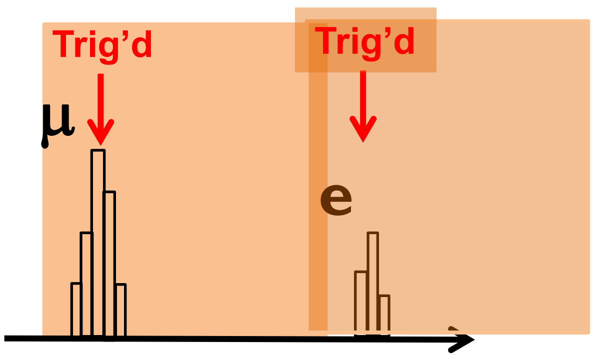
Development of new electronics for Super-K
→ S. Nakayama

Requirement for Mton detector DAQ

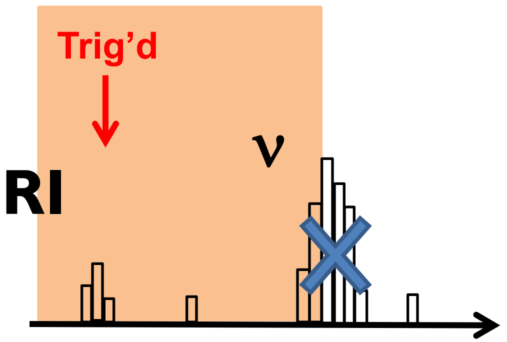
- Proton decay and neutrinos are rare events
  - can happen anytime
  - need to make trigger by event itself
  - need to minimize dead time
- Backgrounds
  - Cosmic ray muon background (10Hz for SK, ~kHz for HK)
  - Radioactive background events
  - (may) need to reduce data size
- Taking successive events is important
  - $p \rightarrow \nu K+$, decay electron

Difficulty in self trigger system

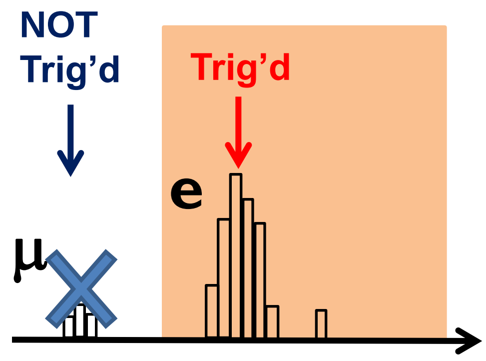
Decay electron



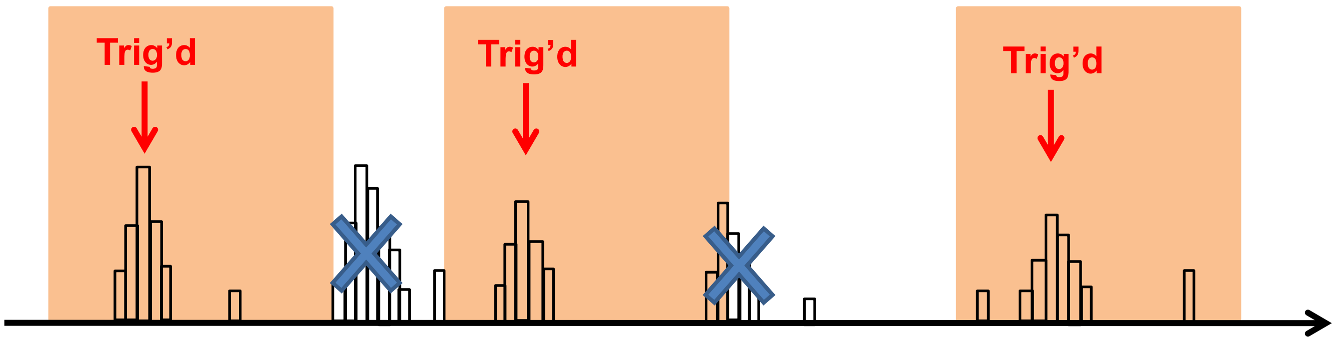
Disturbed ν trigger by background hits



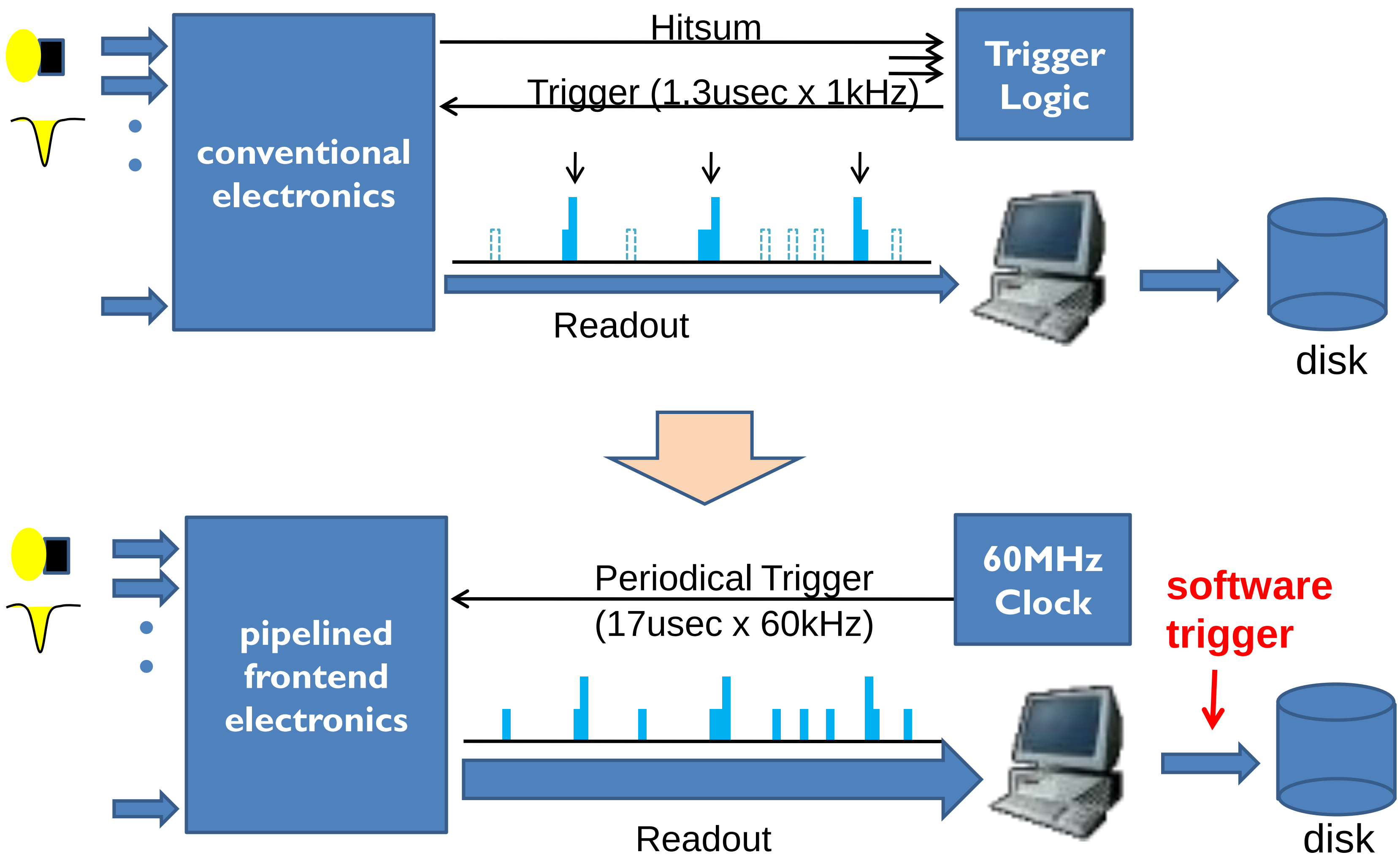
atm νμ BG for relic SN ν



Extreme high rate SN burst !!



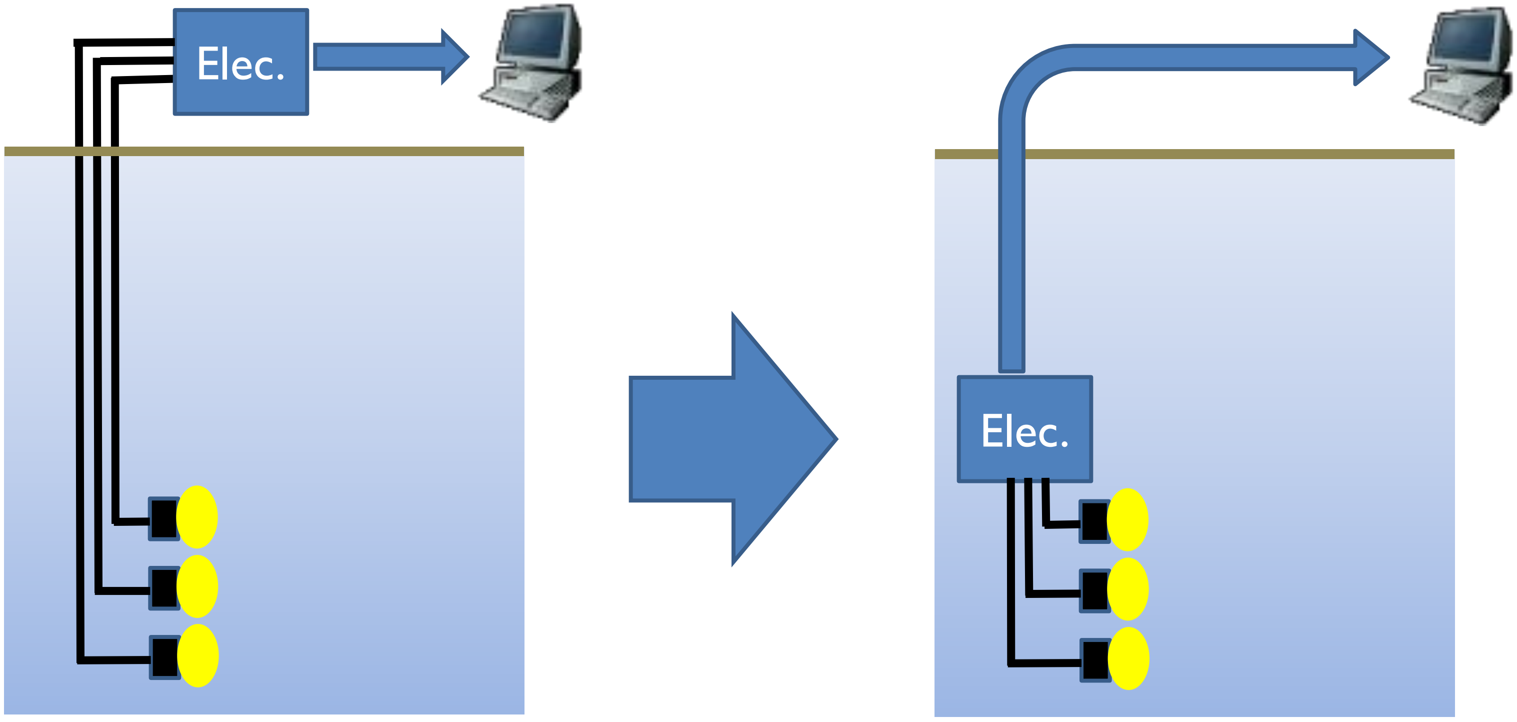
We propose "record-every-hit"



Advantage of this system

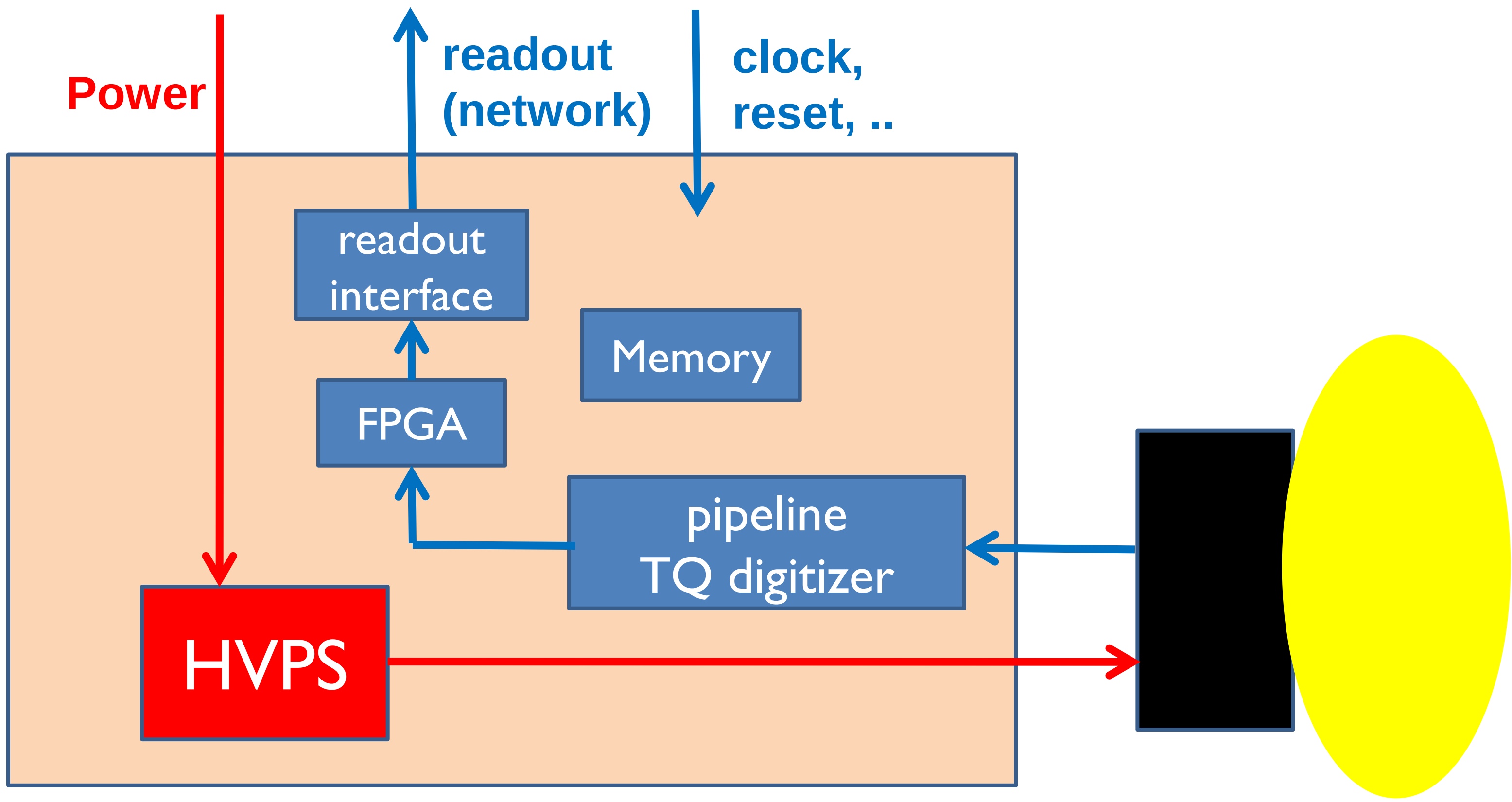
- hardware trigger is no more necessary
  - reduce hardware resources for assembling HW trigger
- dead time is zero !
- Intelligent and flexible software trigger is available
  - reduce RI background by online event fitter information
  - reduce cosmic-ray muons by online
  - gate window is changeable
    - wide timing window for proton decay, atm. ν events (~30μsec)
    - narrow timing window for solar neutrino
  - super nova burst events

Electronics at Photo sensor side



Placement of electronics at photo sensor has the following merits :

- better timing resolution
- reduce hardware resources and cost (cable, connector, etc.)
- easier installation, no cooling inside water (?)


Power
readout
(network)
clock,
reset, ..
readout
interface
Memory
FPGA
pipeline
TQ digitizer
HVPS

Summary

- Hyper-K is very attractive detector and it has a potential for probing a lot of physics
  - Proton decay
  - T2K-II and T2KK
  - Atmospheric neutrinos
- Prospect of electronics system for Hyper-K
  - Pipelined electronics and `record-every-hit` system will make simple and efficient
  - Electronics at photo sensor side will make much simpler and improve detector performance