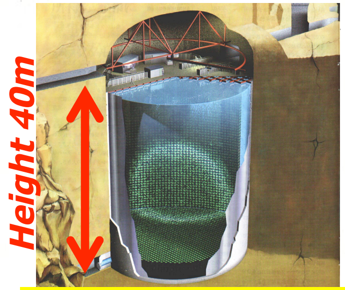
Large Water Cherenkov Detectors
- Technical Issues -

Hiroaki Aihara
University of Tokyo

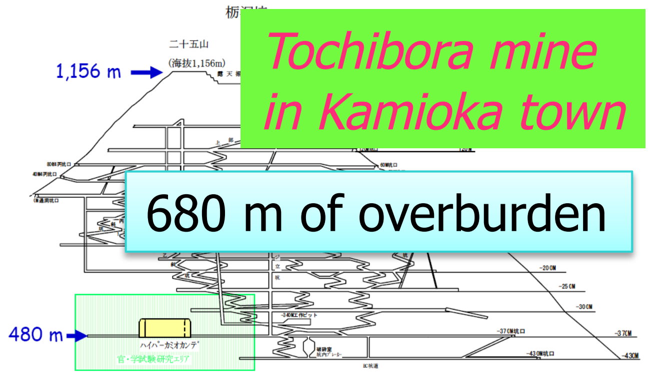
Workshop for European Strategy for Future Neutrino Physics, October 1-3, 2009 CERN

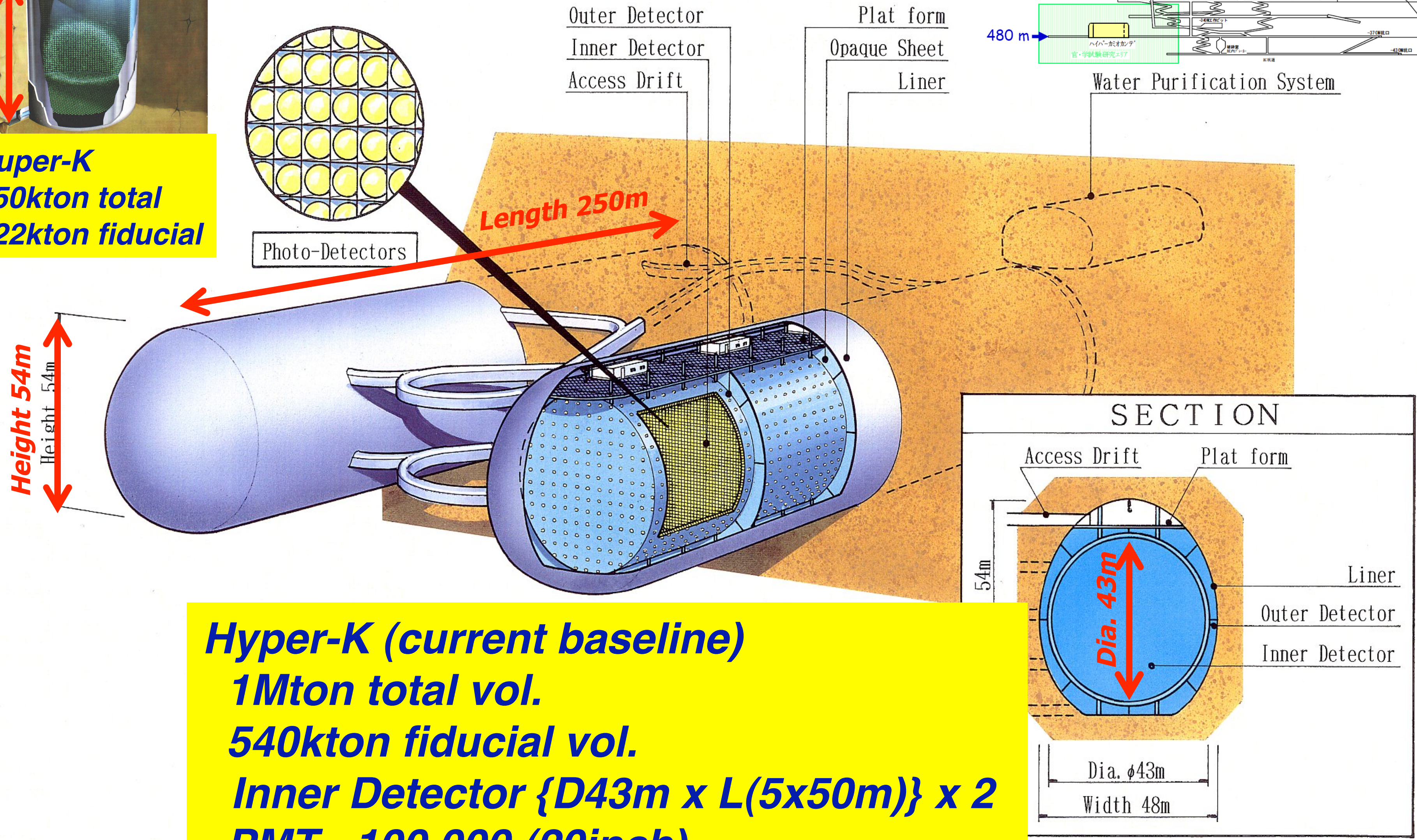
Hyper-Kamiokande

Ring-imaging water Cherenkov detector



Super-K
- **50kton total**
- **22kton fiducial**





Hyper-K (current baseline)
- **1Mton total vol.**
- **540kton fiducial vol.**
- **Inner Detector {D43m x L(5x50m)} x 2**
- **PMT ~100,000 (20inch)**
- **(Photo-coverage 20%)**

Hyper-K continued

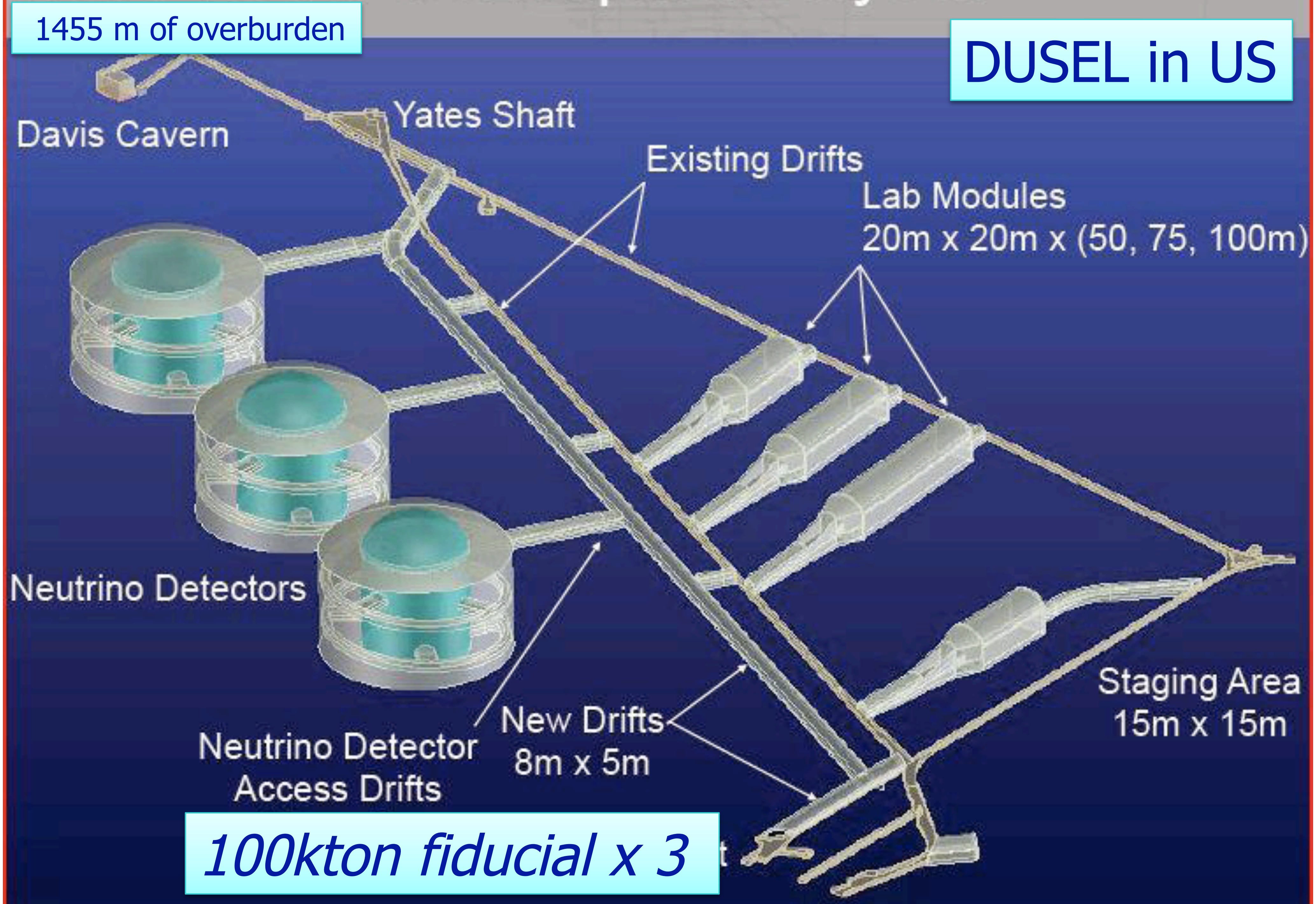
- Energy coverage good for

$$\sim 200\text{MeV/c} < p_\mu <\sim 5\text{GeV/c}$$

$$\text{a few MeV/c} < p_e < 100\text{GeV/c}$$

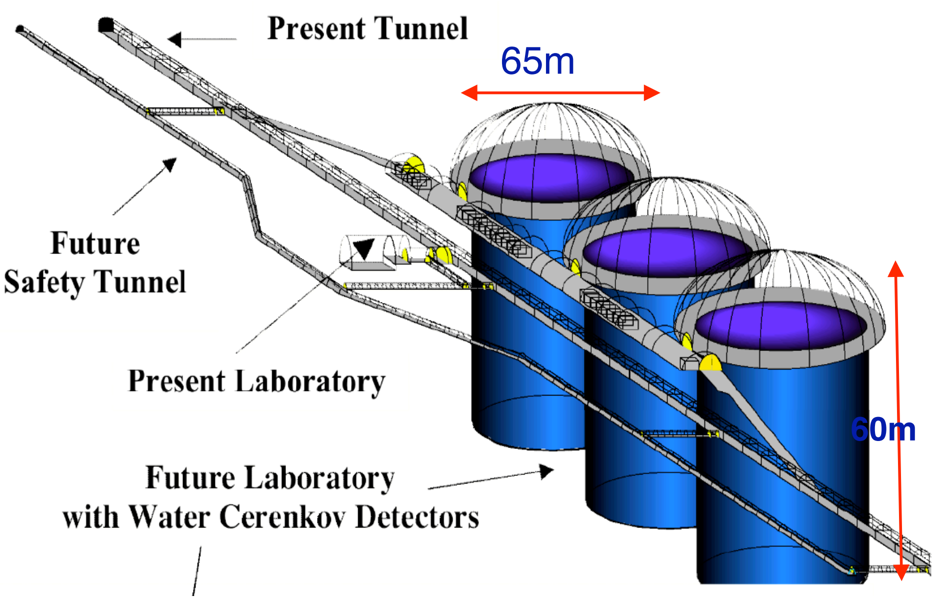
- 2.5 m veto (outer) layer and
  2 m (from PMT surface) fiducial volume cut
  (equivalent to ~10 interaction length)
  reject fast neutrons from rocks to
  a negligible level.

4850 Level Conceptual Layout



MEMPHYS : MEgaton Mass PHYSics
a brief reminder

- water Cherenkov ("cheap and stable")
- total fiducial mass: 440 kt
- 3 cylindrical modules 65 x 65 m
  - size limited by light attenuation length (λ~80m) and pressure on PMTs
  - readout : ~3 x 81k 12" PMTs, 30% geom. cover
  - PMT R&D + detailed study on excavation @Fréjus existing & ongoing



4800m water equivalent

physics goals :

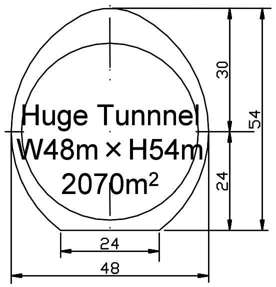
- proton decay searches
- superNovae core collapse and diffuse neutrinos
- precision measurement of neutrino oscillations with beams and solar neutrinos

Large Cavern Engineering

-Site specific-

FEM analysis of cavern displacement and stability

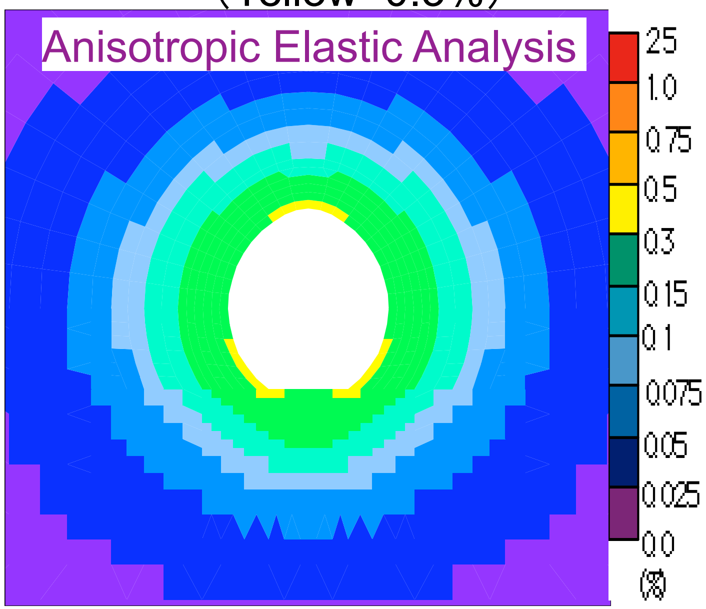
Hyper-K site



Crack-tensor analysis

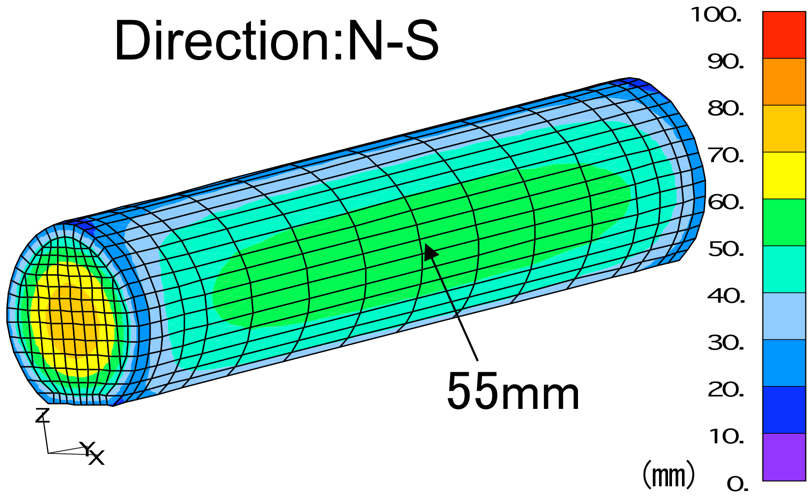
- Anisotropic Young's Modulus considering joint distributions and Rock properties
- In-situ stress; isotropic (overburden=500m)
- cavern direction; North-South

Maximum shear strain (central section)
（Yellow=0.3%）



Share stran＞0.3% in 2.5m

Displacement of cavern wall
（Red~100mm）



55mm displacement at central section

N-S cavern direction is better (due to E-W joint directions)
Feasibility of the cavern with our best knowledge of the site

Cavern R&D issues

- Further Site evaluation
  - Global geological mapping
    - Rock composition, position of faults
  - In situ rock mass properties
    - 3D Initial stress, Modulus of deformability, Young's Modulus

- Cavern's location, orientation, size, shape
  - Baseline design; letter box shape with (250m length x 2)
  - Detailed site evaluation is indispensable
  - Exploratory drilling should be done prior to finalizing cavern design

- Excavation method
  - Speedy and cost-effective method
  - Main haulage tunnel
  - Excavated waste rock – disposal place? Reuse them?
  - Environmental assessment
  - Impact on construction schedule

Tank and Water

Liner types

- Self supporting Steel can (PSL)
- Segmented Concrete blocks (Laurenti)
- Self supporting concrete vessel (BNL)
- Slip formed concrete from top or bottom
- No liner (ie water barrier over shotcrete) (LBNL./UCB)
- Pressure balanced wall

R&D issues

- Plastic liner (such as High Density Polyethylene)
  - Long term stability (mechanical strength, no creep?)
  - Interference with PMT support structure
  - Sequence of construction

- PMT support structure

- Water purification system
  - Exploring water quality, amount of available water
  - Minimize system and study attenuation length
  - Investigation of each material's emanation (no effect on water quality?)
  - Super-K water must be continuously purified. Similarly in IMB (plastic) and in SNO (acrylic)

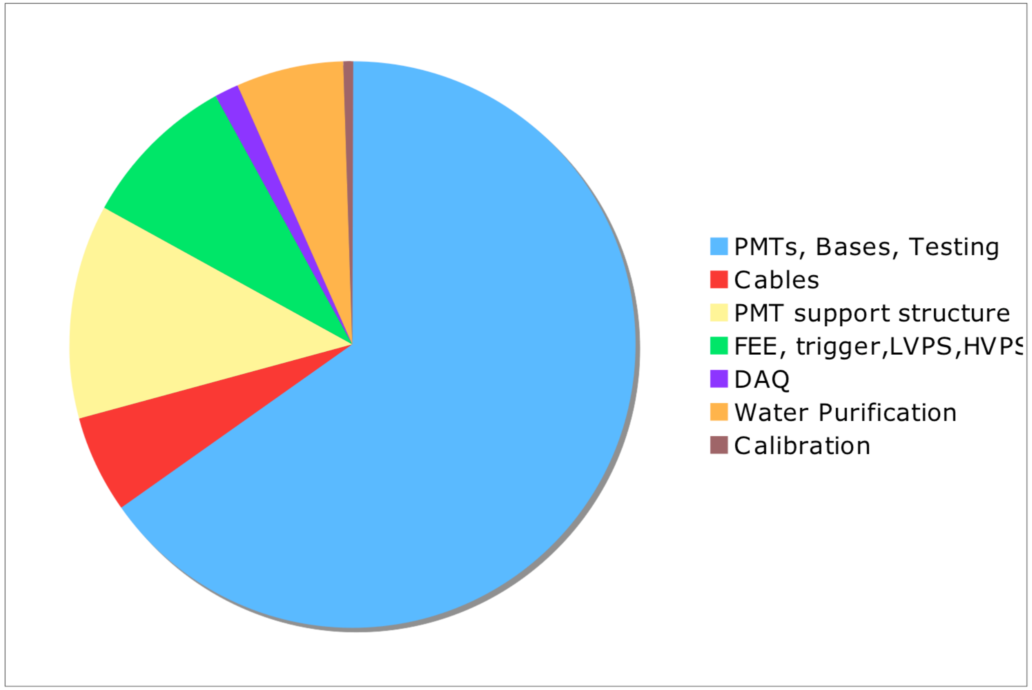
- Possible to remove the segmentation wall (in Hyper-K design) without degrading the performance?

Photosensors and Electronics - Cost drivers and Schedule driver, too -

Cost Drivers

- Study done for NuSAG: 30% cavern, 70% instrumentation
- Instrumentation costs driven my PMT's, mounts, electronics
- Cost analysis for CD-0 is in progress

Instrumentation only
~70% of total cost

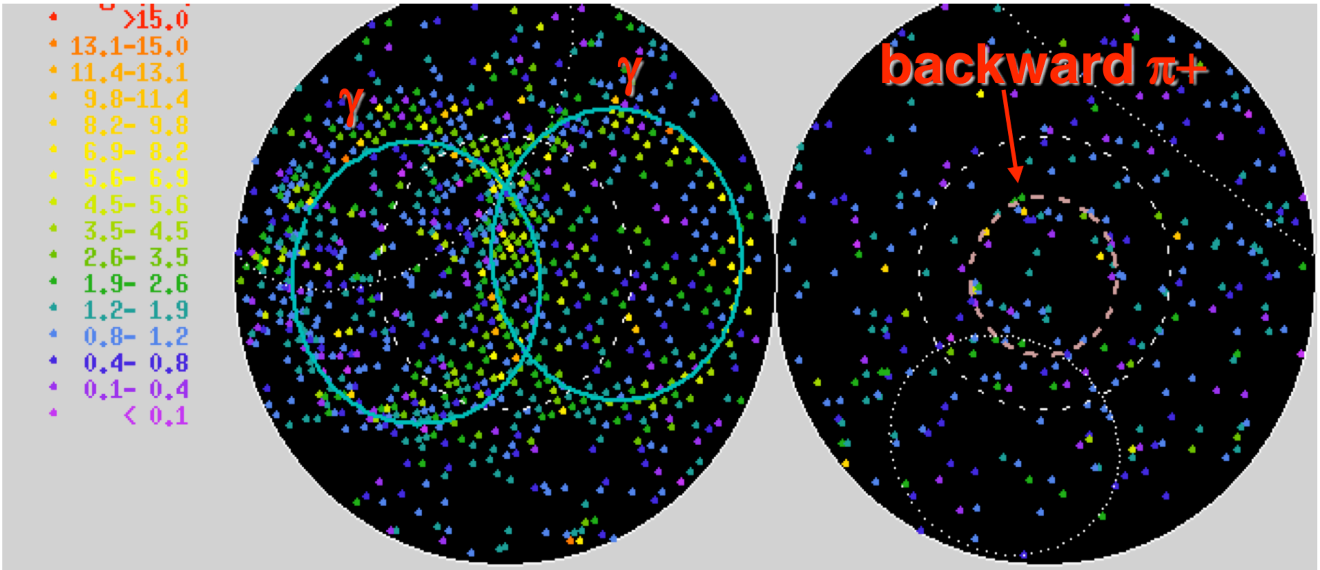


DUSEL study

Photo-sensors

- Cost : Take Hyper-K baseline as an example
  - $350M（20inch PMT+ protective case）＋ $30M（electronics）
    for 100,000 PMTs with the photo cathode coverage of 20%
- Cost reduction
  - fewer sensors
    - Simply reduce the photo cathode coverage from 40% to 20%
    - Higher quantum efficiency
  - Cheaper sensors
- Other issues
  - Size (20inch or smaller ?)
    - Pattern recognition, Logistics
  - Electronics in general
  - Protective case design or improve PMT pressure-resistance

$p \Rightarrow \nu + K^{+},\ K^{+} \rightarrow \pi^{0}\pi^{+}$



SK-I (full density) forward-backward display

Faint π^{+} signature; $Q\pi^{+}$ ~ 60p.e.s even in SK-I (full PMT)

Criteria for SK-I (Phys.Rev.D72:052007,2005)
40 p.e. < Qback < 100 p.e.

40% photocathode coverage

Criteria for SK-II (preliminary)
20 p.e. < Qback < 50 p.e.

20% photocathode coverage

Preliminary result for $p \rightarrow \nu K^+$

SK-I (40%) vs SK-II (20%)

- Prompt γ tagging

	Full PMT density	Half PMT density
• criteria	8 < Number of γHIT < 60	4 < Number of γHIT < 30
• efficiency	7.2%	5.8%
• background	1.7+-0.4 events / Mton-years	1.7+-0.3 events / Mton-years

- backward light ($K^+ \rightarrow \pi^+ \pi^0$)

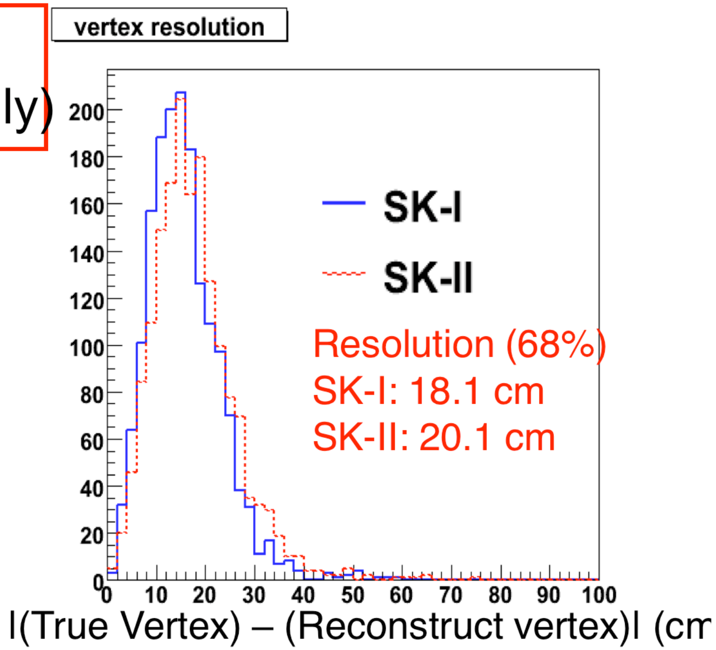
	Full PMT density	Half PMT density
• criteria	40 p.e. < Qback < 100 p.e.	20 p.e. < Qback < 50 p.e.
• efficiency	6.2%	4.8%
• background	4.7+-0.6 events / Mton-years	6.3+-0.7 events / Mton-years

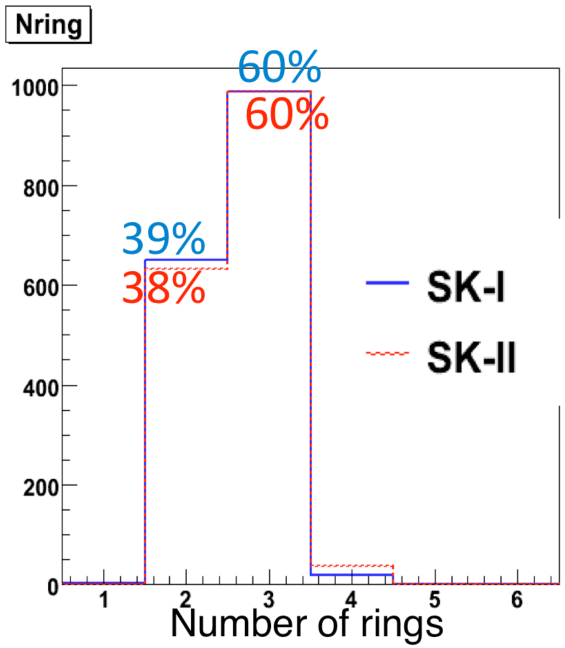
even for half PMT density (SK-II)

- Small BG → νK^+ search is feasible
- ε(SK-II)/ε(SK-I)~80%   not bad !

Reconstruction performance

$p \rightarrow e^+ + \pi^0$ MC
(free proton only)





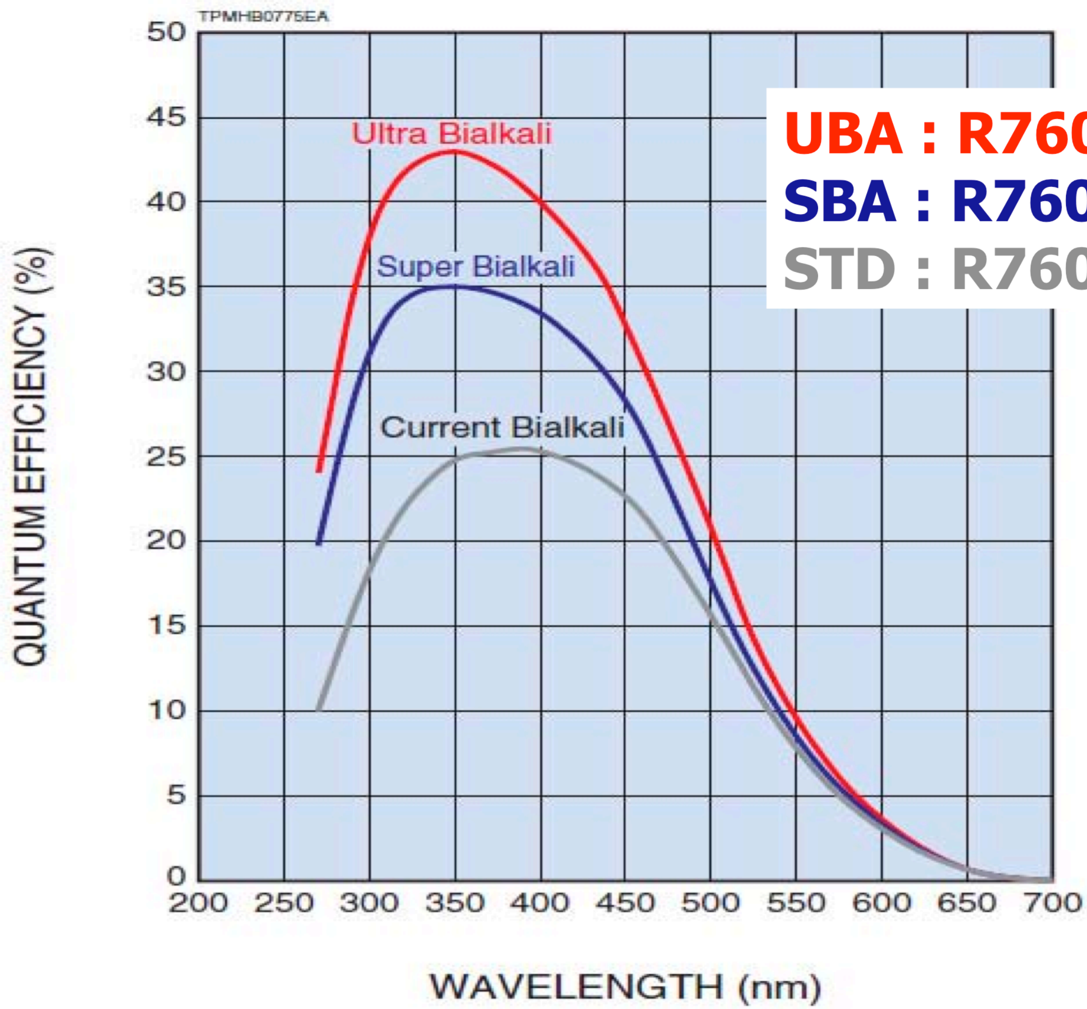
mode	Period (coverage)	Detection efficiency
$p \rightarrow e^+ + \pi^0$	SK-I (40%)	44.6%
	SK-II (19%)	43.5%
$p \rightarrow \mu^+ + \pi^0$	SK-I (40%)	35.5%
	SK-II (19%)	34.7%

Reconstruction performance is not degraded much for $p \rightarrow e^+(\mu^+) + \pi^0$ modes.

Excellent efficiency even with half PMT density

HAMAMATSU

Ultra bialkali (UBA)

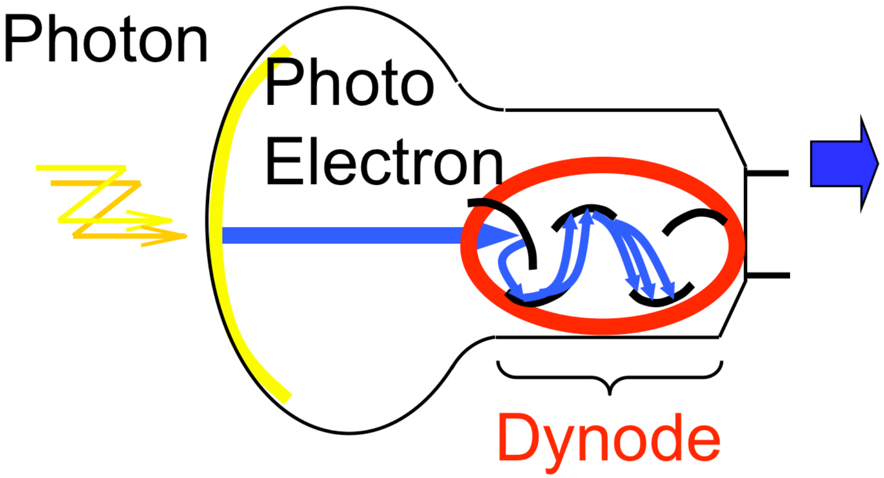


UBA : R7600-200
SBA : R7600-100
STD : R7600

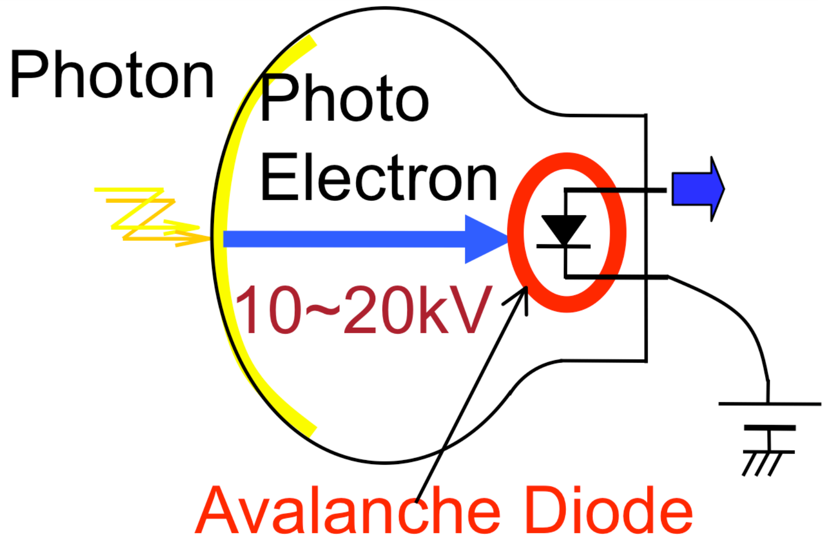
Hamamatsu Photonics

Operation Principle

PMT



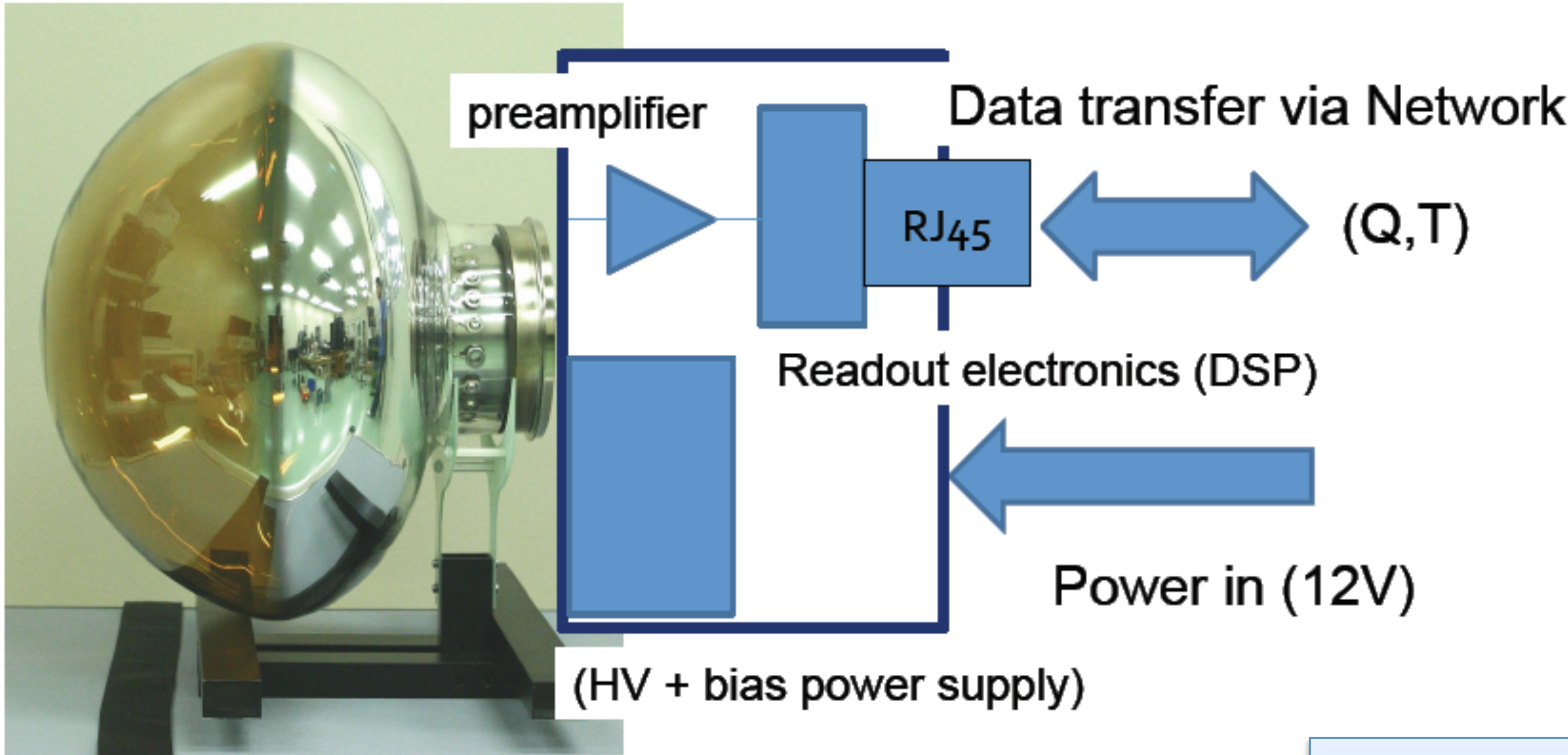
Hybrid (Avalanche) Photo Detector



Fewer components leading to cost reduction (1/2 - 1/4)

Digital HPD

Compact detector with Network + Power supply



Dynamic range : 1000 – 2000 p.e.

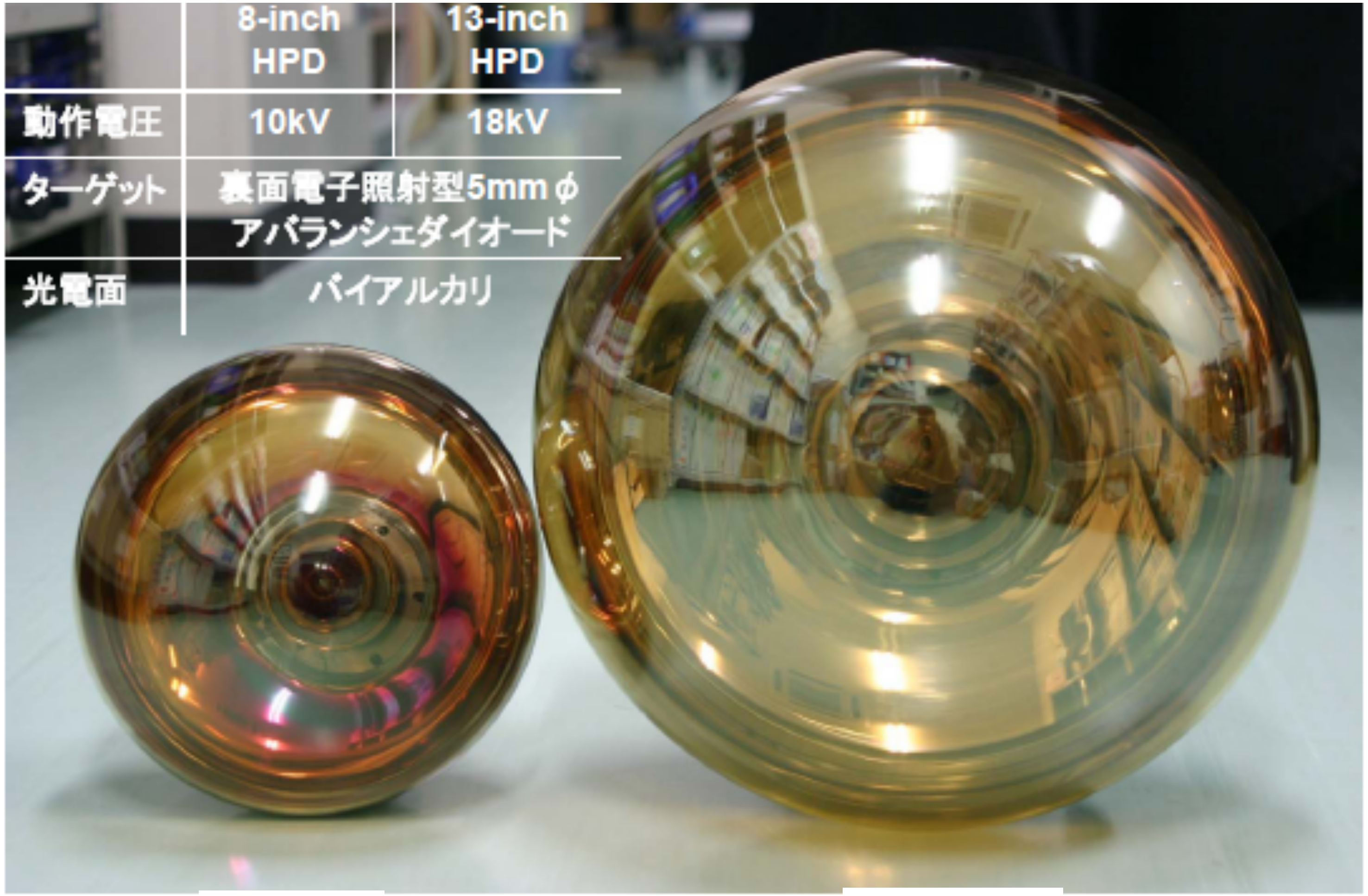
Hamamatsu Photonics / Tokyo /KEK

HPD vs PMT

	13inch HPD	13inch PMT (R8055)	20inch PMT (for SK)
Single Photon Time Resolution	190ps	1400ps	2300ps
Single Photon Energy Resolution	24%	70%	150%
Quantum efficiency	20%	20%	20%
Collection efficiency	97%	70%	70%
Power consumption	<<700mW	~700mW	~700mW
Gain	10^5	10^7	10^7

Hamamatsu/ Tokyo/ KEK

With 5mm diameter back-illuminated avalanche diode

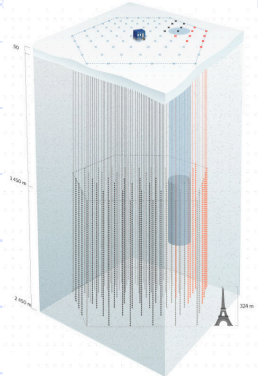


8inch

13inch

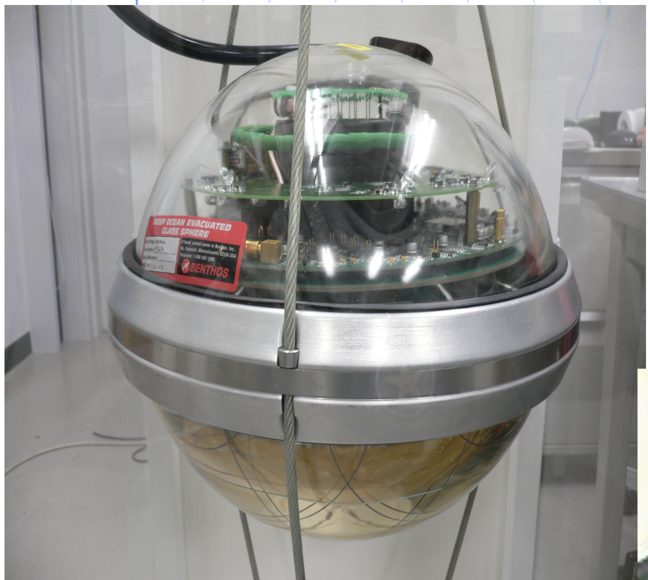
Large format HAPDs will be available from HPK by 2013

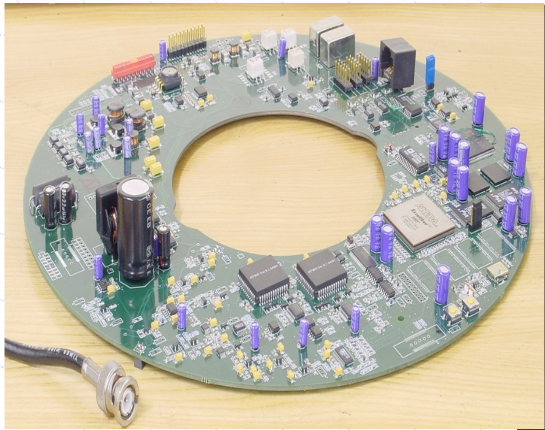
Digital Optical Module

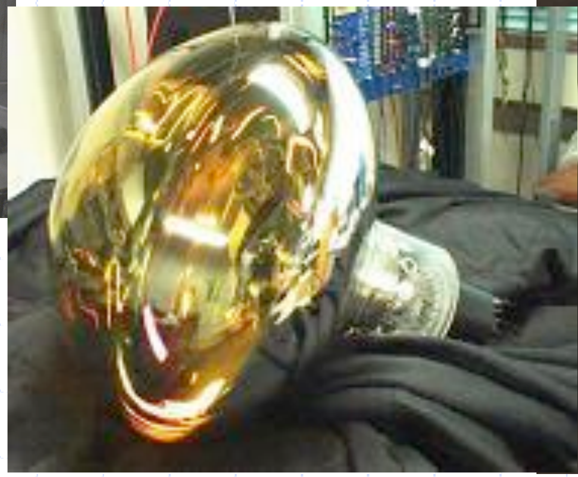


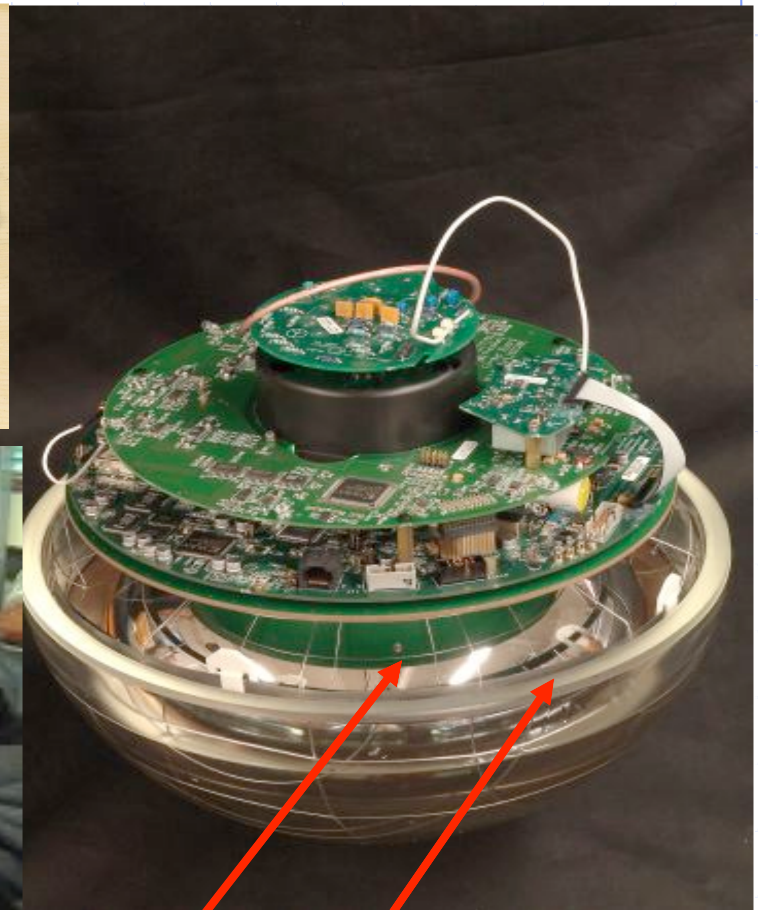
IceCube Digital Optical Module

Waveforms, times digitized in each DOM









- **400 photoelectron/15ns**
- **400ns/6.4ms time range**

25 cm PMT

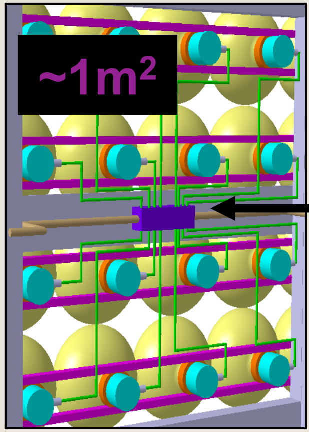
33 cm Benthosphere

European R&D on Readout System

PMm^2 philosophy for large detectors*:

Replace large PMTs (20") by groups of smaller ones (eg. 12"); originally proposed by Photonis Co. at NNN05

Modular construction



x16

"Local"

FE-ASIC | Monitoring | HV

FPGA + μC

Network Controller

Twisted pairs cables for Clock sync. - Digitized Data - Power

"Outside"

Ethernet switches + server

DAQ | GPS receiver

"No possible local coincidence"
(low energy event 10PMs/MeV over 81000 PMs)
⇓
TRIGGER LESS

Synergy with ILC DAQ

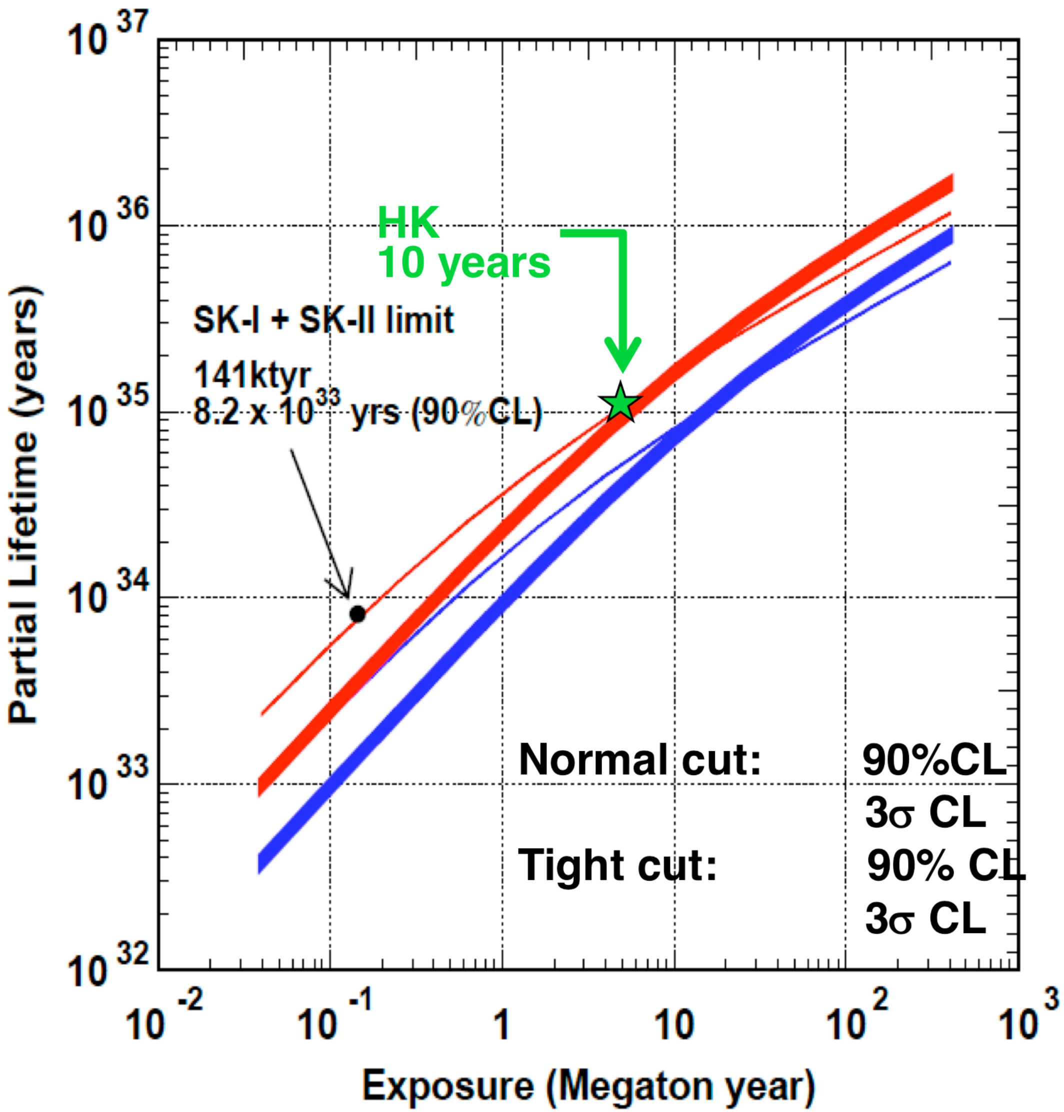
*: MEMPHYS ~ 3 x 81,000 PMTs; LENA & GLACIER ~ 20,000 ÷ 30,000 PMTs

Summary

- Feasible ? : Yes, definitely.
- Cost driver : Photosensors
  - For example, current estimate of the total construction cost of Hyper- K is $700-750M.
  - Cost reduction efforts under way.
- Construction time scale : 7-10 years
- Need intermediate steps towards full scale ? : Do not think so.
  - Caveat : If we employ new photosensors, better experience a reasonably large system before get to full scale.

Physics Reach
of
Hyper Kamiokande

$p \rightarrow e^+\pi^0$ sensitivity for full and half PMT density

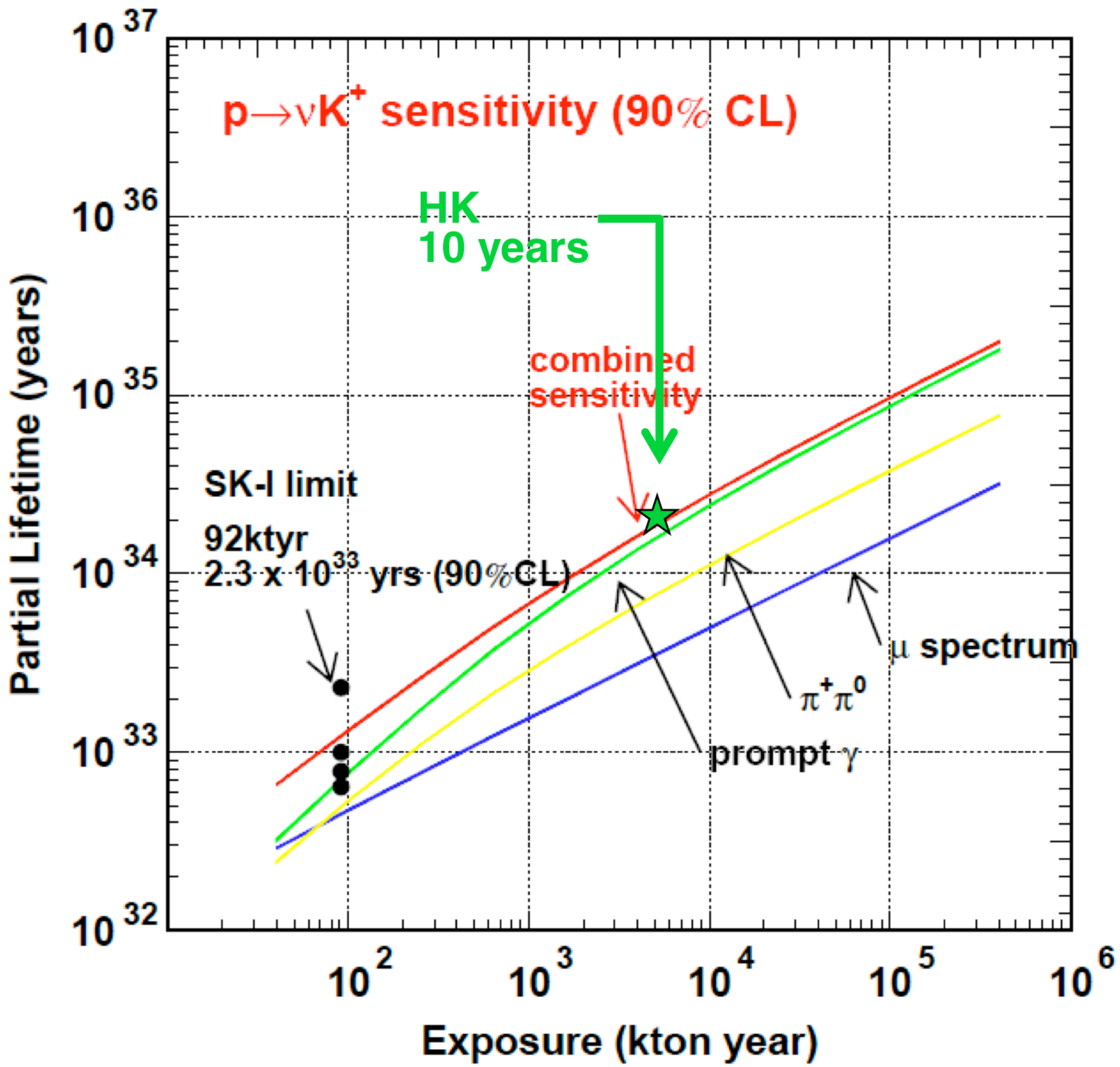


- Ptot < 250 MeV/c (SK cut)
  BG=***2.2*** ev/Mtonyrs, eff.=***44%***
- Ptot < 100 MeV/c (tighter cut)
  BG=***0.15***ev/Mtonyrs, eff.=***17.4%***

SK-I+SK-II
0.14Mtyr
→
8.2×10^{33} yrs @ 90% CL

HK(0.5 Mt):10years
5.0Mtyr
→
$\sim10^{35}$ yrs @ 90% CL

$p \to \nu K^+$ sensitivity (half PMT)



SK-I
0.092Mtyr
→
2.3×10^{33} yrs @ 90CL

HK(0.5 Mt):10years
5Mtyr
→
$\sim 2 \times 10^{34}$ yrs @ 90% CL

Physics goals

- *CPV with accelerator ν (LBLE)*
- proton decay searches
  - ~10^{35} years for $p \rightarrow e^+\pi^0$
- *precise meas. of atmospheric ν*
  - δ, θ_{13}, mass hierarchy (if $\sin^2\theta_{13}$ >~0.01)
  - θ_{23} octant
- *supernova ν*
  - mechanism of stellar collapse
  - mass hierarchy?
- *solar ν*
  - day-night flux (matter effect)
  - Hep ν

JPARC upgraded 1.66MW beam + 540kton Hyper-K (10years)