Development of Hybrid Photo-Detector for the Hyper-Kamiokande Project

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For Hyper-Kamiokande working group

2013. 2.14 @VCI

ICRR, Univ. of Tokyo., Kyoto Univ. IPMU, Hamamatsu K.K.

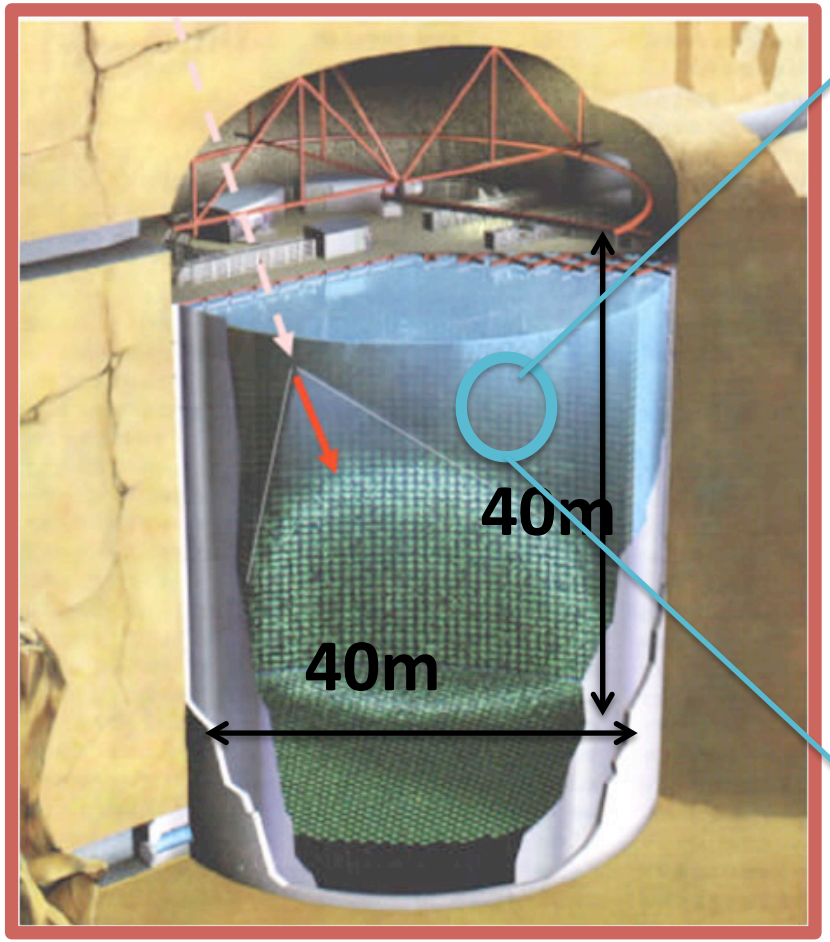
Outline

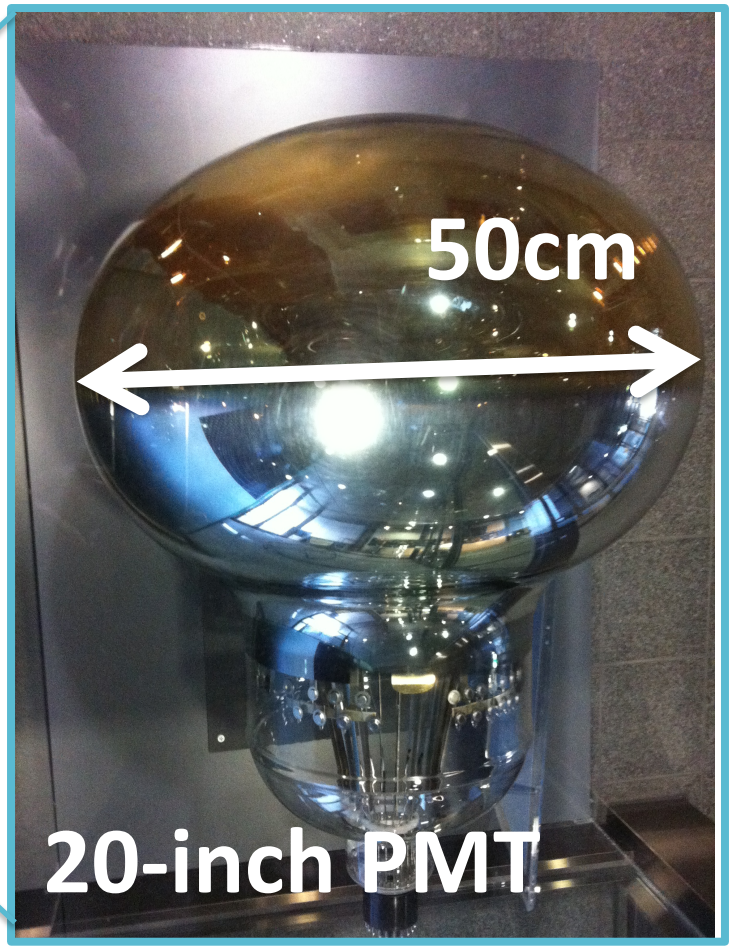
- Hyper-Kamiokande Project (HK)
- Hybrid Photo-Detector (HPD)
  - Development of 8-inch HPD
    - Performance evaluation
    - Check for practical use
    - Proof-test plan in 200t water tank
  - Schedule
- Summary

Introduction

Super-Kamiokande in Kamioka, Japan

for many topics in physic and astronomy



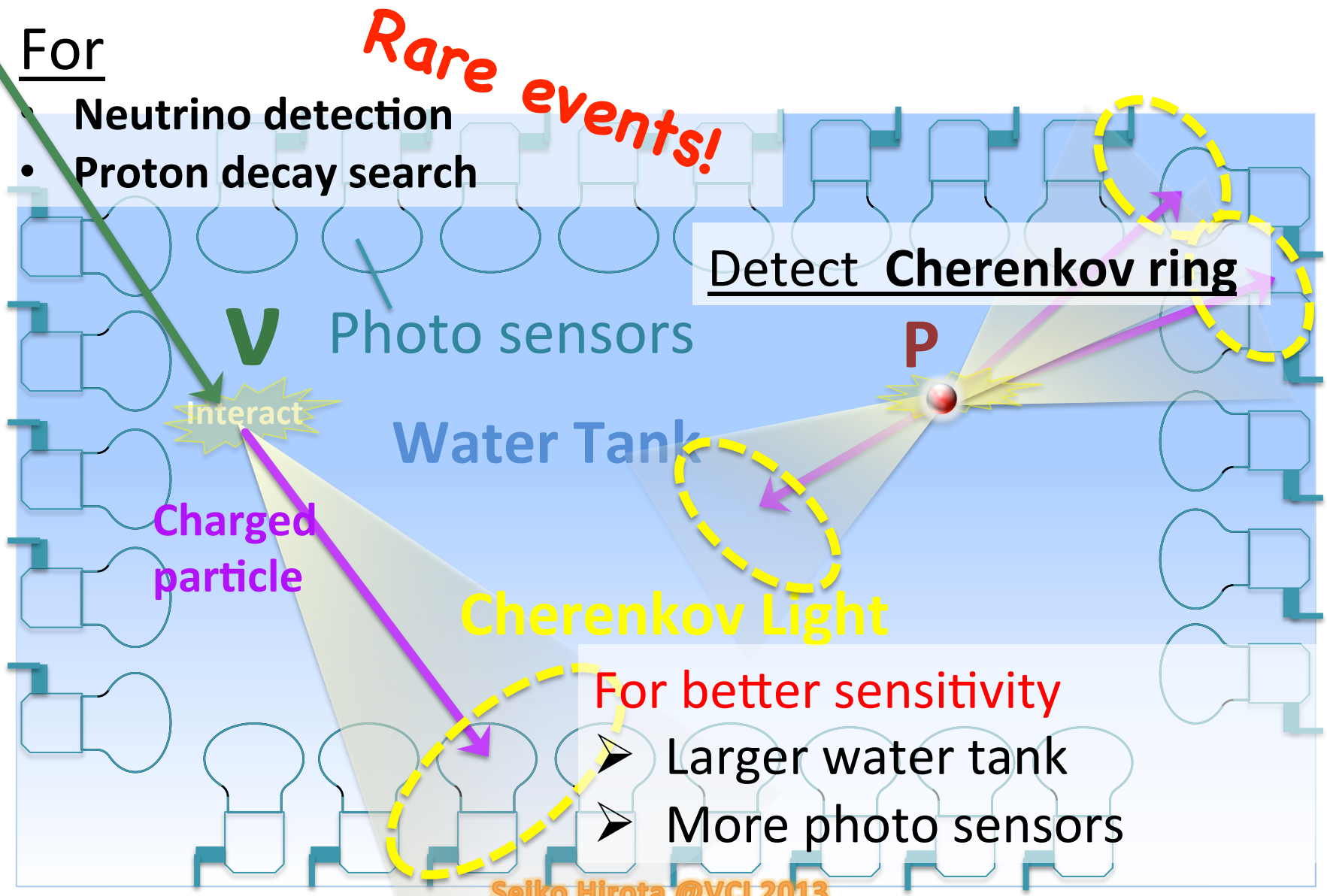


Large water tank! **Many (11129) PMTs!**

Large Water Cherenkov Detector

For

- **Neutrino detection**
- **Proton decay search**

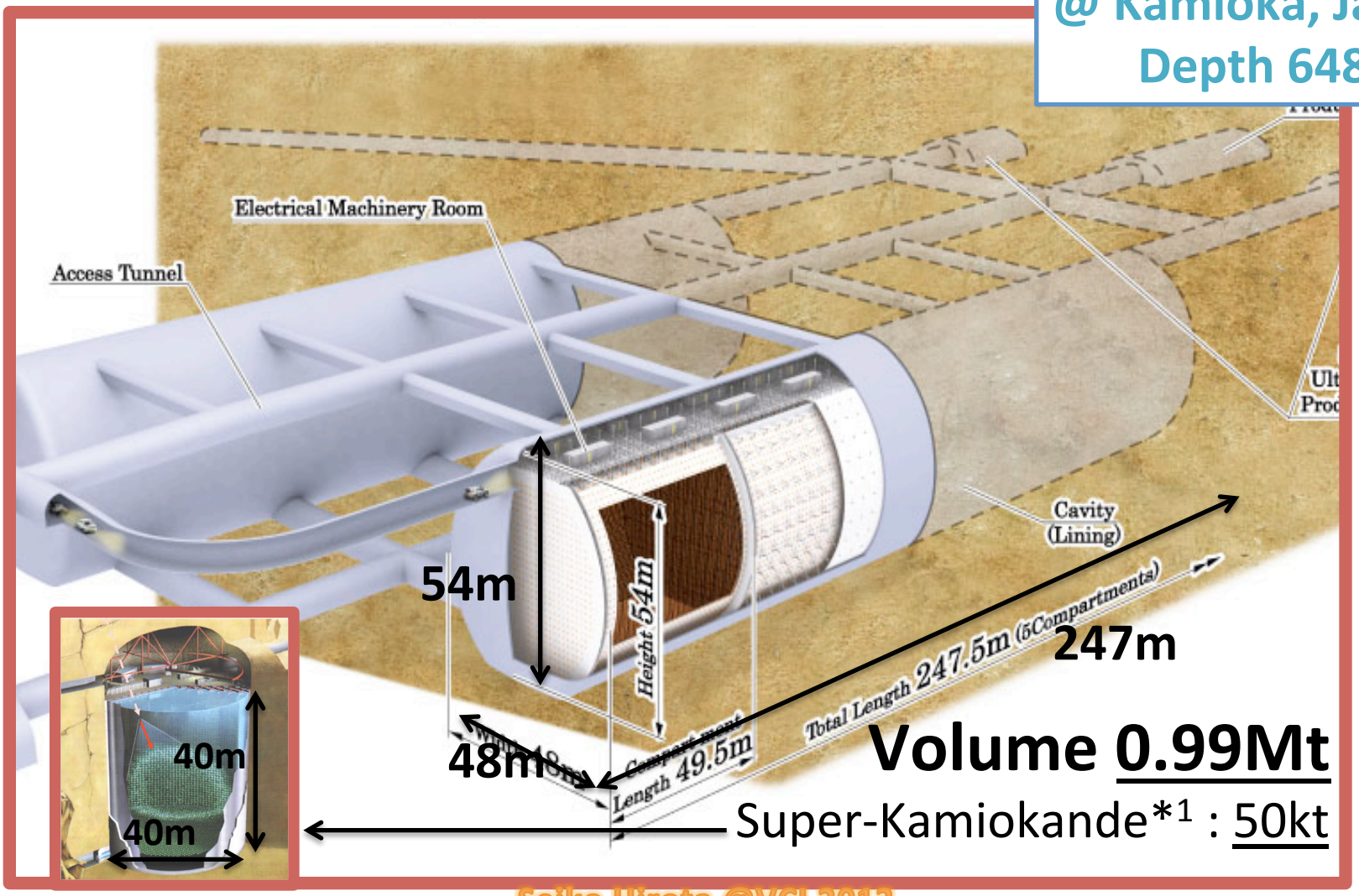


Hyper-Kamiokande Project

HK Base Line Design

Next generation under ground water Cherenkov Detector!

@ Kamioka, Japan
Depth 648 m



Volume 0.99Mt

Super-Kamiokande*1 : 50kt

Hyper-Kamiokande Project

HK Base Line Design

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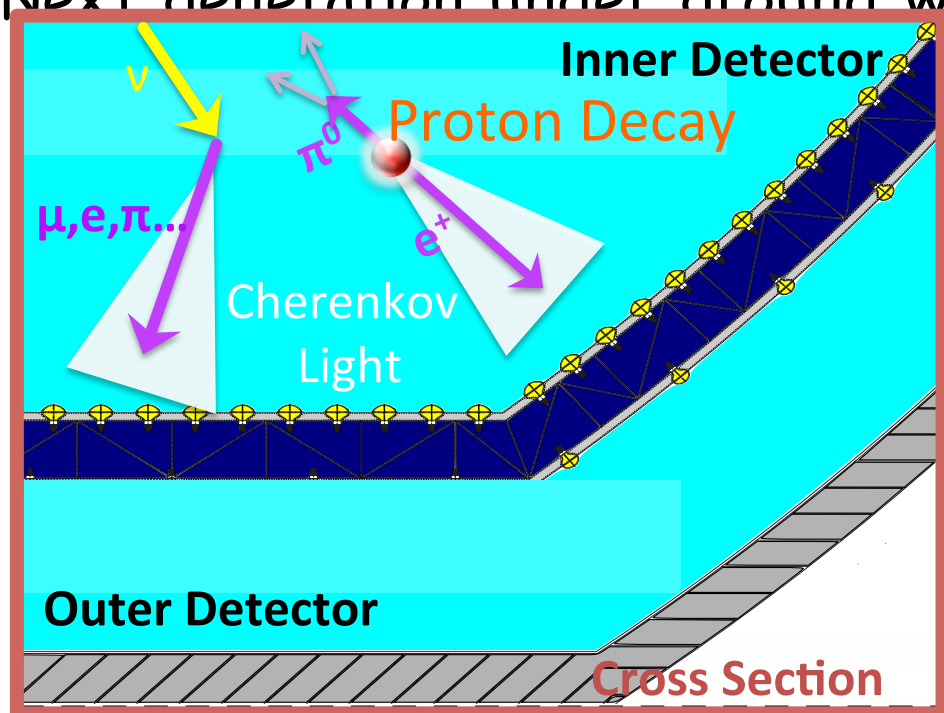

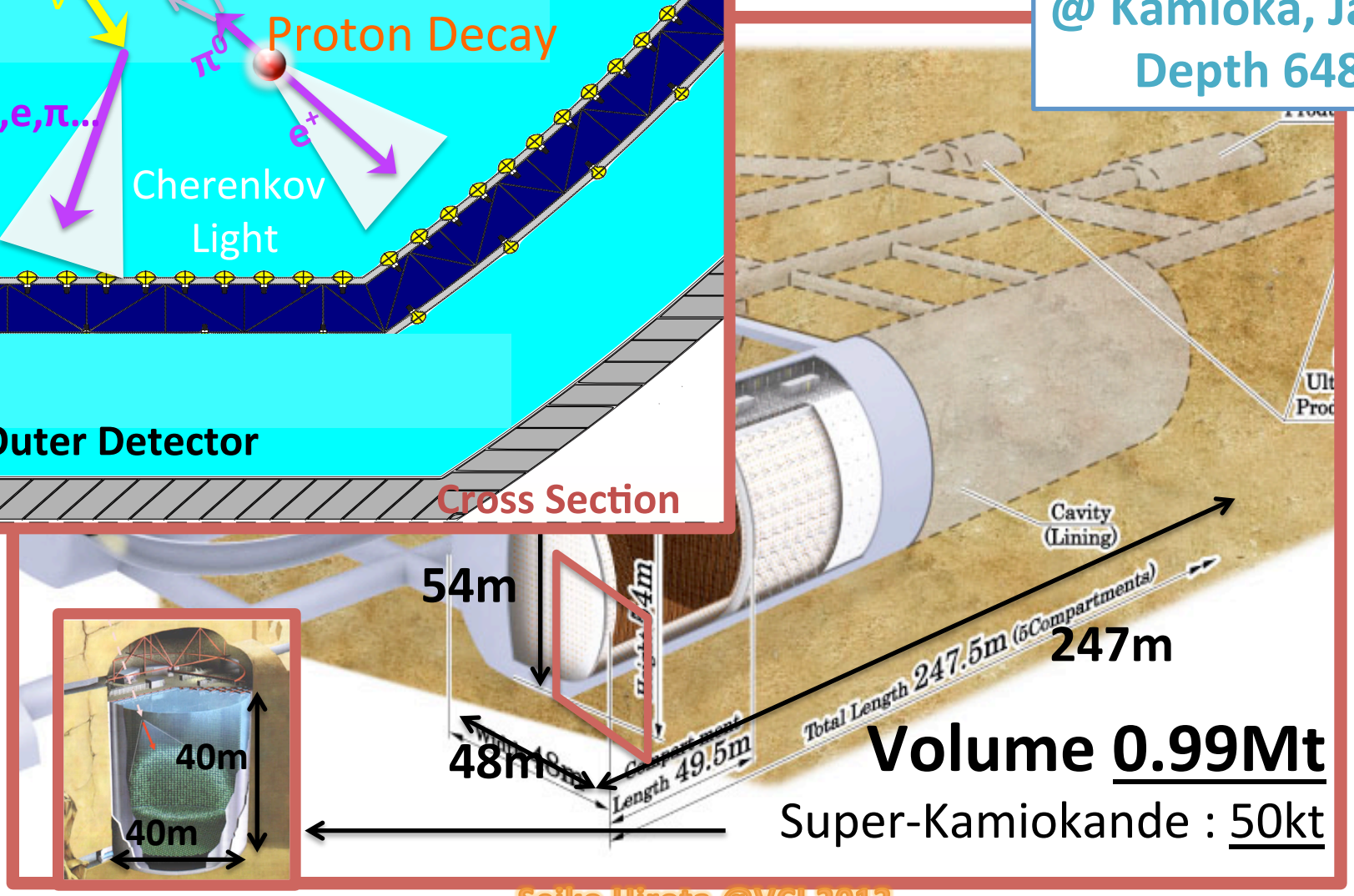

Hyper-Kamiokande Project

HK Base Line Design

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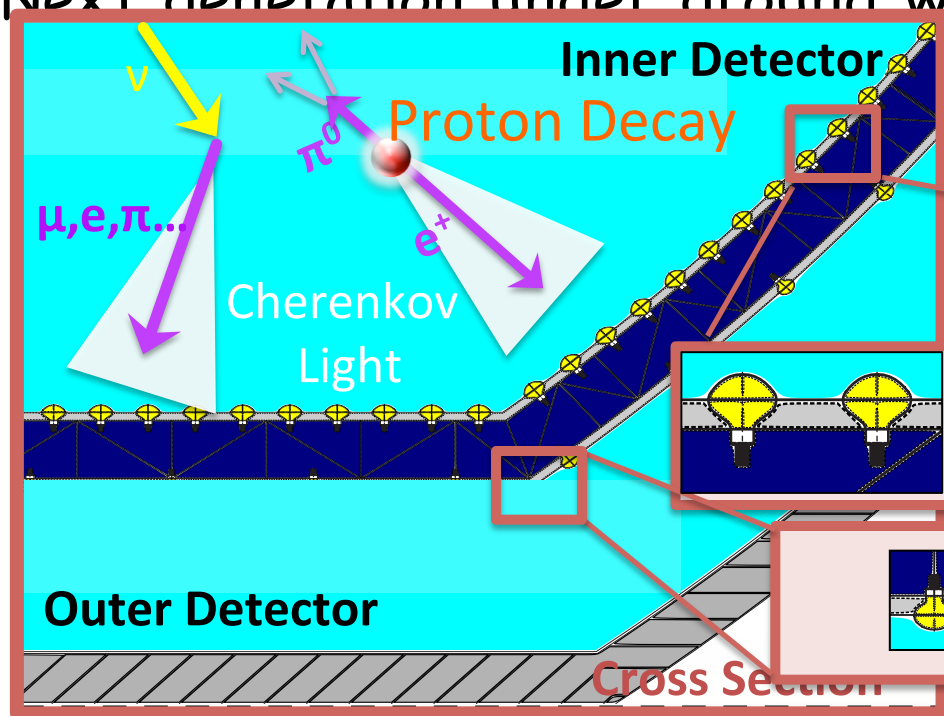
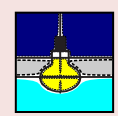


@ Kamioka, Japan
Depth 648 m

MANY photo-sensors!!

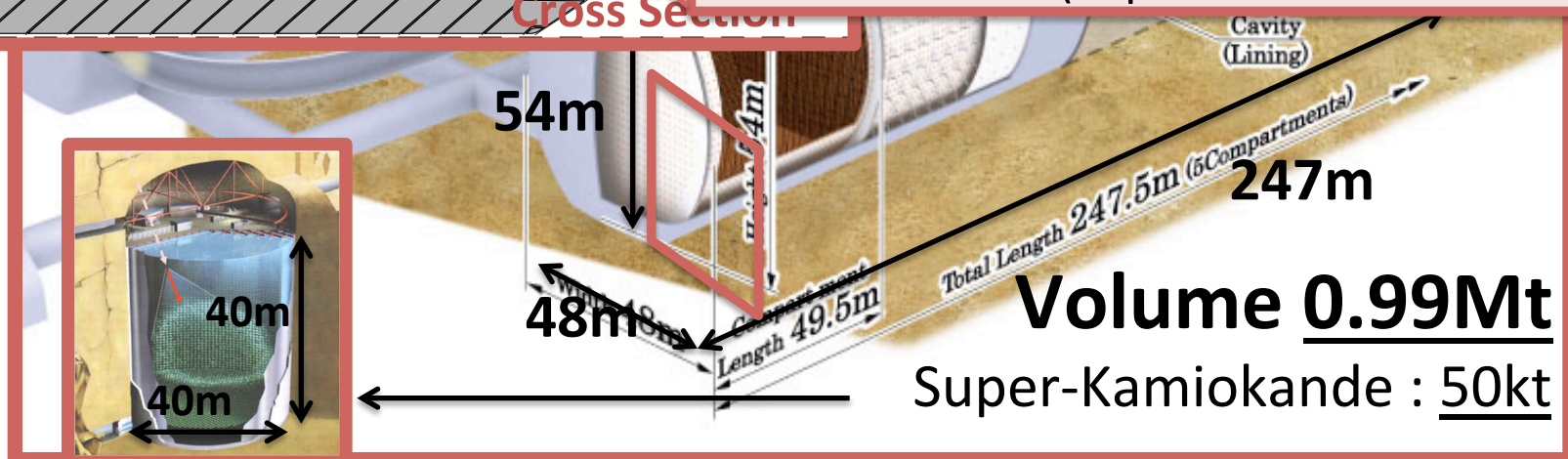
20-inch PMT: **99000**

(Super-Kamiokande : 11129)



8-inch PMT : **25000**

(Super-Kamiokande:1885)



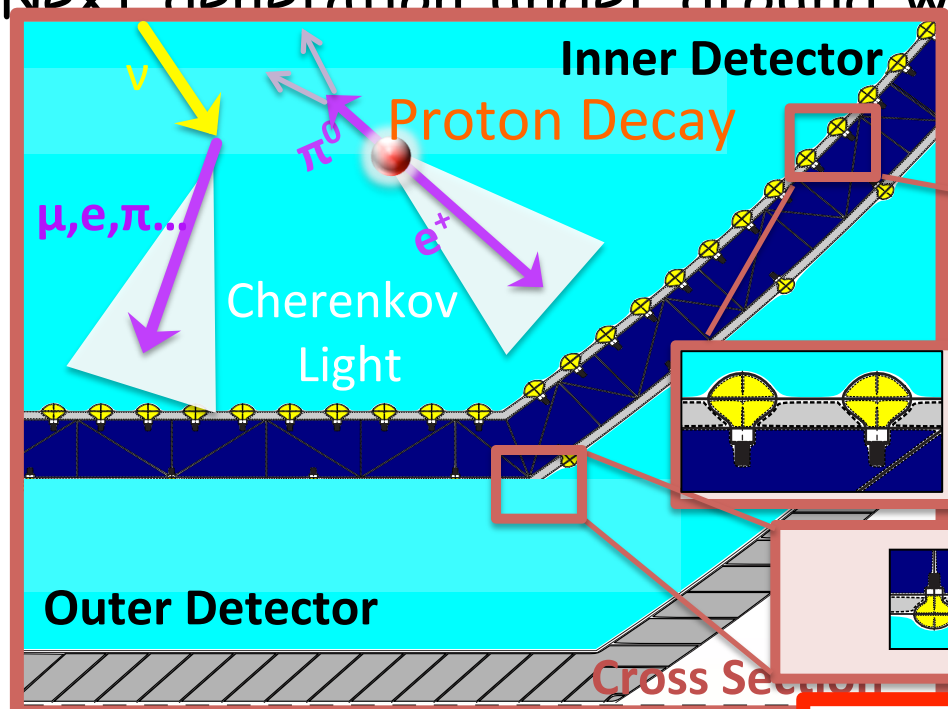
Volume 0.99Mt

Super-Kamiokande : 50kt

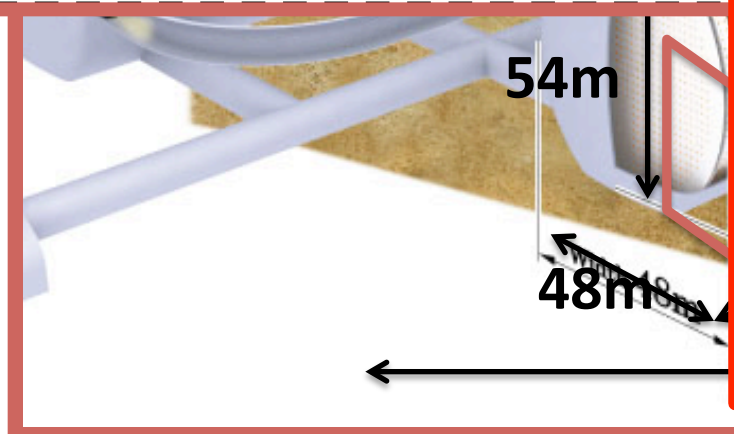
Hyper-Kamiokande Project

HK Base Line Design

Next generation under ground water Cherenkov Detector!



Cross Section



@ Kamioka, Japan
Depth 648 m

MANY photo-sensors!!

20-inch PMT: **99000**
(Super-Kamiokande : 11129)

8-inch PMT : **25000**
(Super-Kamiokande:1885)

Alternative candidate,
Hybrid Photo-Detector (HPD) with

- Higher performance
- Lower mass production cost

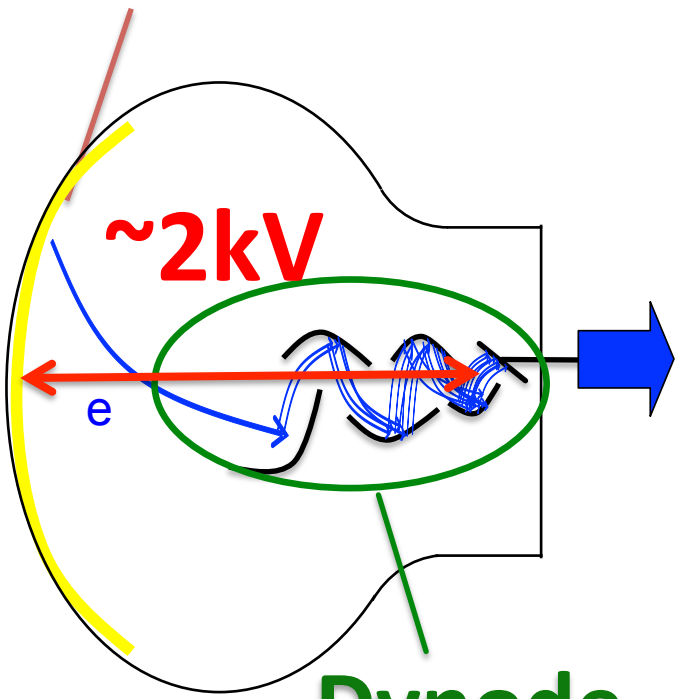
is being developed for HK

Hybrid Photo-Detector

conventional

20-inch PMT

A large photo cathode

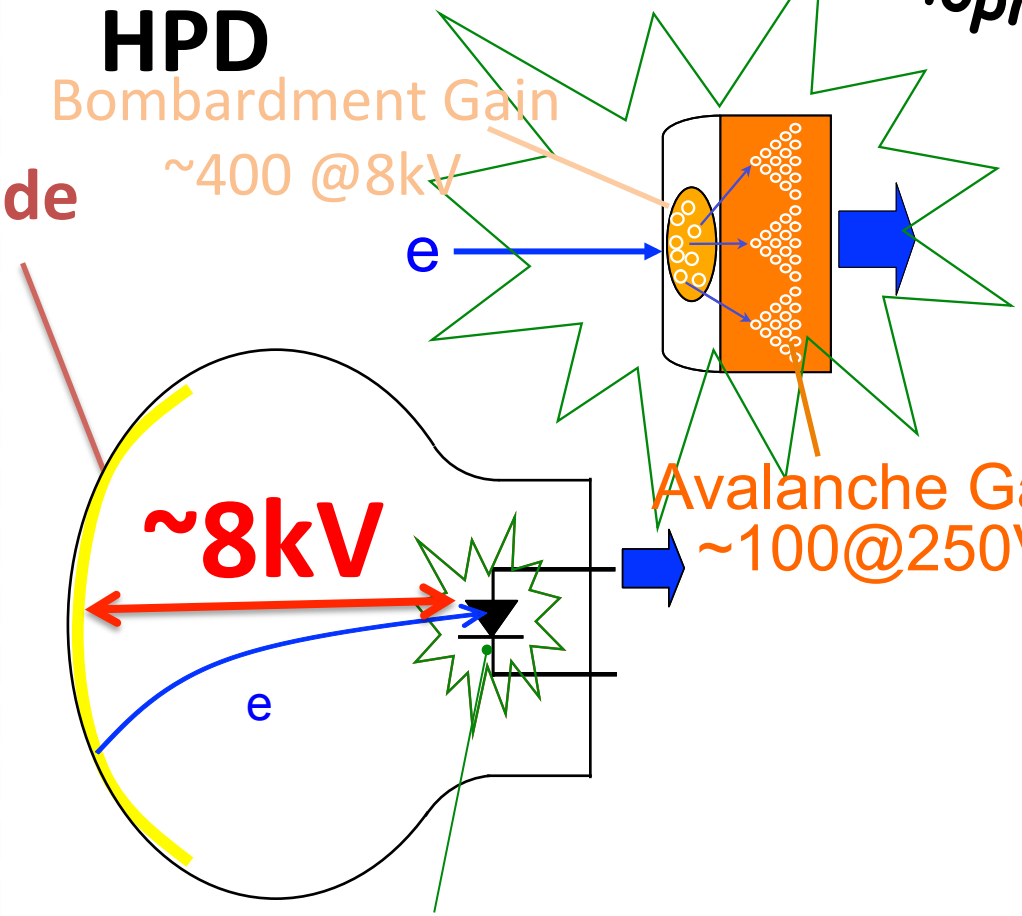


Dynode

HPD

Newly Developing

Bombardment Gain
~400 @8kV



Avalanche Gain
~100@250V

Avalanche Diode (AD)

Gain :	10^6~10^7	10^4~10^5 (~$400_{bombardment}$×100_{AD})

Advantage/Disadvantage of HPD

Advantage ⇒Performance evaluation

- ✓ Large gain on 1st step : **Better photon separation**
- ✓ Faster transition time : **Better timing resolution**
- ✓ Strong electric field : **Better collection efficiency**

Large bombardment gain (8kV)

	HPD (expected)	20-inch PMT
Photon separation (P/V* page13)	~5	1.9
Timing resolution (σ)	~1ns	2.2ns
Collection efficiency	~95%	75%

- ✓ Simple structure : **Low mass production cost!**
- ✓ Axial symmetry : **Uniformity**

AD

Disadvantage ⇒Proof-test

- ✓ **NO experience** to use HPDs in water
- ✓ **NO experience** to run for long time*
- ✓ **Small** gain
- ✓ Concerning about 8kV (2kV in PMTs)

*HK is expected to run for more than a few tens of years

Goal of HPD R&D for HK

Goal

- We want to develop two size of HPD for HK.
  - 20-inch HPD
  - 8-inch HPD

← We started R&D for 8-inch HPDs and prepared prototypes for 200t tank test. **Today's topic.**

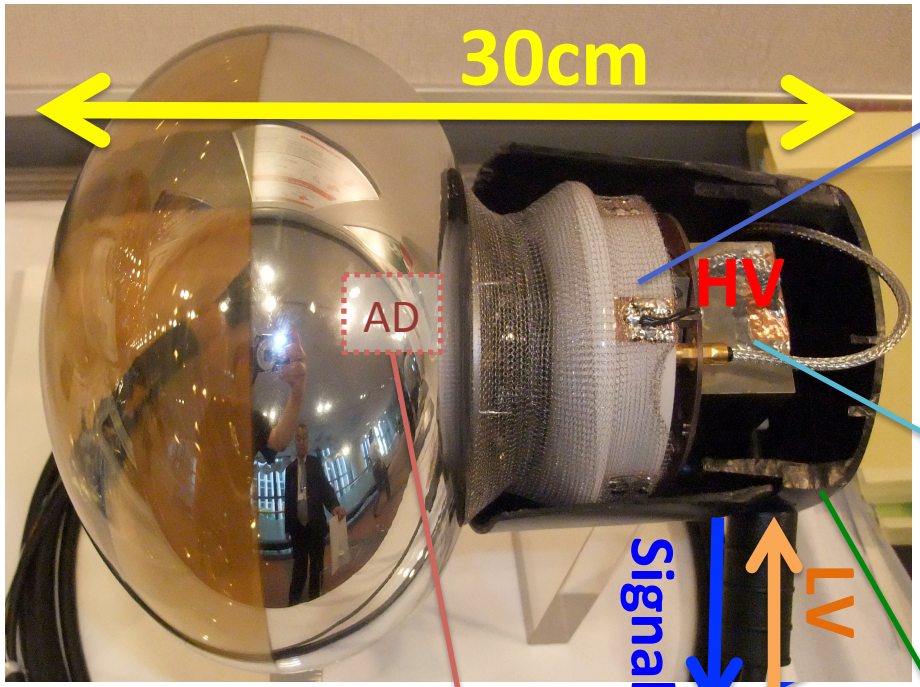
How to overcome disadvantage

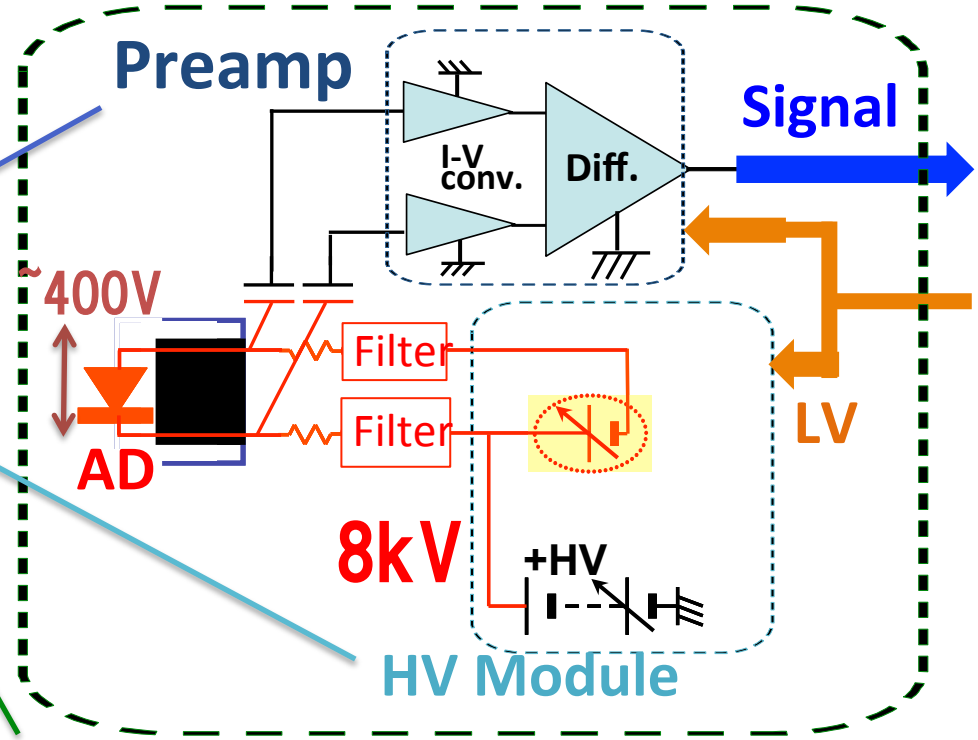
- To confirm feasibility of practical usage as water Cherenkov Detector,
  - Test HPDs in 200t water tank
  - Evaluate actual performance of HPDs compared with PMTs

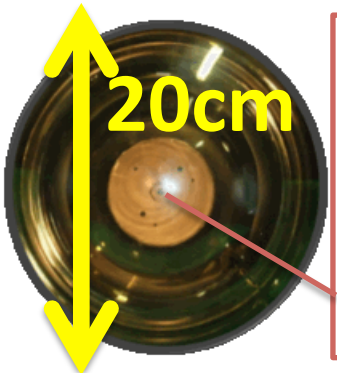
Design of 8-inch HPD module

by Hamamatsu Photonics K.K.

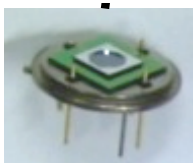
Size for Outer Detector!







AD (5mmϕ)



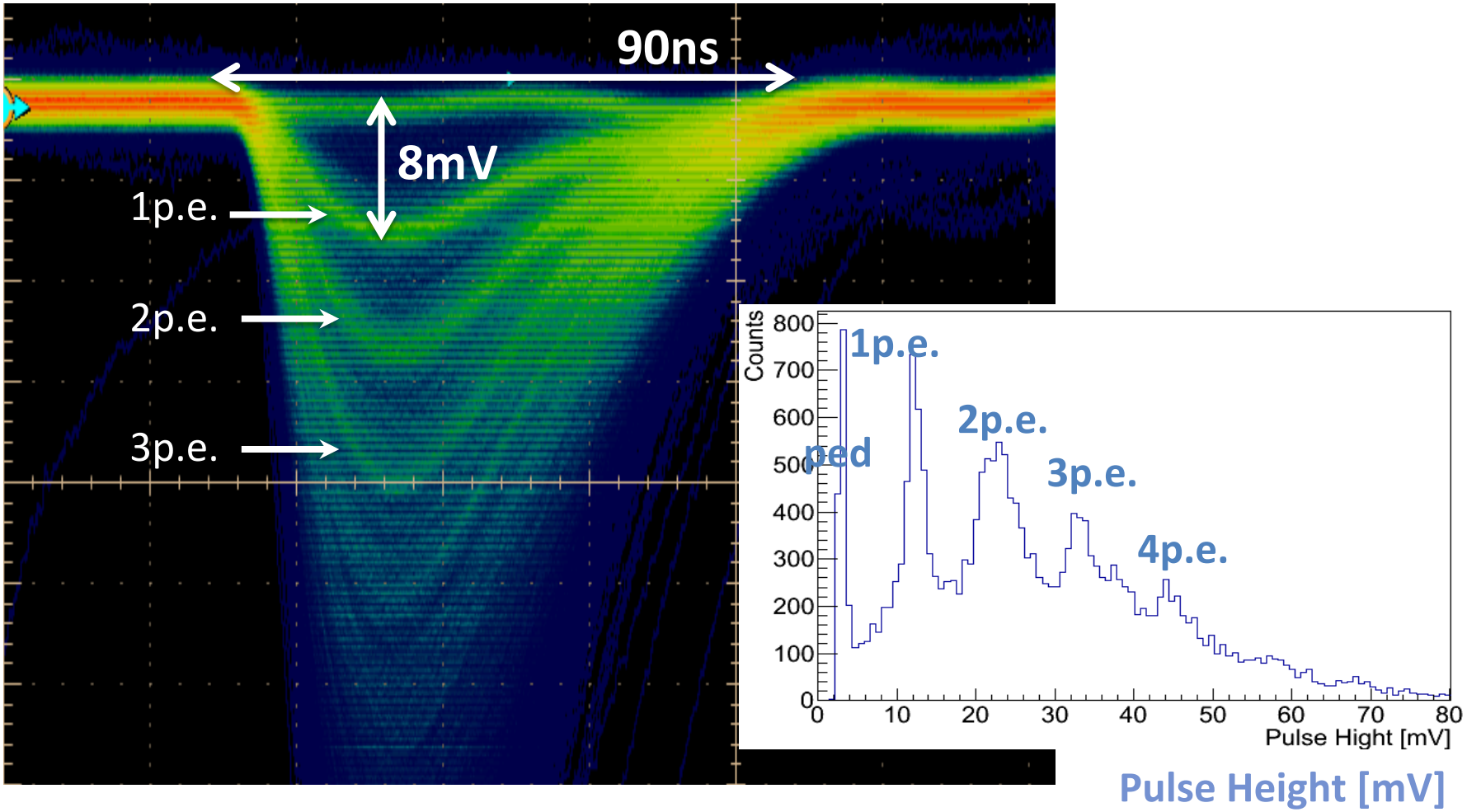
Power LV 10V
Control LV < 4V

Water-proof Housing

→ enable operation of HPDs in water!

HPD Performance

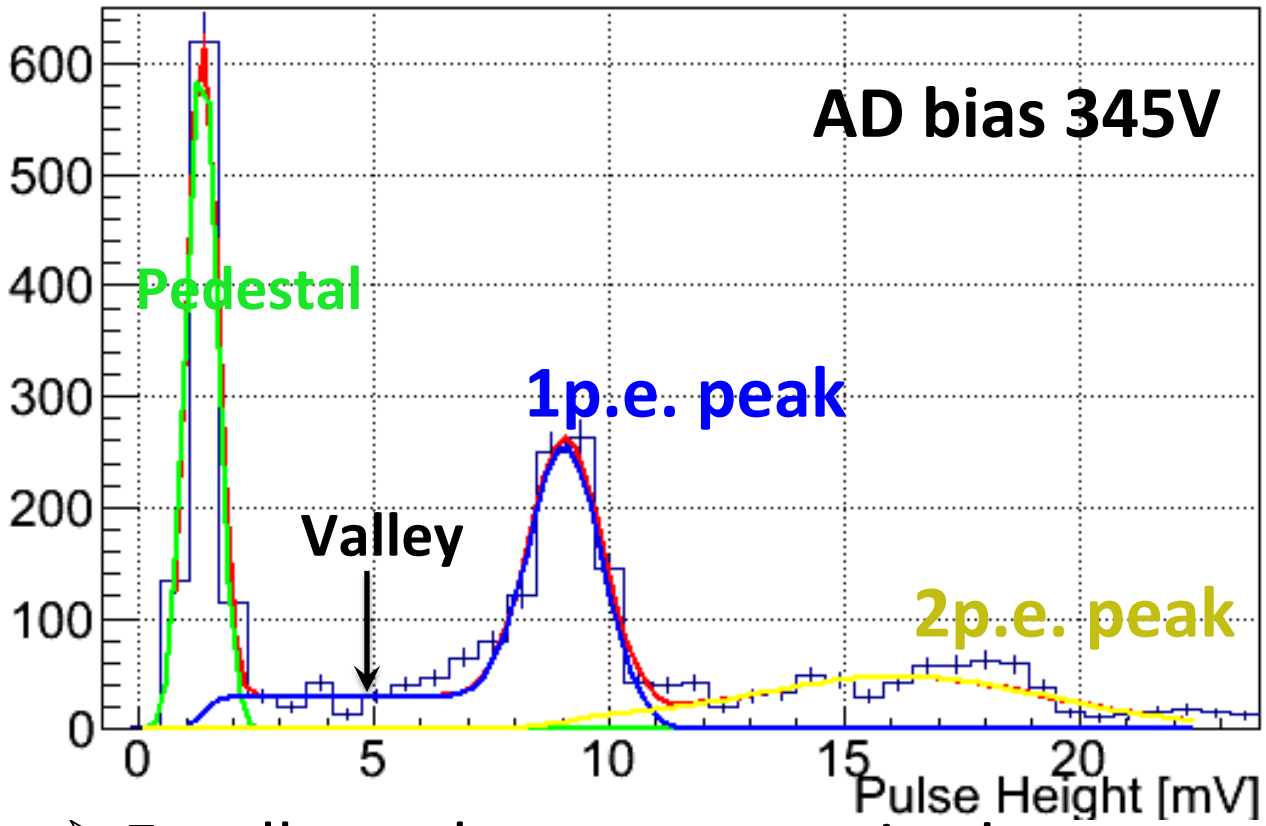
Photon Discrimination



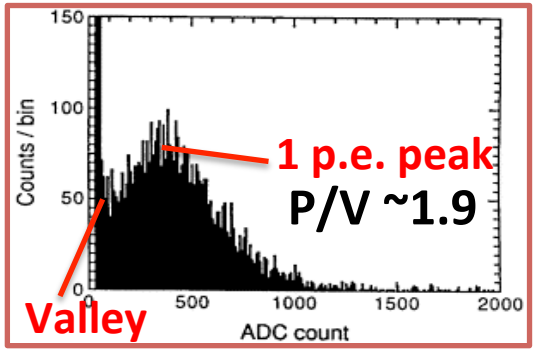
- ***Excellent Photon discrimination!***

Single Photon Separation

1p.e. **Pulse Height** distribution



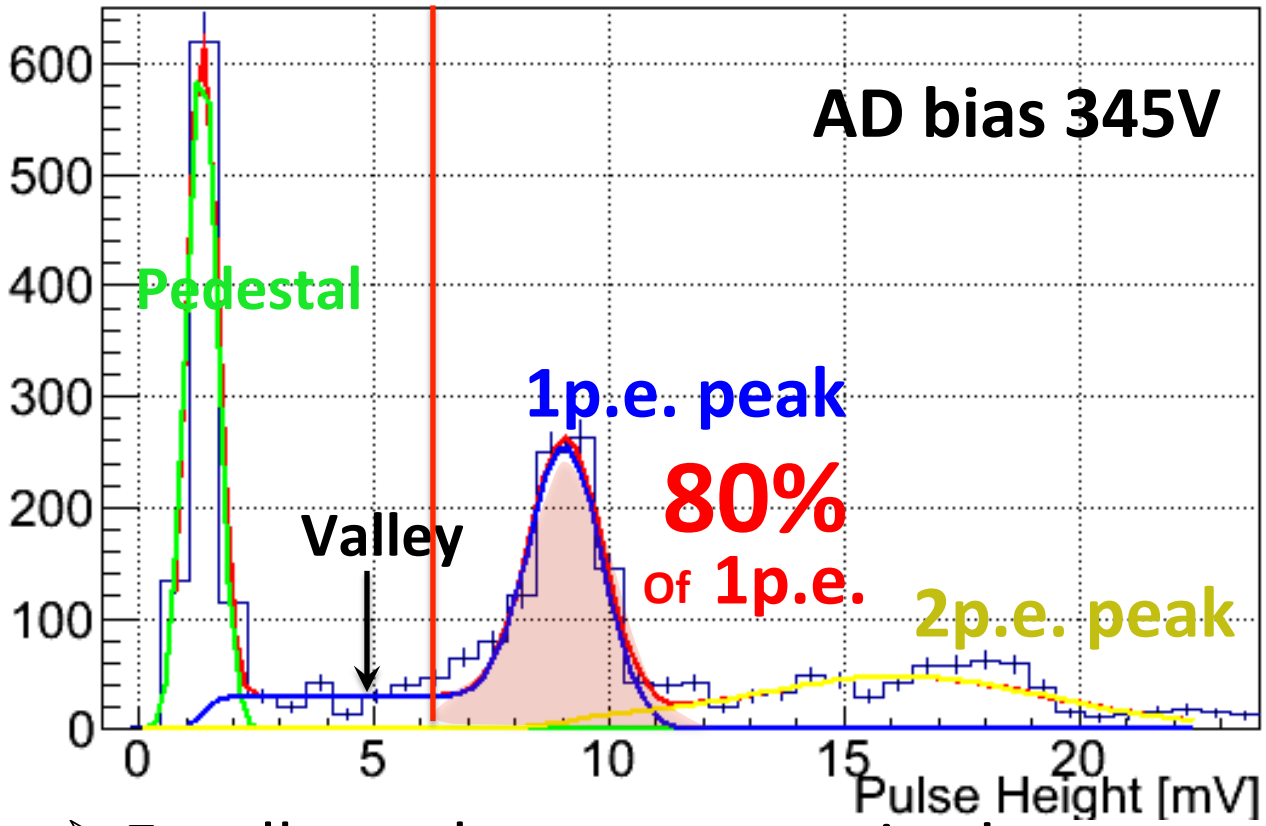
20-inch PMT
1p.e. Charge distribution



- Excellent photon separation!
  Peak to valley ratio (P/V) ~8.9 （ref: 1.9@PMT）
- Better signal efficiency 80~90% (@Thr. in valley region)

Single Photon Separation

1p.e. **Pulse Height** distribution



20-inch PMT
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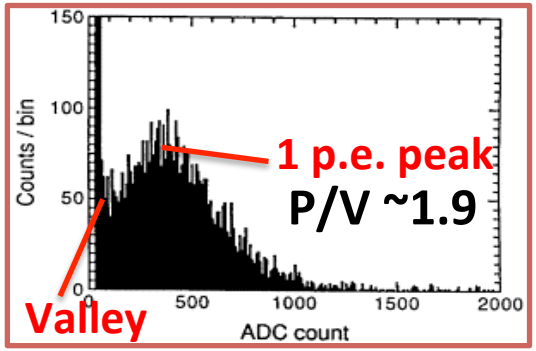

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  Peak to valley ratio (P/V) ~8.9 （ref: 1.9@PMT）
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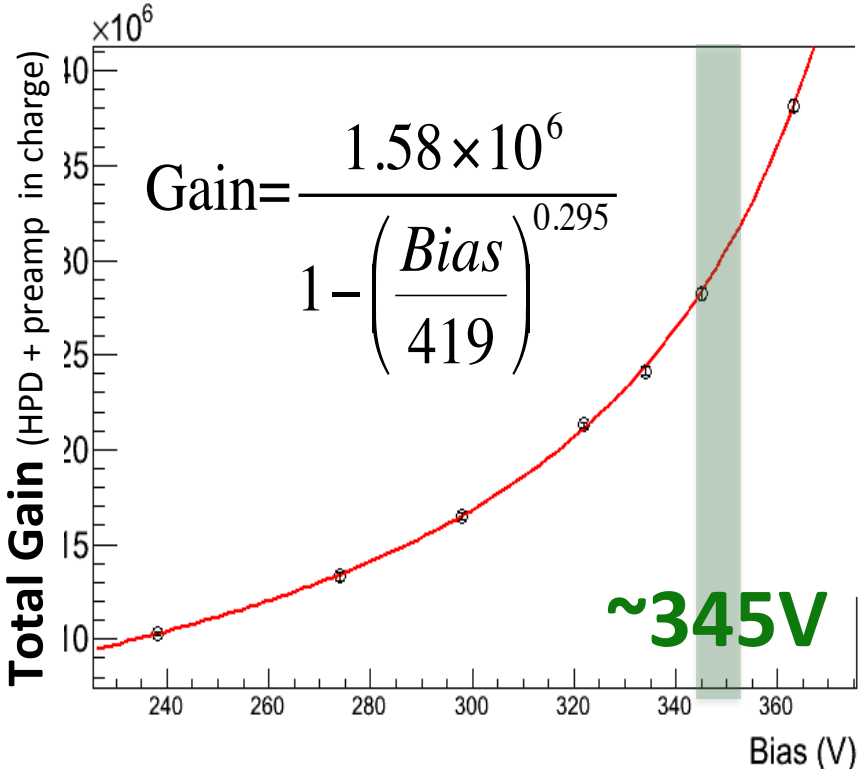
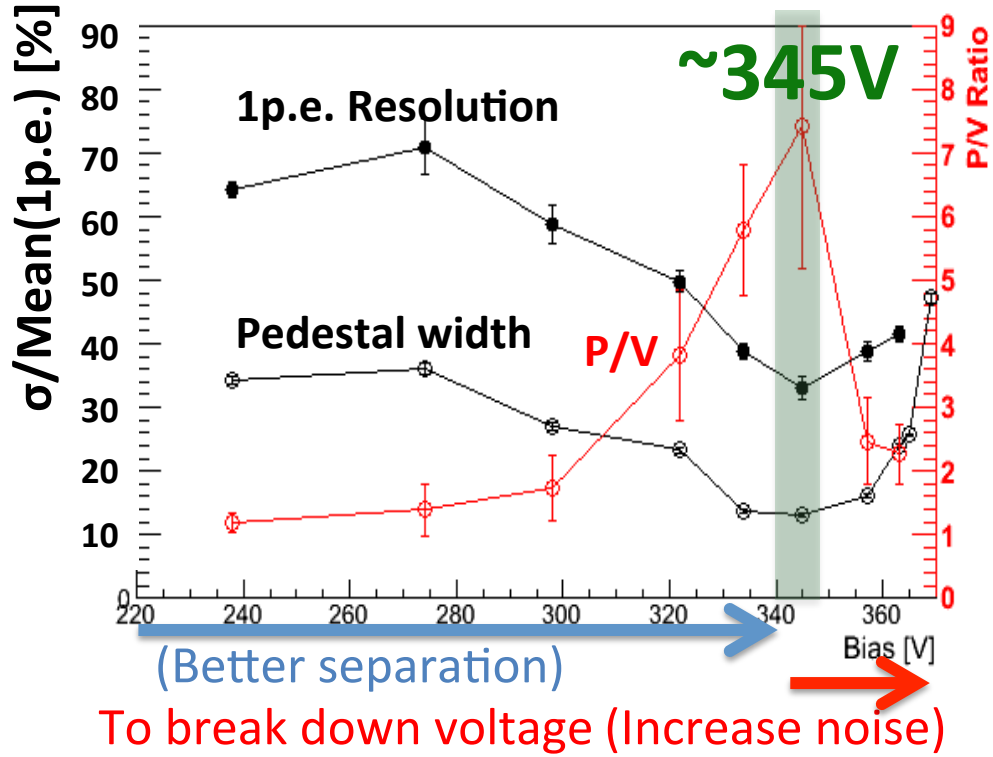
Performance by AD Bias Voltage

w/ 70m cable
@25℃

Gain Curve



Photon Separation (charge distribution)



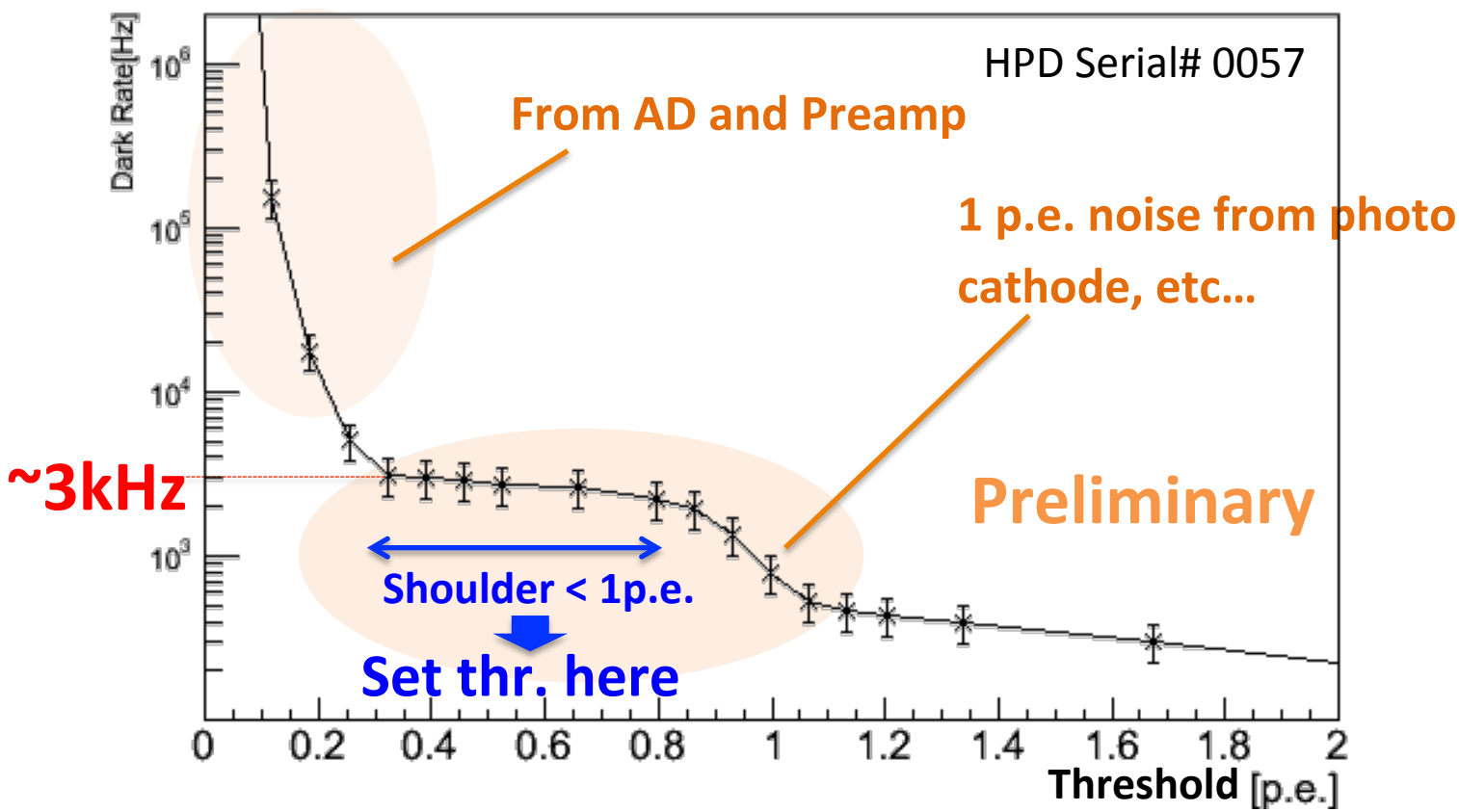
- ✓ Tune AD bias voltage under break down voltage to maximize p.e. resolution

With optimized Bias Voltage….

Gain (HPD + preamp)	**~ 2.8×10^7**
1p.e. resolution	**~35%**
P/V (charge)	**~7**

Dark Hit Rate

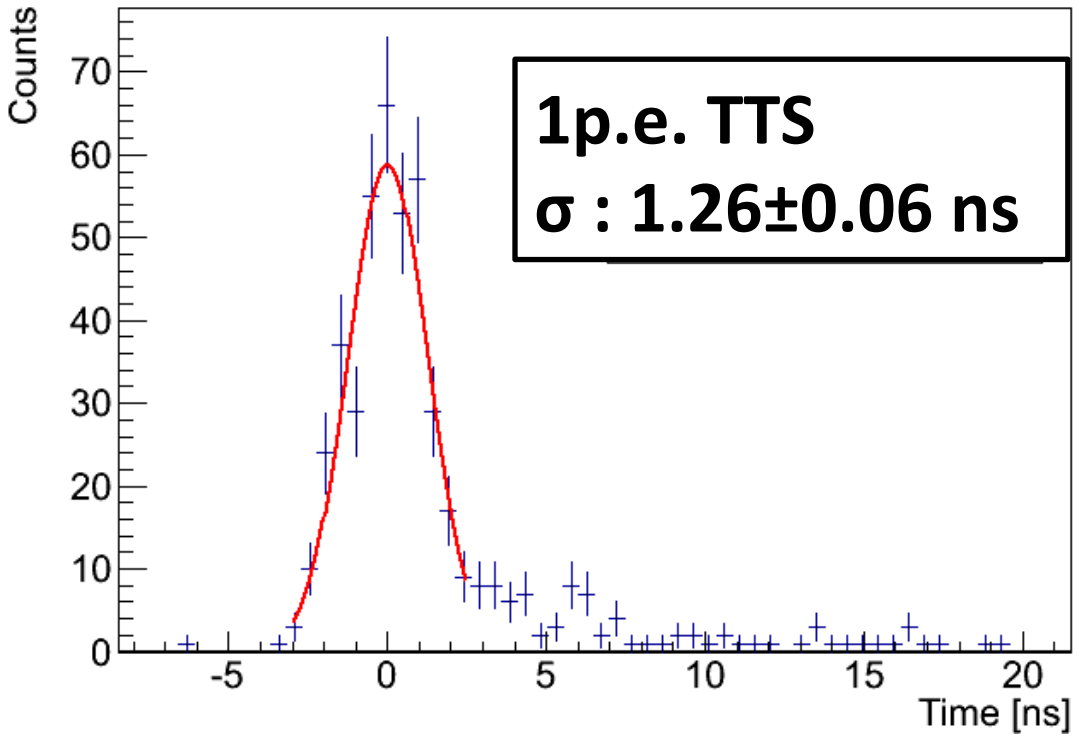
Bias 345V @25℃



- Dark Hit Rate is critical to trigger rate, because HK events are recognized by coincidence of hits in photo sensors (= **Self trigger**)
  - Dark Rate @ threshold must be stable and low for trigger rate
- 3kHz @ threshold for 1p.e. events (HPD Serial# 0057)

ref) 4kHz@0.25p.e. (20-inch PMT in Super-K tank)

Timing Resolution



- 1p.e. transition time spread (TTS) is **~1.3ns** with preamp and 70m cable.
  - Only HPD, 1p.e. TTS (σ) is **0.62ns** reported by Hamamatsu
  - 20-inch PMT ~2.2ns
- HPDs show good timing resolution.

Current 8-inch HPD performance

	8" HPD for Proof Test	20" PMT (in Super-K: R3600)
Amplification	Bombardment + AD	Dynode
HV	8kV + AD Bias 350V	2kV
Gain	10^4~10^5 (~10^7 with amp)	10^6~10^7
1p.e. P/V (charge distribution)	5~7	1.9
1p.e. Resolution (charge distribution)	~35%	~150%
Dark Rate	~3kHz-40kHz (~25℃) @ 0.5 p.e. Dark rates are different tube by tube	~4kHz (~13℃) @0.25p.e. Different measurement condition from in case of HPDs
TTS	~1.3ns @1p.e. with preamp and 70m cable (Only HPD, **0.62ns**)	~2.2ns @1p.e.

HPD Proof-test

Durability Check

Disadvantage

✓**NO experience** to use HPDs in water
✓**NO experience** to run over 10 years.

We must check….

- ☐ Long-term Stable operation
- ☐ Usability as water Cherenkov Detector

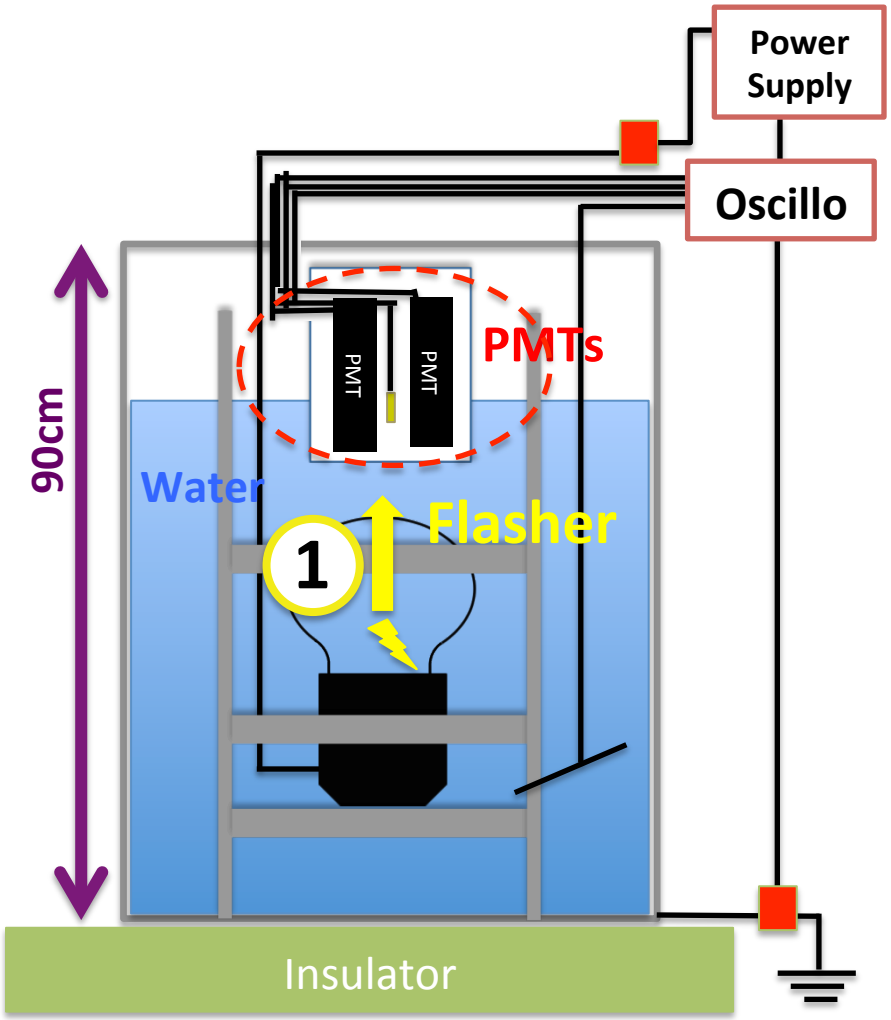
Durability Check ~ Jan. 2013

✓ We tested 5 HPDs.
✓ 1HPD was alive more than **1 month.**
✓ **NO failure** during 30k times HV (8kV) switching (equivalent to 5 years operation for 8 HPDs assuming 200t water tank test. Page21)

HPD Serial No.	HV applying time	HV switching time
0056	33 days	22490
0057	33 days	2350
0058	17 days	8087
0062	37 days	900
0072 (in Water)	16 days	50
Total	**136 days**	**33281 times**

Safety Check

1 HPD was mounted in a small water tank to confirm safety operation with 8kV applied.



Items	Trigger	Rate
Flasher → Background	PMT coincidence	<0.003Hz
Leak Current →Danger	Clump Sensor2	0 / 14h.
Discharge →Breakdown of electronics	Antenna, Clump Sensor1, HPD signal	<0.1Hz

- ✓ Confirm safety operation of 1 HPD in this set up.
- ✓ We will check safety operation of all HPDs for next proof test in 200t tank (Next Page).

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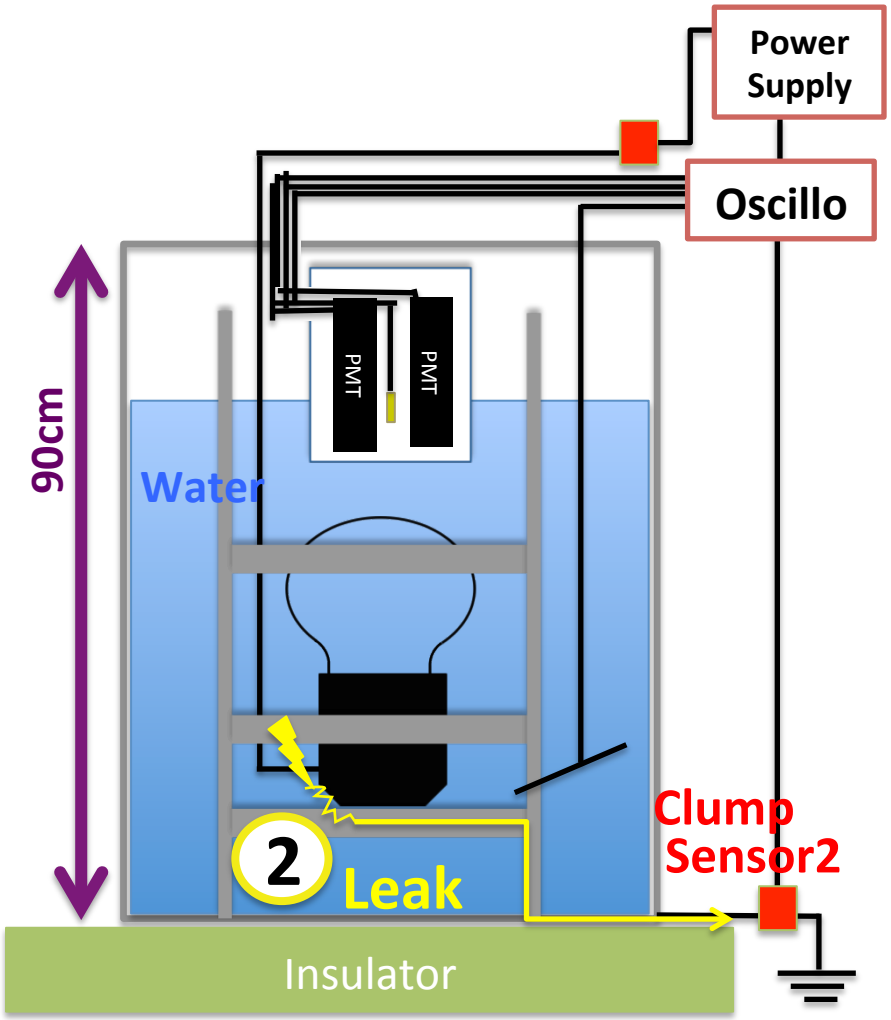

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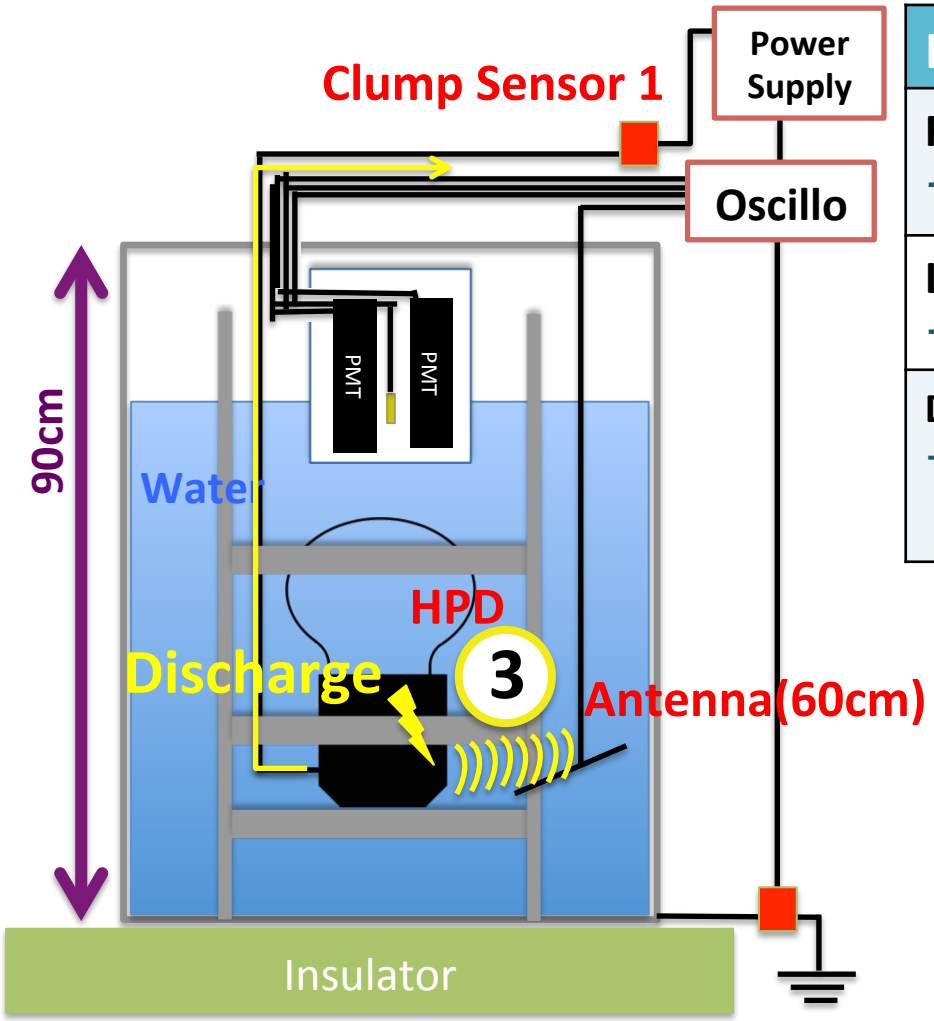

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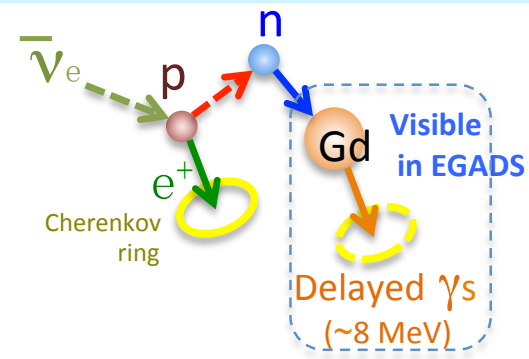
Next Plan : Proof-test in 200t tank

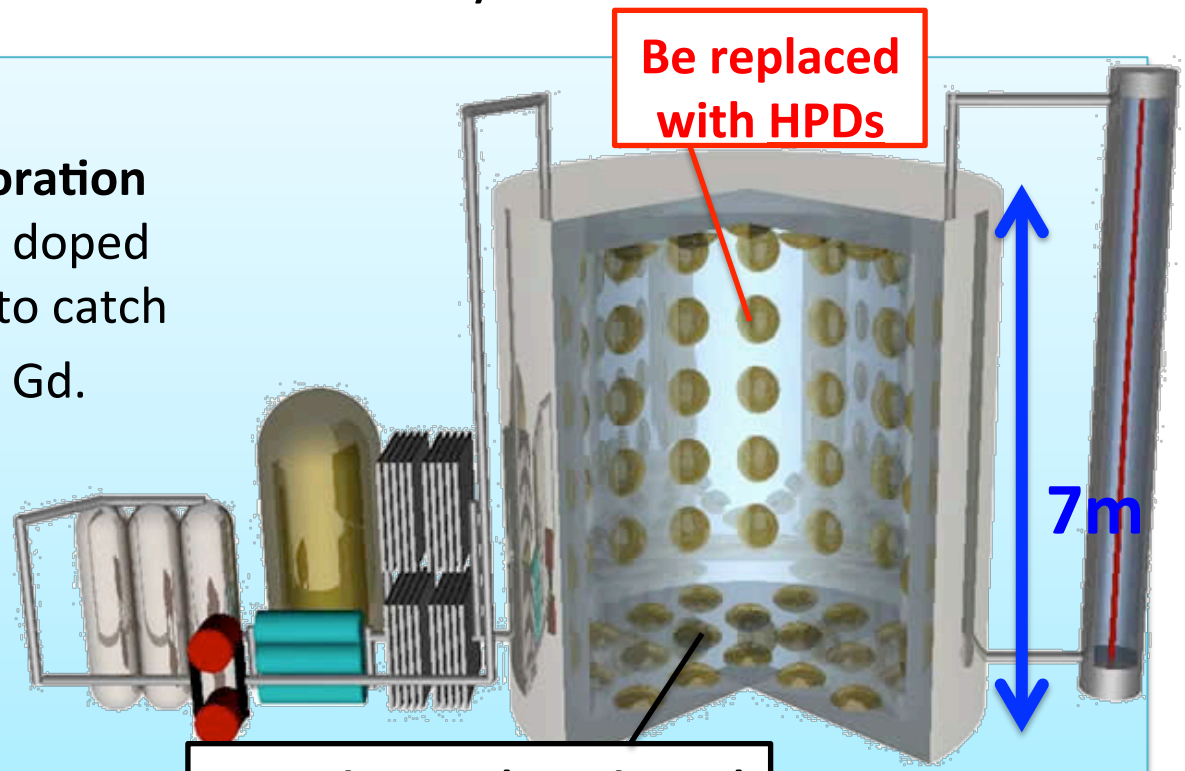
To confirm feasibility of HPDs as Cherenkov detector.

- ✓ Both 8-inch and 20-inch HPDs will be tested.
- ✓ Check stability for few years.
- ✓ Compare HPDs to 20-inch PMTs in terms of practical usage.
- ✓ We will start for 8 of 8-inch HPDs in this year at first!

200t tank

- ✓ Prepared **by EGADS collaboration**
- ✓ For verification study of Gd doped water Cherenkov detector to catch $\bar{\nu}$ by tagging neutrons with Gd.





@ Kamioka

Schedule of HPD R&D

Year	Season.	8 inch HPD		20 inch HPD
2013	Spring	Proof test 200t tank	Performance Evaluation (detail)	Prototype Performance Evaluation
2014		• Uniformity • B-field/Temp. dependence		Proof Test in 200t tank
2015	Spring			?
2016	Determine HK photo sensor !			

Plan to finish our HPD study by 2016.

Summary

- Hybrid Photo-Detector (HPD) is being developed for Hyper-Kamiokande.

- **Prototype of the 8-inch HPD was developed and tested**.
  - The HPD shows better performance than PMTs.
  - Durability for a month usage and safety operation in water were checked.

  →We will check feasibility of HPDs in 200t water tank since 2013

- The proof test and performance evaluation of both 8-inch and 20-inch HPD will continue until 2016. Our R&D has a possibility to improve the sensitivity of Hyper-Kamiokande by photo-sensor upgrades.

Backup

Target Schedule