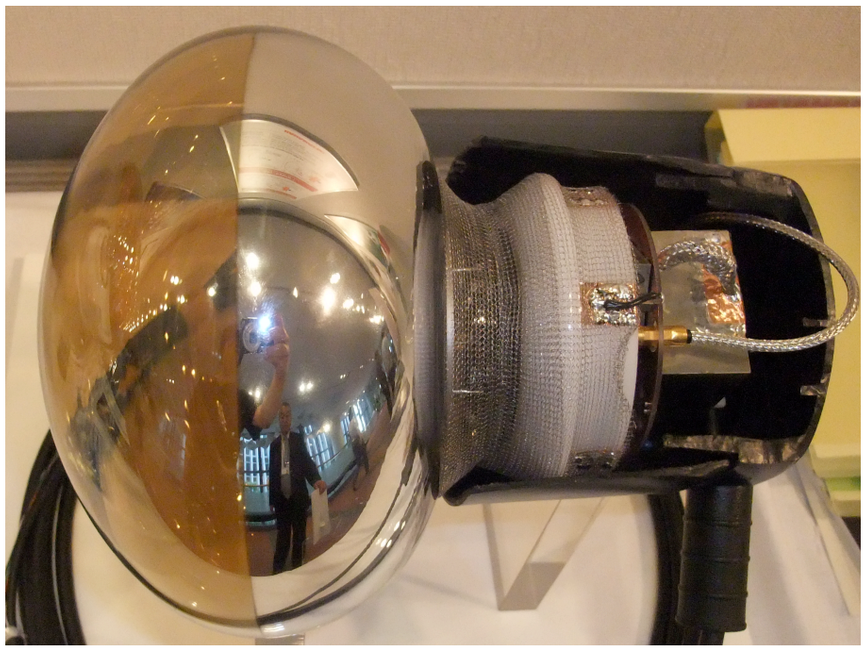
Development of Large Aperture Hybrid Photodetector



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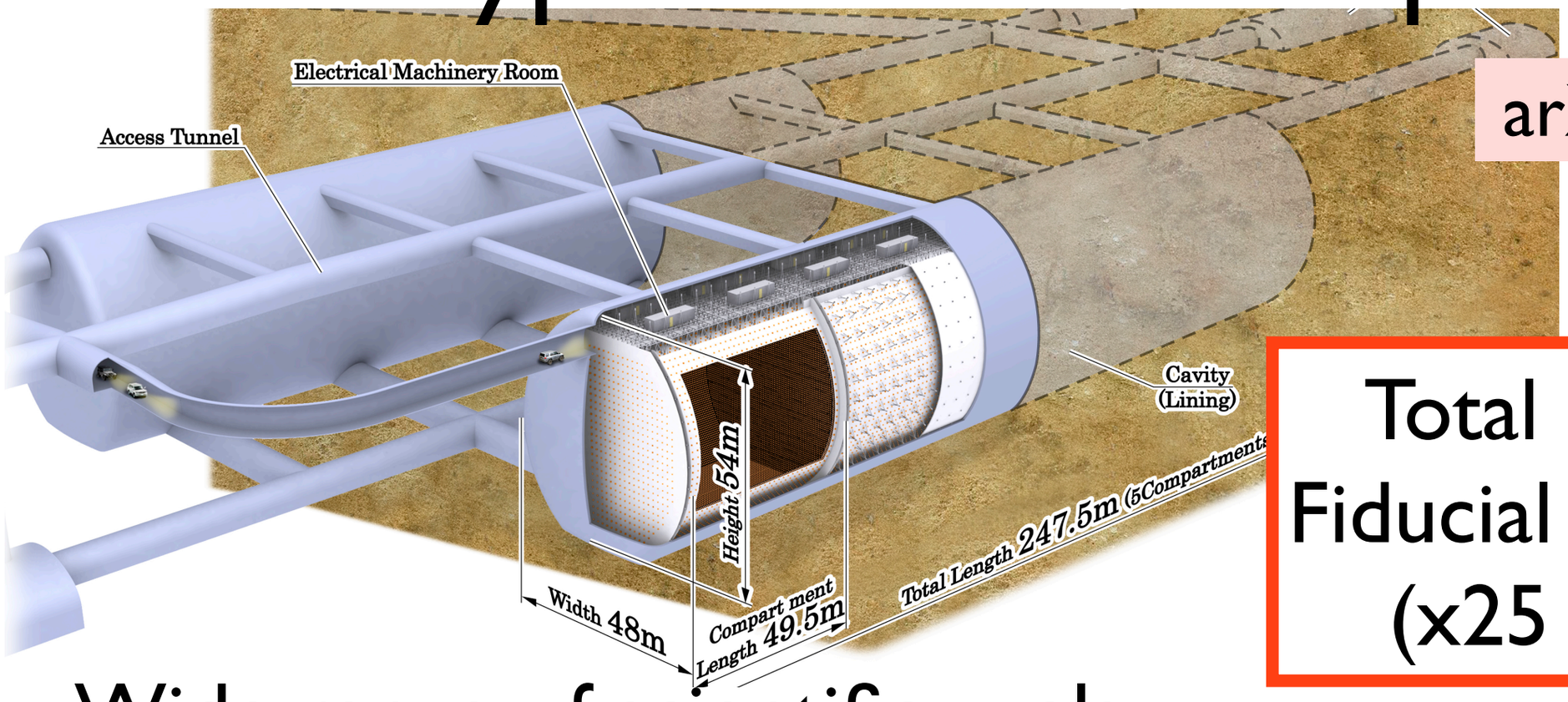
SCHOOL OF SCIENCE
THE UNIVERSITY OF TOKYO

Cosmic Frontier workshop Mar. 6-7 2013 SLAC

Hyper-Kamiokande project



arXiv:1109.3262

Total mass: 1Mton
Fiducial mass: 560kton
(x25 of Super-K)

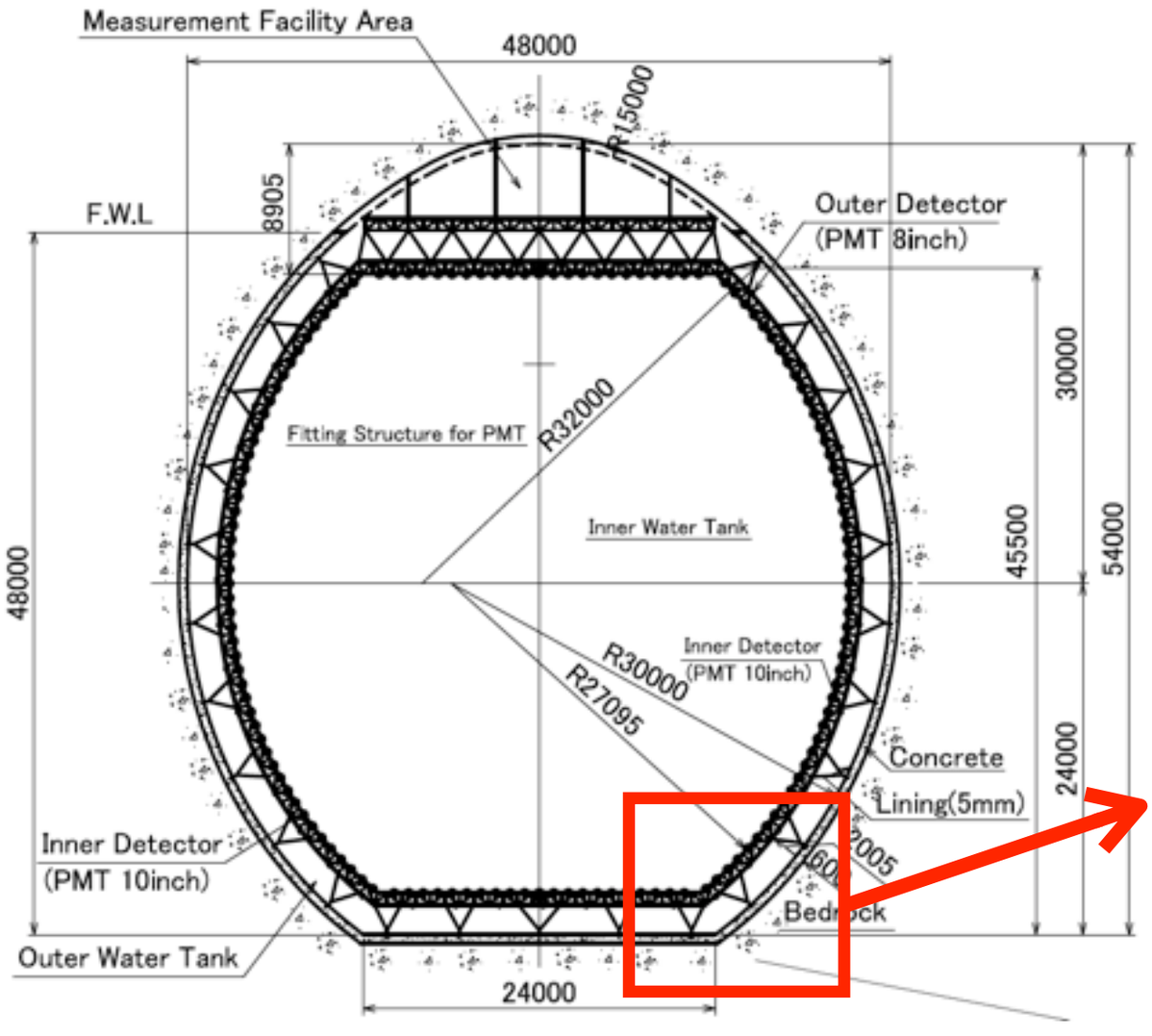
Wide range of scientific goals

- Exploring the full picture of neutrino oscillation
  - Neutrino beam from J-PARC (≥ 1MW expected)
    - CP asymmetry in lepton sector
  - Atmospheric neutrino
    - Determination of mass hierarchy and θ_{23} octant
- Search for proton decay
- Measurements of solar and astrophysical neutrinos

Hyper-K baseline design

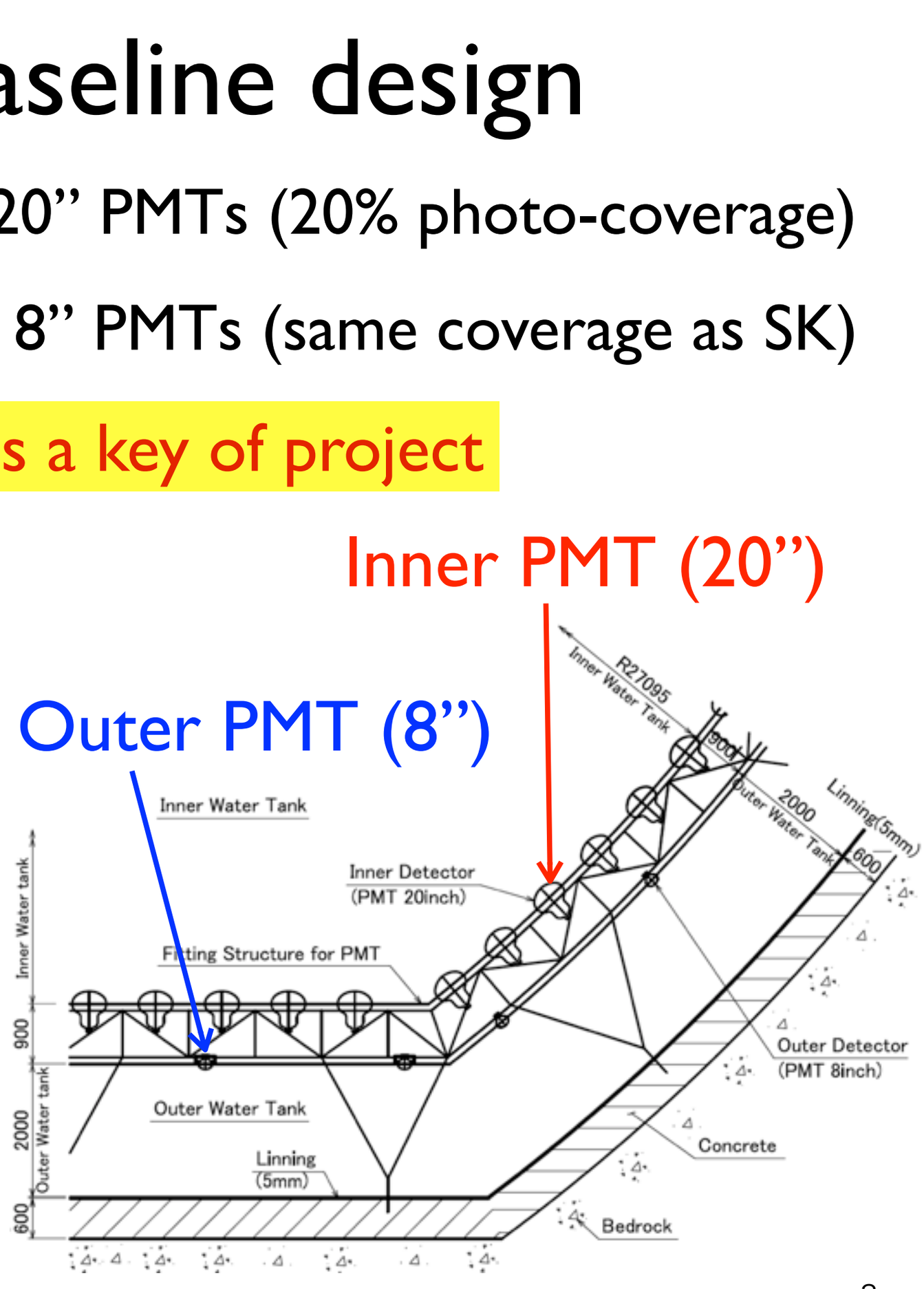
- Inner detector: ~99,000 of 20” PMTs (20% photo-coverage)
- Outer detector: ~25,000 of 8” PMTs (same coverage as SK)

Photosensor is a key of project



Inner PMT (20”)

Outer PMT (8”)



Requirements for photosensor

- High photo-coverage with minimum cost
  → large aperture
- Vertex reconstruction
  → timing resolution (≤3ns)
- Wide range of science
  → wide dynamic range
  1p.e. to >a few 100 p.e.
- High reliability, long lifetime
- Low cost

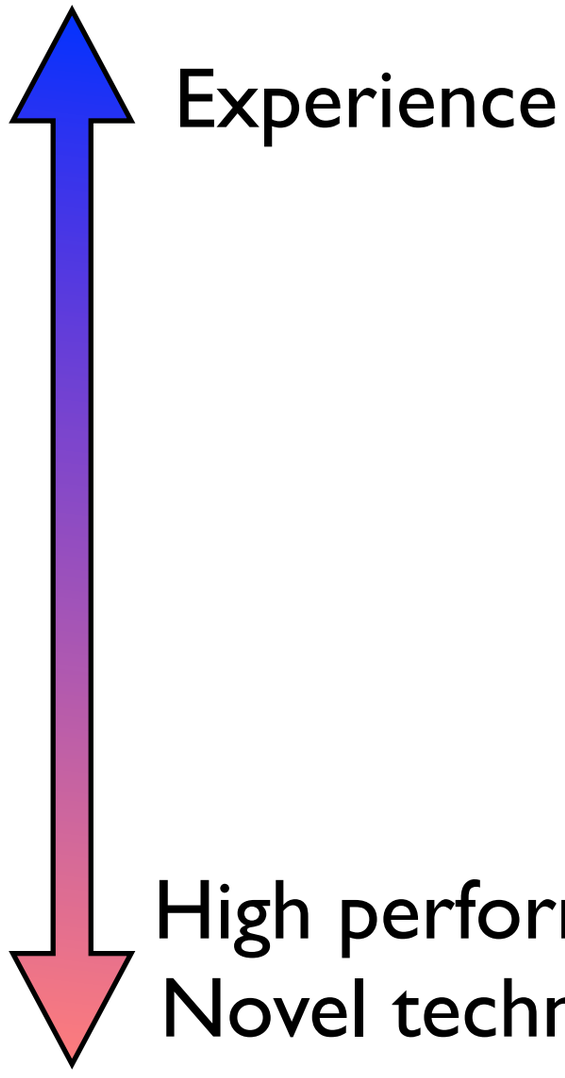
Candidates of sensors

In hand

- PMT (venetian blind dynode)
  - Used for SK/Kamiokande
  - Assumed in baseline design

New development

- PMT (box & line dynode)
  - Better timing resolution
- HPD
  - High performance
  - Lower cost exptected

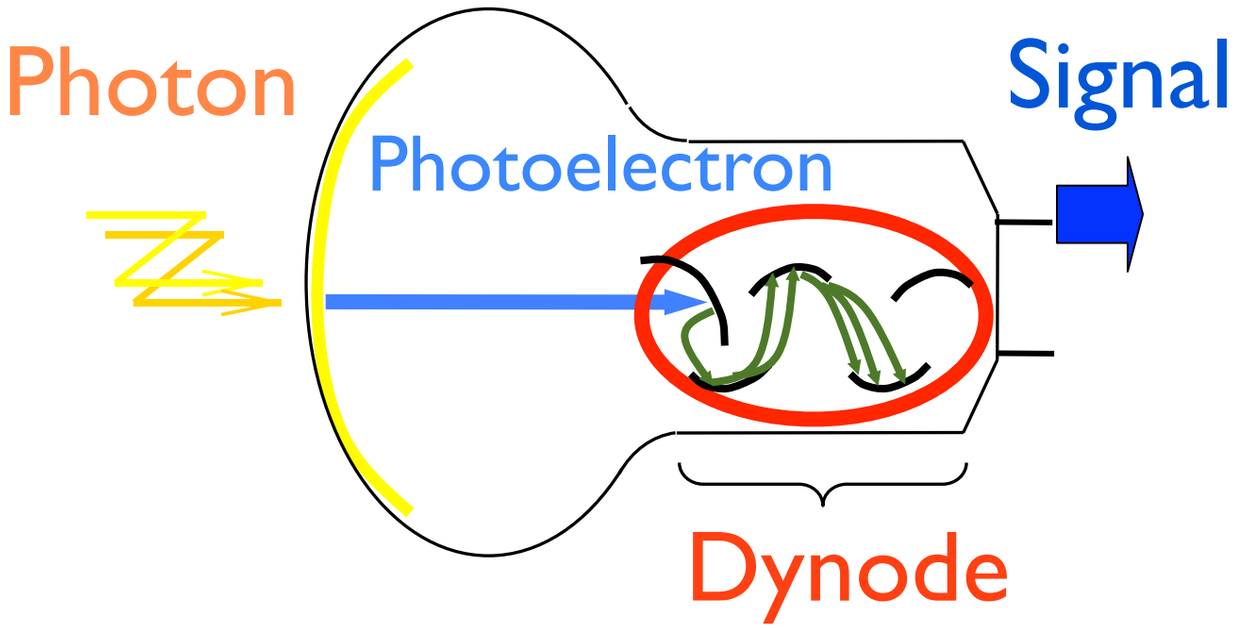


- Higher QE photocathode (for all options)
  - 20 inch prototype under evaluation

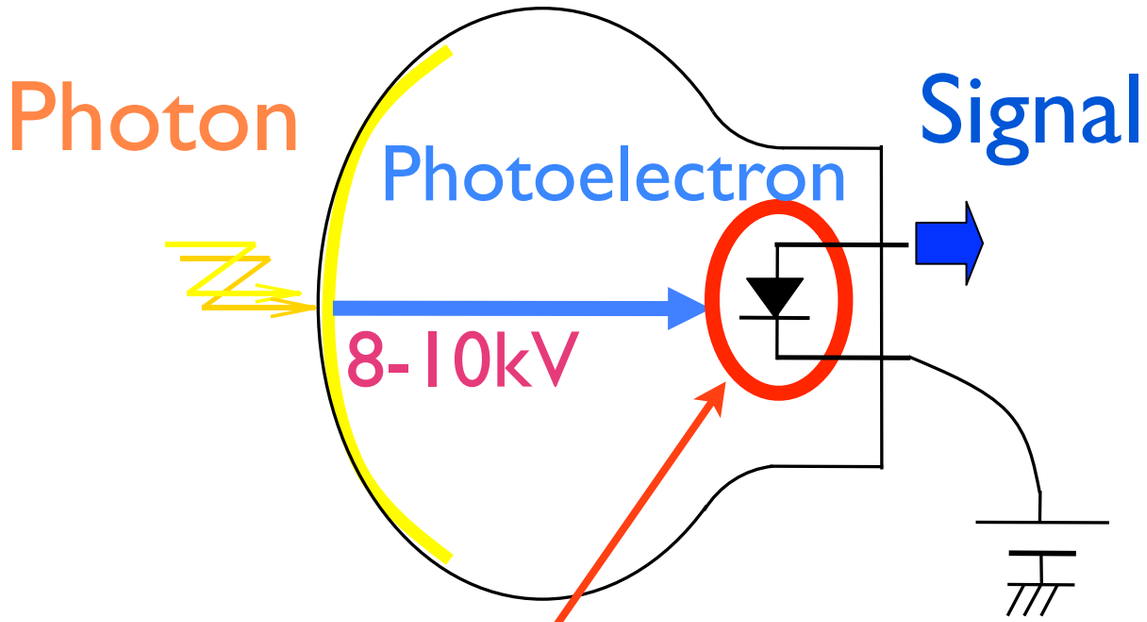
Need to evaluate overall cost and performance

Operation principle

PMT

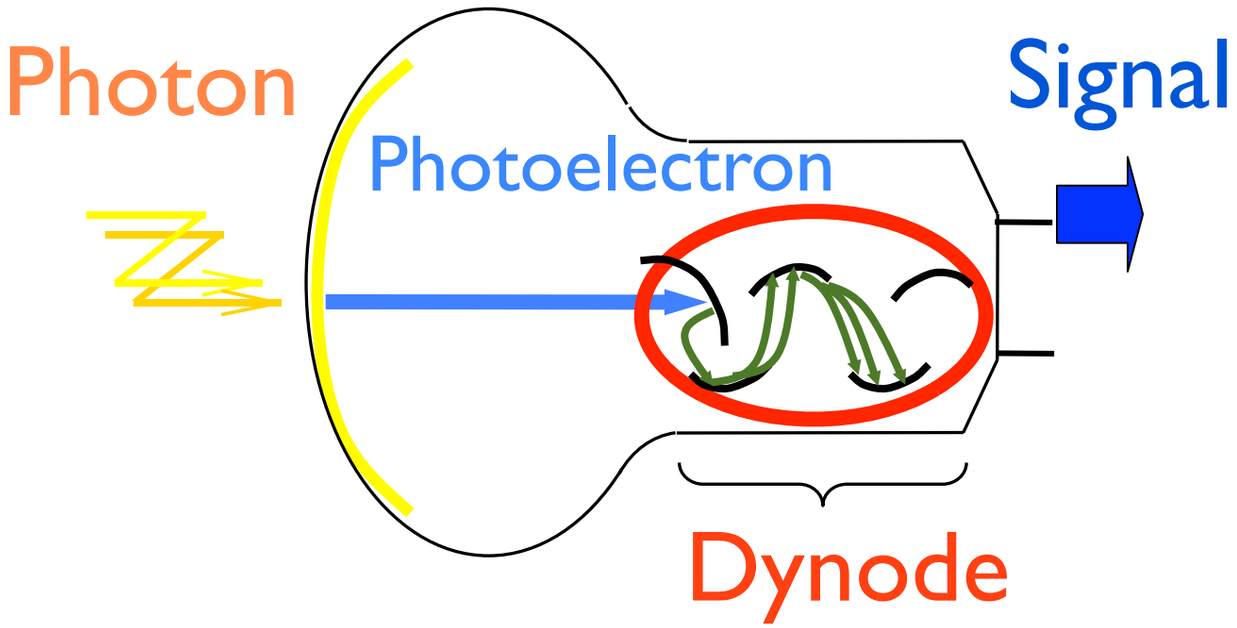


HPD



Operation principle

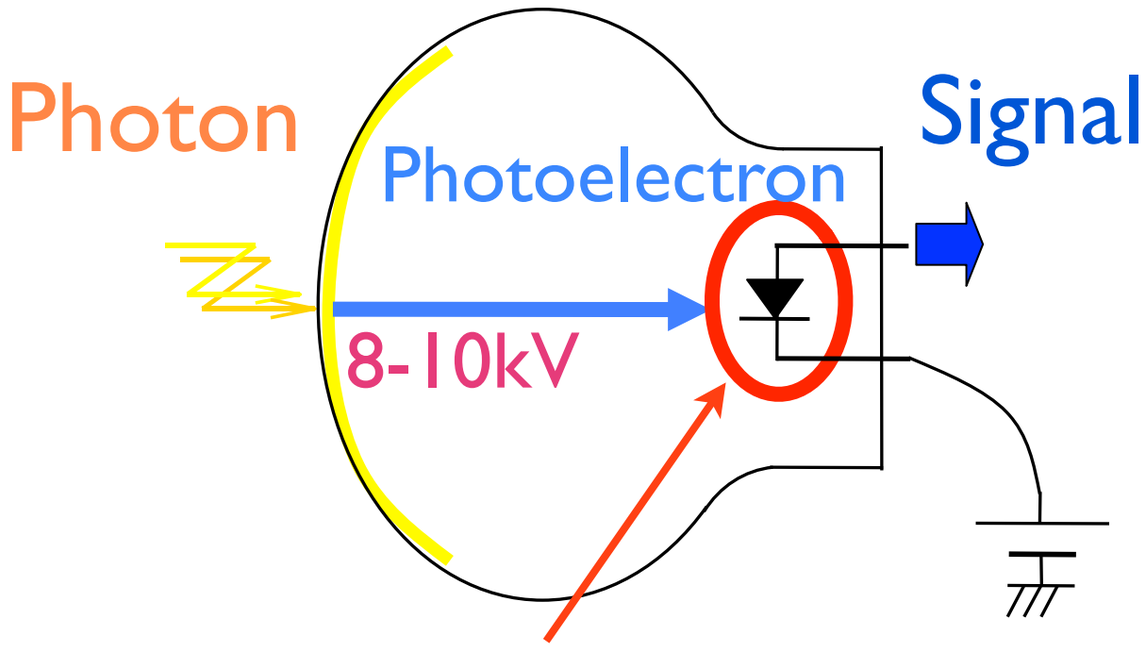
PMT



First dynode gain: ~5

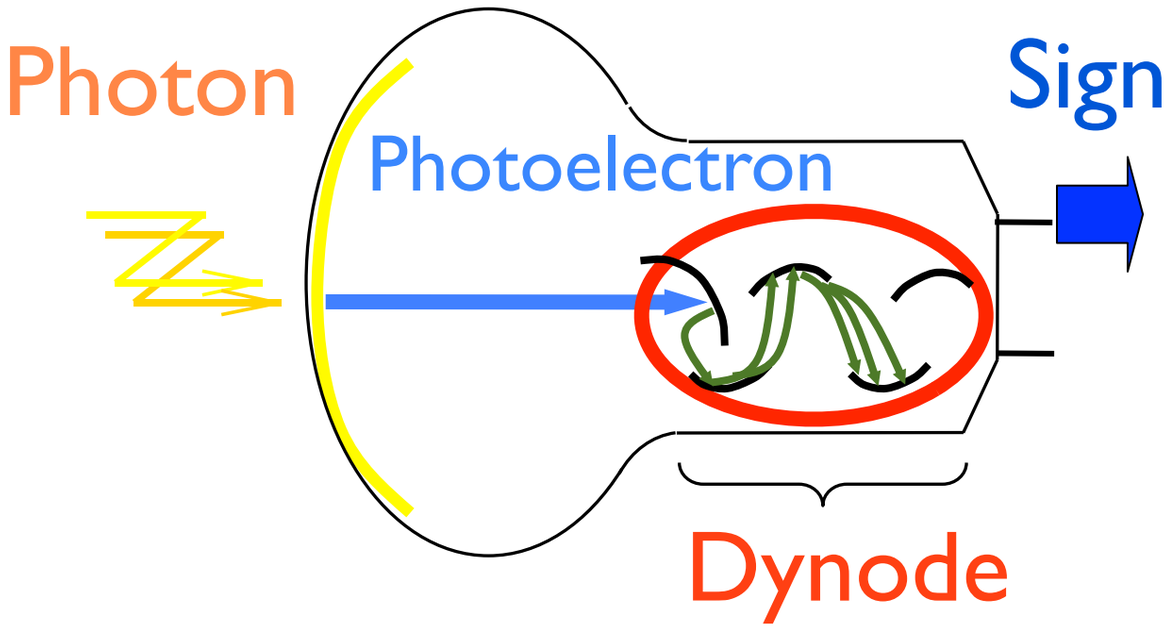
Total gain: ~10^7

HPD



Operation principle

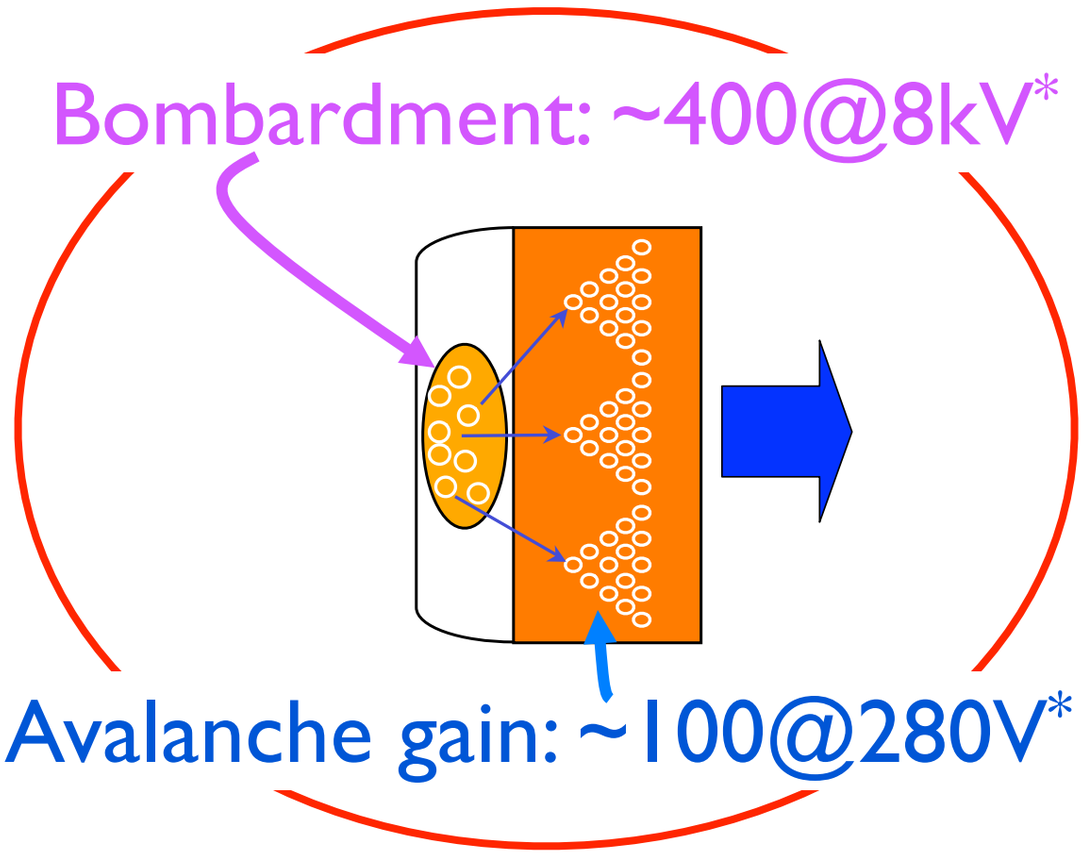
PMT



First dynode gain: ~5

Total gain: ~10^7

HPD



Total gain: ~10^4-10^5

* values for 8-inch prototype

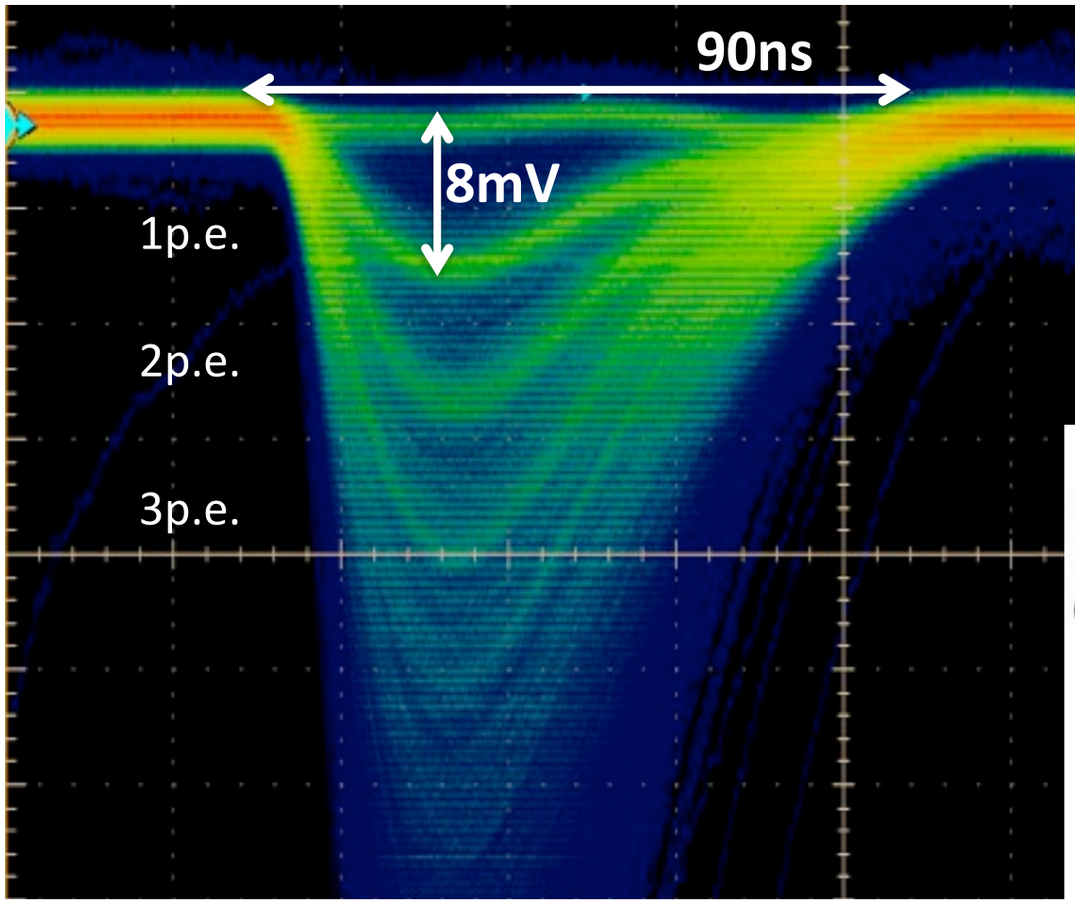
Advantage of HPD

- Electron multiplication with avalanche diode
  - Large gain at the first stage
    → good S/N
  - Good timing resolution
- High collection efficiency
- Simple structure
  - Easy assembly,
    better quality control
  - Cost reduction

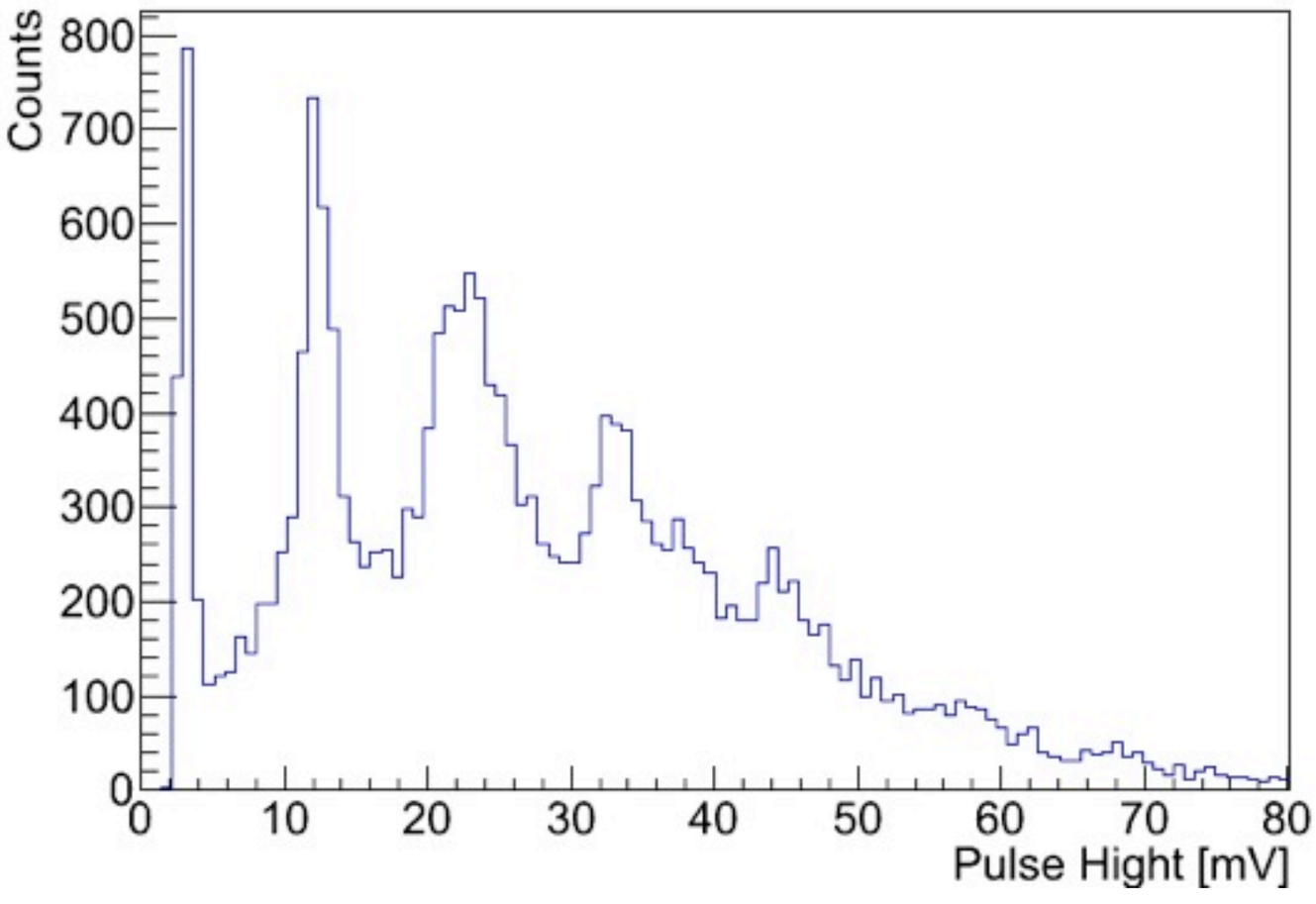
	8"HPD	20"HPD	20"PMT
HV	~8kV	~8kV	~2kV
Gain	10^4-10^5	10^4-10^5	~10^7
TTS(ns)	0.6	1.1(*)	2.2
C.E.	~97%	~95%(*)	~70%
AD dia.	5mm	20mm	-

(*) expectation from field calculation. preliminary value

Signal from HPD



8 inch prototype

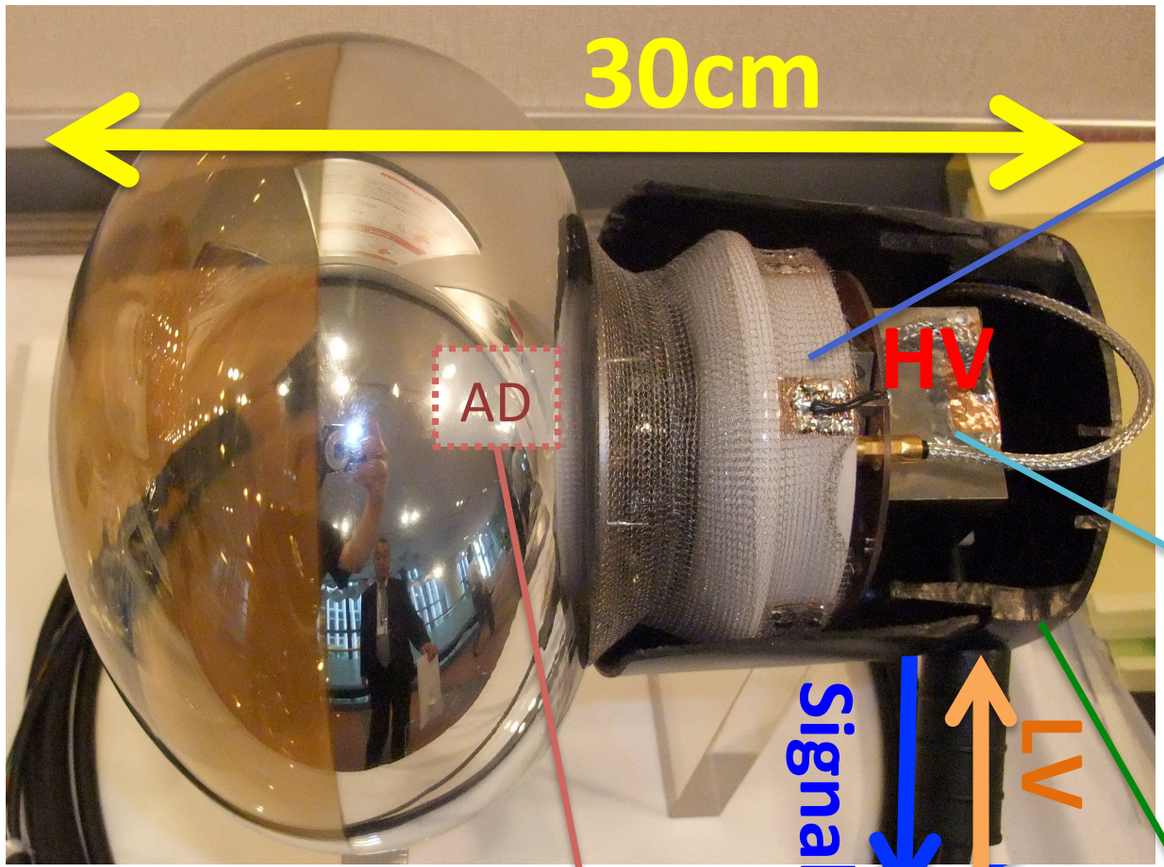


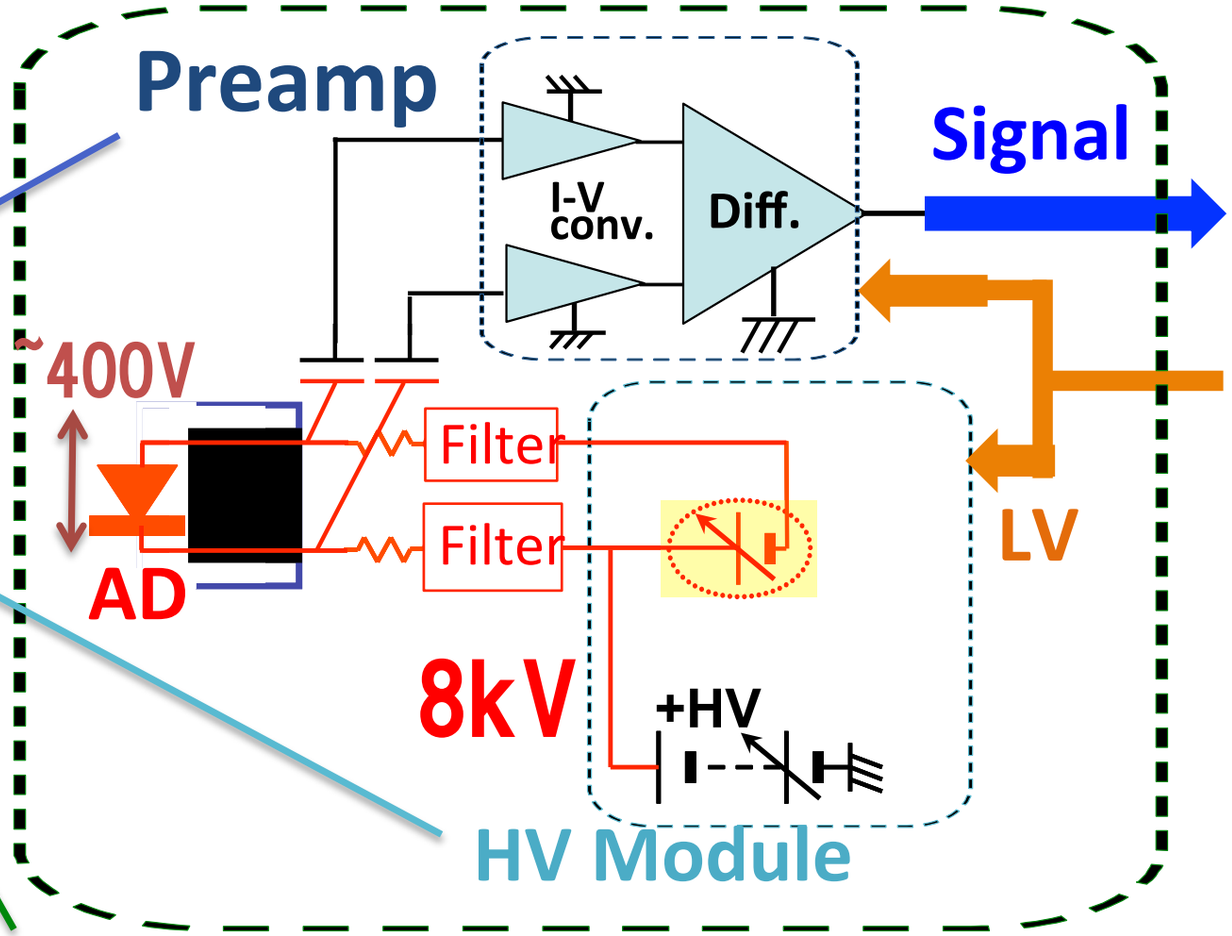
Photon counting capability

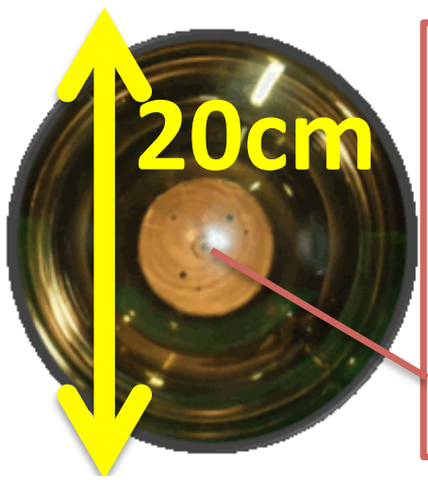
R&D status and plan

- 8” HPD prototype now under evaluation.
  - Long term (~1 year) test in a large water tank going to start (see later)
- 20” HPD first prototype will be delivered in 2013.
  - Evaluate performance and feedback to design
  - Hope to start test in the water tank in 2014.
- Development of high QE 20” photo-cathode.
  - Test production done (Super-K type PMT).

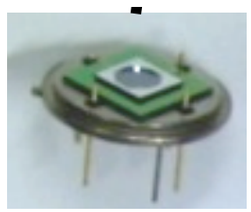
8 inch HPD for evaluation







AD
(5mmϕ)

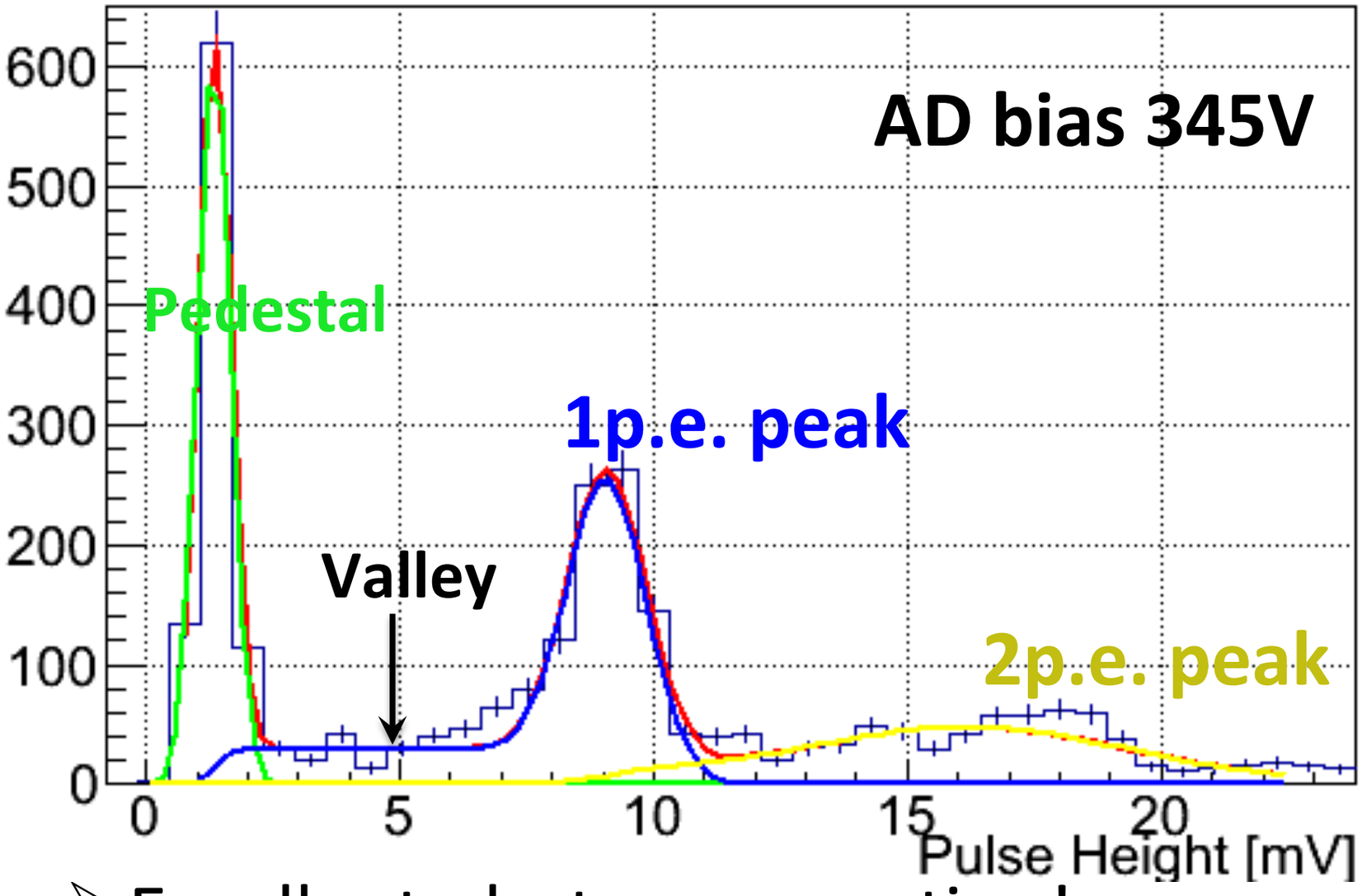


Power LV 10V
Control LV < 4V

HV supply module embedded

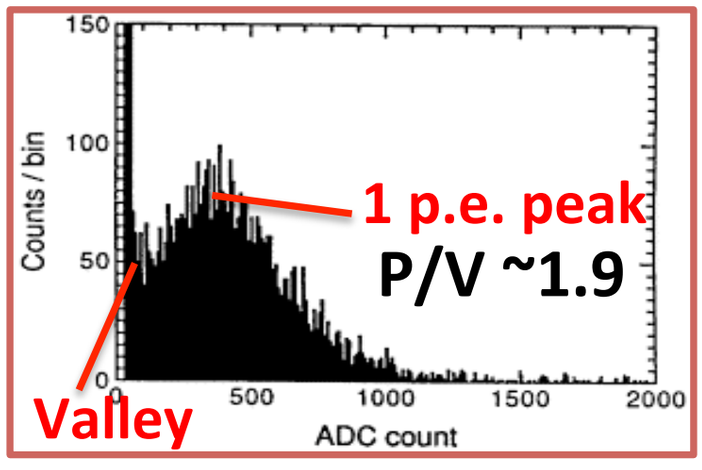
Single Photon Separation

1p.e. Pulse Height distribution



20-inch PMT

1p.e. Charge distribution

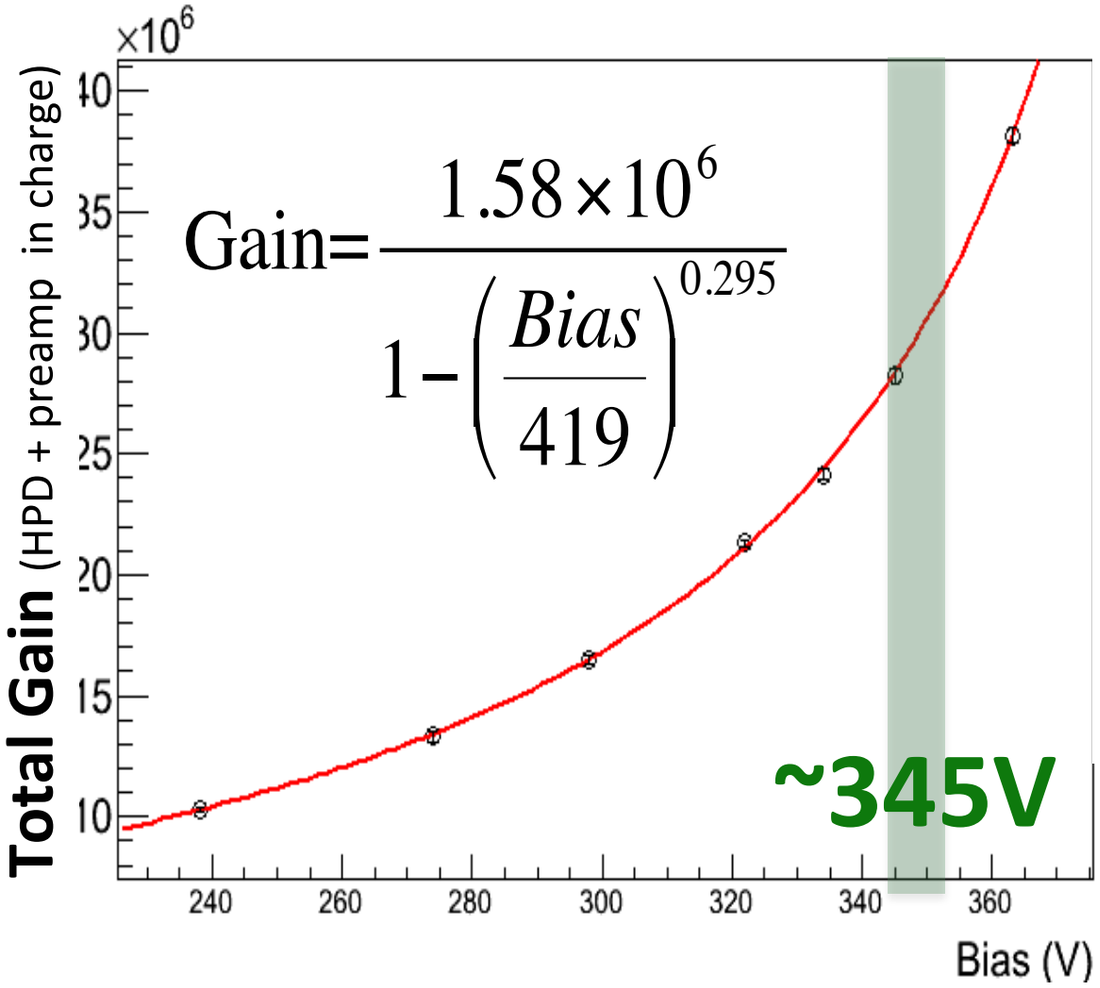


- Excellent photon separation!
  Peak to valley ratio (P/V) ~8.9 （ref: 1.9@PMT）

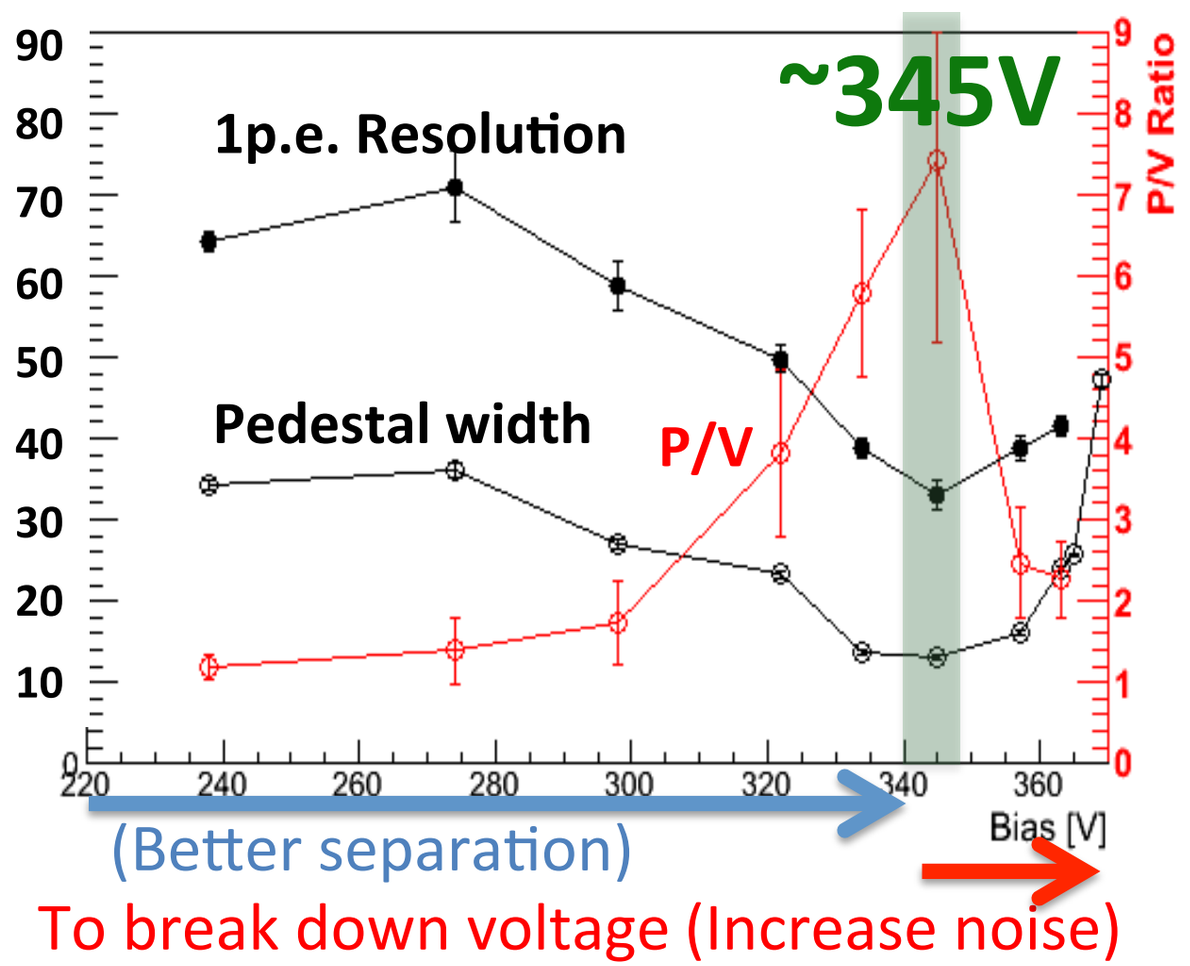
Performance by AD Bias Voltage

w/ 70m cable
@25℃

Gain Curve



Photon Separation (charge distribution)

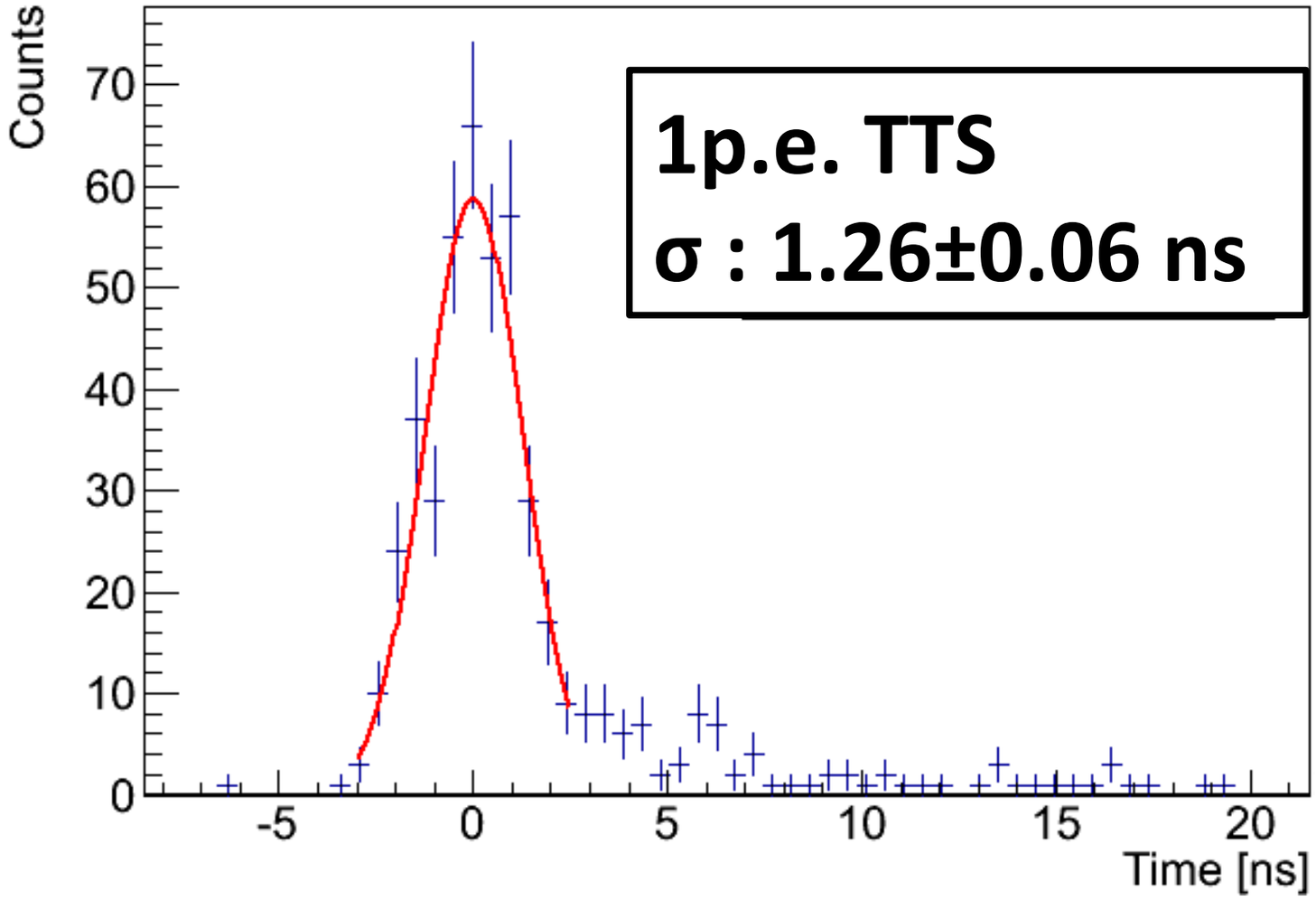


✓ Tune AD bias voltage under break down voltage to maximize p.e. resolution

With optimized Bias Voltage….

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

Timing Resolution



- 1p.e. transition time spread (TTS) is **~1.3ns** with preamp and 70m cable. ← Not optimized for timing
  - Only HPD, 1p.e. TTS (σ) is **0.62ns** reported by Hamamatsu
  - 20-inch PMT ~2.2ns

Other checks

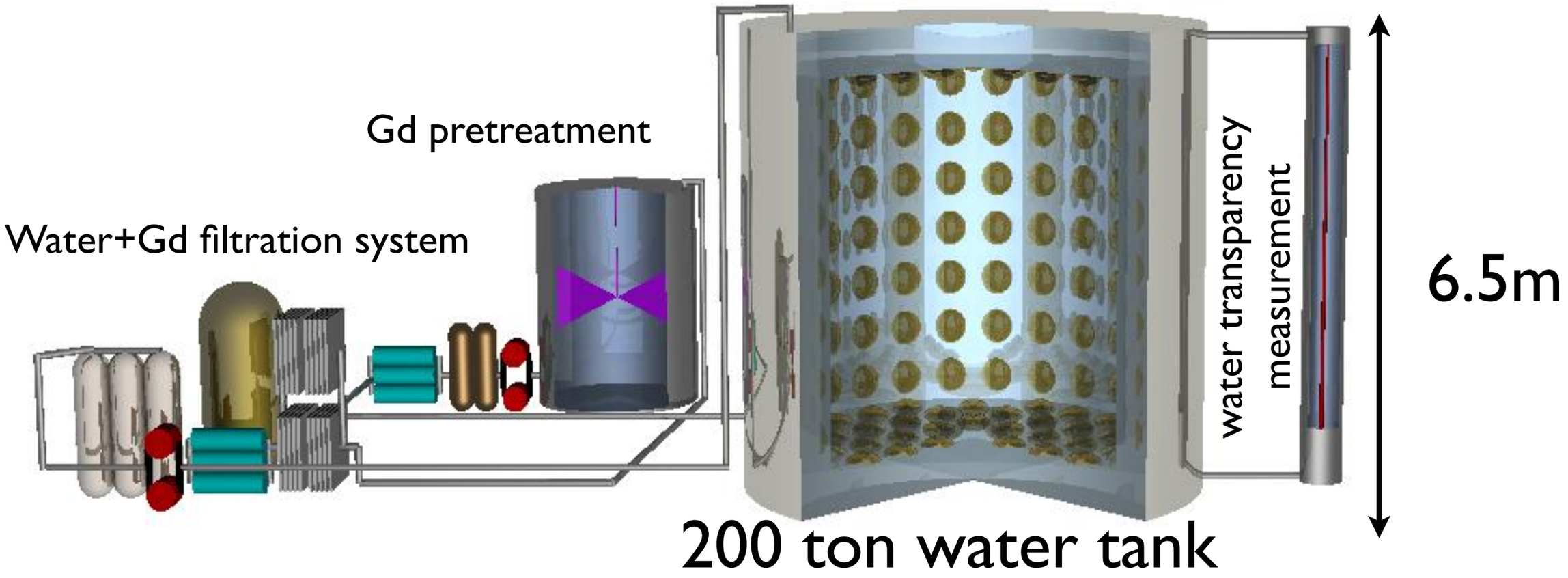
- Long term test with HV switching on/off
  - No failure in >5 month operation (in total)
  - No damage with >30k switching
- Operation in water
  - No change in performance
  - No leakage current / discharge to outside detected

Long term test in a 200 ton water tank

"EGADS" (Evaluating Gadolinium's Action on Detector Systems)

Test facility for Gd doping in water Cherenkov detector

aka *GADZOOKS!*



240 PMTs can be installed → replace some with new sensors

Start with eight 8" HPDs this year, 20" when available

Long term test in EGADS

- Evaluate performance as a sensor for water Cherenkov detector
  - Direct comparison to 20” PMT used for Super-K
- Long term operation experience
  - Stability / lifetime of device
  - Identify possible problems and feedback to the design of the final device

Preparation for long term test

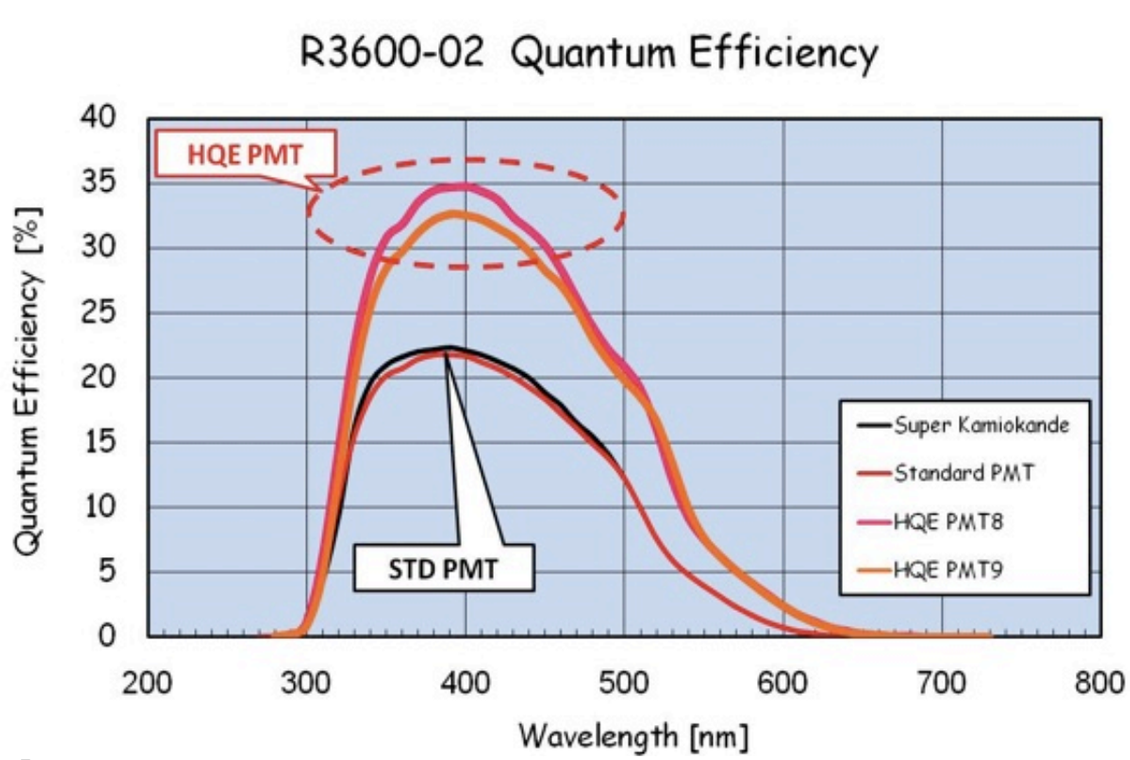
- Ten 8” HPD were delivered.
- Acceptance inspection has been finished.
- Calibration of each HPD scheduled this month.
- Installation schedule / procedure under discussion with EGADS group.
- Long term test will start soon.

20” HPD prospects

- Field calculation and design finished.
- 20mm diameter AD being processed.
- First “trial” version expected in spring this year.
- Hope to fix design, including water-proof / implosion-proof casing within 2013.
- Detailed performance evaluation and long term test from 2014.

High QE 20” photocathode

- Common R&D for HPD and conventional PMT.
- 20” high-QE PMTs (R3600, Super-K type) just delivered.
  - Expect >30% QE @ 400nm.
  - Performance evaluation will start soon.
  - Plan to install some in EGADS tank.
- Will be applied to HPD when 20” HPD is developed.



Prospects

- Develop 20” HPD and PMT (box&line) in ~a year.
  - Feedback from 8” HPD evaluation.
- Long term test in 200 ton water tank and detailed performance evaluation will follow.
- 20” high QE photocathode development in parallel.
  - R3600 prototype in hand.

Decision of sensor technology expected in 2-3 years.

Target Schedule of Hyper-K

Construction start

JFY2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
-4	-3	-2	-1	1	2	3	4	5	6	7	8	9

access tunnels, waste rock tunnels

cavity excavation

concrete, liner

PMT support, PMT installation

photo-sensor R&D

preparation for glass valve, PMT production

PMT production

water filling

Operation

assuming budget being approved from JPY2016

Summary

- We are developing 20” hybrid photodetector and improved 20” PMT for Hyper-Kamiokande.
  - 8” HPD prototype under evaluation.
  - 20” HPD/PMT prototype expected this year.
  - High QE 20” photocathode being developed.
- Plan to finish R&D in 2-3 years.
- New sensors will be also useful for other projects.