Development of 50 cm Photo-Detectors for Hyper-Kamiokande

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Development of 50 cm Photo-Detectors for Hyper-Kamiokande

Super-Kamiokande (Super-K)

- Large Water Cherenkov detector in Kamioka, Japan
- 50 kton
- 50 cm Photomultiplier tubes (PMTs)
- Plan to launch in 2026
- 40% photo-coverage
- 260 kton
- 74m φ

Hyper-Kamiokande (Hyper-K)

- 39.3 m φ
- 53,119
- 50 cm PMTs
- 6,700 of 20 cm (8") PMTs
- ×40,000
- Mass
- Fiducial kton
- 295 km

→ Performance was improved in two newly developed photodetectors for Hyper-K.
  - ×2 high detection efficiency
  - ×1/2 time & charge resolutions
  - ×2 high pressure bearing for 60 m height

Super-K PMT

- Hamamatsu R3600
- Venetian blind dynode
- QIE ~22%
- +2kV, 10⁷ gain
- ×11,129

Box & Line PMT

- Hamamatsu R12860
- Box & Line dynode
- high QIE ~30%
- +2kV, 10⁷ gain
- ×40,000

HPD (Hybrid PhotoDetector)

- Hamamatsu R12850
- Avalanche diode (AD)
- High initial gain
- high QIE ~30%
- +8kV, 10⁷ gain
- ×100 + preamp

- Simple inside structure
- Short path
- High bias volt

- Over 100 PMTs were prepared for operation.
- Ready for mass production.
- New photo-detector covers were tested in deep water.

Hyperfine burst ν, ...

ν oscillations
- Leptonic CP violation
- ν mass hierarchy, ...

ν astrophysics
- Supernova burst ν, ...

Efficient collection

Uniform path

New PMTs were tested in deep water.

×2 high detection efficiency

Plan to launch in 2026

50 cm Photo-Detectors for Hyper-Kamiokande

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2018/Jul/6
High Resolutions

Single PE peak

[σ / peak]
Super-K 53%
Box&Line 35%
HPD (1ch) 15%

Pedestal →
1 PE
2 PE

Entries (a.u.)

Photoelectrons

Single PE transit time spread

Super-K PMT 7.3 ns
Box&Line PMT 4.1 ns
HPD (1ch) 3.6 ns
(HPD w/ time walk correction 3.2 ns)

FWHM

2018/Jul/6 Development of 50 cm Photo-Detectors for Hyper-Kamiokande
Dynamic range was improved to detect wide energy range of MeV-GeV ν.
Optimized voltage dividing ratios without losing performance.
5.2V → 7.5V max (~6 mV/PE) in a sample.

→ Confirmed sufficient high rate tolerance for supernova burst detection (10MHz at max in low PE)

→ Increased voltage at first and latter three dynodes.

Rate Tolerance of Gain

Within 5% up to 170 μA
→ 78 MHz at single PE
Optimizing photocathode production to minimize the dark rate:

- 20 kHz → 10 kHz → 8 kHz (1st) → (2nd) → (3rd) → (4th) → ...

2014 2015


Measured a stabilized level of dark rate after a few months.

Dark room w/ cooling at 14deg.

Univ. of Tokyo, Japan

Monitoring 16 of 50 cm PMTs

Dark rate dependence by gain (HV)

Gain [x10^7]

5 6 7 8 9 10 11 12

0.7 0.8 0.9 1 1.1 1.2 1.3 1.4

Fixed at 1/6 p.e. thre.

(Threshold Volt changed by gain)

Dark rate dependence by Temperature

Temperature [°C]

5 10 15 20 25 30 35 40

5.7 6 6.3 6.6 6.9 7.2 7.5 7.8

Studies for dark rate reduction are ongoing with reconsidering material / structure inside in a year.
Testing initial type of 3 Box&Line PMTs
- in a 200-ton water Cherenkov detector (EGADS) since 2014.
- Working for ~3 years stably!

Smooth shift of gain was always monitored.

Dark rate is almost constant for 2.5 years (except for one).
(Typical dark rate was reduced in recent products by a factor of 1/3 after the initial samples.)

One Box&Line PMT is getting high rate.

50 cm φ HPD
200ns

Developed 1 waterproof HPD with preamplifier improved for narrow pulse width.

Installed the HPD in late 2017.
~150 Box&Line PMTs were manufactured.

All PMTs were screened at high pressure water up to 0.95 MPa.
- No damage found in the bulb.
- Calibrated all PMTs at Kamioka, JP.
  - Gain, resolutions, dark count rate, etc.
  - No rejected PMTs by performance in our tentative criteria for Hyper-K.

Resolution at single photoelectron peak

HV calibrated to 1.4×10^7 gain

Within reasonable operation range

Ready for mass production with a good quality control.

2018/Jul/6
Accidental implosion of bulb in water might cause a chain implosion by a shock pulse.
- A shockwave prevention cover made of FRP was developed for Super-K for 40m depth.

New covers were developed for a deep Hyper-K tank up to 60 m with clean materials.
- A cover made of stainless steel was developed for Hyper-K and established with tests in 2016.
- Further improvement with light weight or low cost for several designs

In 2016
- Initial prototype for 60 m water depth

1. Improved cover
- Cover pressurized test in water \( \rightarrow 1 \) MPa
- Weight \( 17\) kg

2. Resin cover
- PPS (Poly Phenylene Sulfide) with carbon fiber
- 0.5-0.57 MPa
- Light weight, fast and easy mass production
- 6.4 kg

3. Stainless steel tube cover
- Stainless steel
- 0.7 MPa
- Cheap and simple, Developed in Spain
- 30 kg

New 3 covers were also tested with bulb implosion inside in 2018.

Super-K cover for 40 m water depth

Vacuum
Bulb is pressurized.
Implied
Cover is pressurized.
Slow water flow through cover holes suppresses the shockwave.
Validation of the Covers

The covers were tested in a deep shaft at 40-80m depth with the bulb implosion.

Procedure
1. PMT is imploded in the cover by a hitting tool with surrounding PMTs without cover.
2. Confirm the cover and surrounding PMTs have no damage with monitoring the shock.

The second test was performed in Mar 2018.

1. Improved cover → Success at 80 m three times
   Shock wave monitor (70 cm front)

2. Resin cover
   Success at 40 m (1 test only), but failed at 60 m

3. Stainless steel tube cover
   Success at 60 m (1 test only)

New stainless steel cover was established!
22kg → 17kg, 15mm→13mm acrylic thickness

Hyper-K Photo-detector system is ready.

In Hokkaido, JP

SHAFT filled with water

4.8mΦ

Peak pressure [MPa]

w/cover
1/100 suppression

w/o cover,
only 1 PMT at center

~ 6 MPa peak shock wave in 60m water

Next:
Reduce weight, reach easy mass production/assembly design

2018/Jul/6

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Installation of ~140 Box&Line PMTs in Super-Kamiokande

Many Box&Line PMTs will be practically operated in Super-K soon.
10 Hyper-K covers, made of clean materials with low backgrounds, are installed in SK top/bottom. Stainless Steel Cover FRP cover in Super-K increases dark rate a little.. PPS Resin Cover View from outer detector on top of the Super-K tank
Conclusion

- Box&Line PMT design is ready for production.
  - We confirmed sufficient quality in the ~150 PMTs’ production.
  - Installed in Super-K, some of them with the improved covers for Hyper-K.

- HPD brings the best resolutions.
  - Operation in the 200-ton water tank started.

- Aiming for start of construction in JFY2019 and operation in JFY2026
Gain tuning

HV at 1.4e7 gain : 1783.22 [V]

Dark rate scan by thresholds

Single PE charge

Transit time spread

PMT Ch4 EA4022-E

Gain tuning

Ch3 EA4022-E 1783.2V Run01788

Single PE RESULT

Gain 1.42e+07
Peak 2.27 [pC]
Sigma 25.9 [%]
P/V ratio 4.16
FWHM 61.1 [%]

Ch3 EA4022-E 1783.2V Run1789

Single PE RESULT

Relative Peak ~0.55 [ns]
Upper Sigma 1.31 [ns]
FWHM 3.1 [ns]