R&D studies of new photosensors for the Hyper-Kamiokande detector

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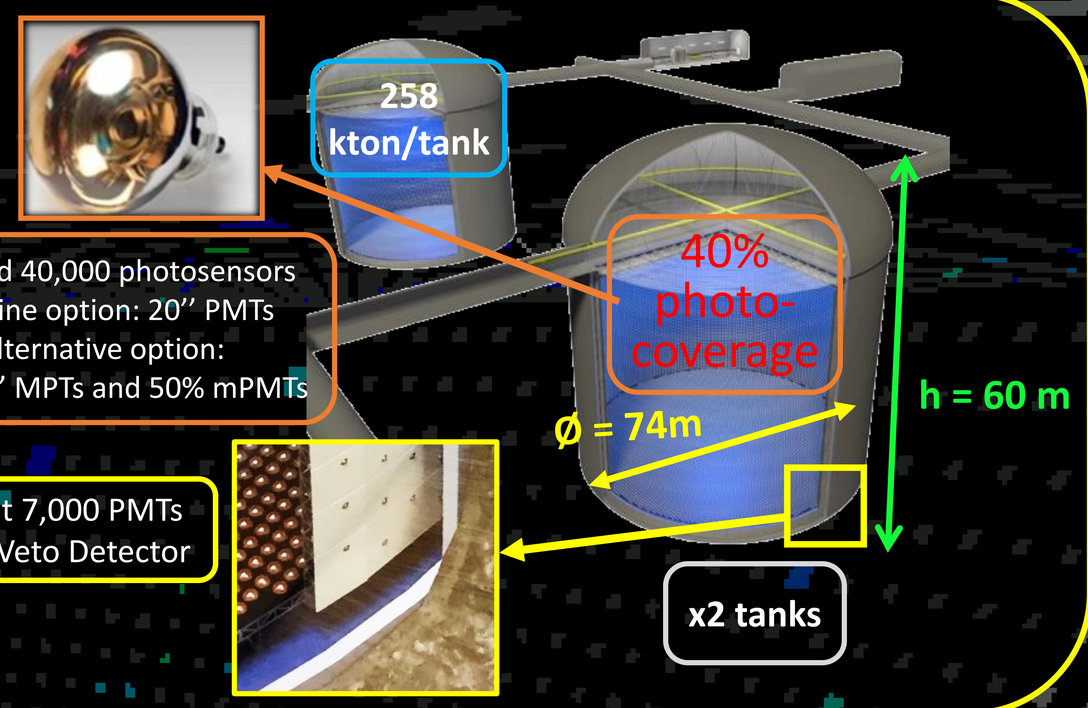
Hyper-Kamiokande

- A future plan of ν experiments with about 0.5 Mton (total volume in two tanks) water-Cherenkov detector (187 kton fiducial mass per tank).
- High sensivity with much higher statistics thanks to the large size.
- A challenge for innovation because of the very large tanks with high water pressure

Physics potential

- ν oscillations, leptonic CP violation, ν mass hierarchy, etc. by high time and charge resolutions, high detection efficiency
- Nucleon decay discovery by ~ nsec time resolution and low background
- Astroparticle physics studies → measurements of accelerator, solar, atmospheric, and SNa neutrino, etc. by high rate tolerance, low background, clear photon counting



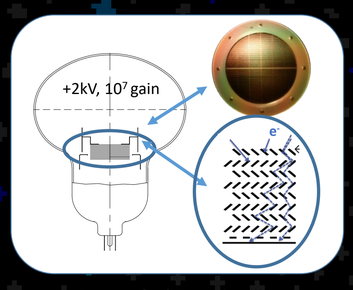
Planned 40,000 photosensors
Baseline option: 20'' PMTs
Alternative option:
50% 20'' MPTs and 50% mPMTs

And about 7,000 PMTs for Outer Veto Detector

Photosensor improvements over the years and experiments

Physics sensitivities are essential to reach mentioned purposes, hence large-aperture photodetectors (PDs) are needed. The photodetectors below have higher quantum efficiency (QE) (30%) than the SK PMT (22%).

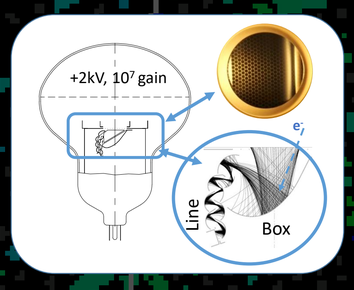
RELIABILITY ← → LOW COSTS & HIGH PERFORMANCES



Venetian blind dynode type PMT (Super-K)

The Hamamatsu **R3600**, in use in Super-K.

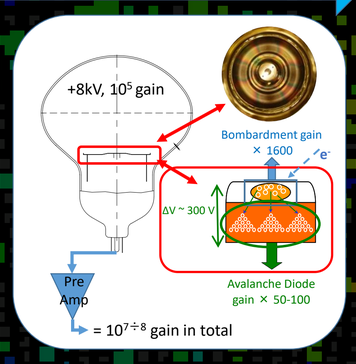
- The performance is established and reliable (for > 20 years)
- The high QE prototype has already been made
- Electron might miss 1st dynode = less collection efficiency
- Ambiguity of drift path limits charge and time response
- Not suitable for 60 m depth of the Hyper-K tank



Box & Line type PMT (50 cm Ø)

The Hamamatsu **R12860-HQE**, a photodetector developed for the Hyper-K baseline design.

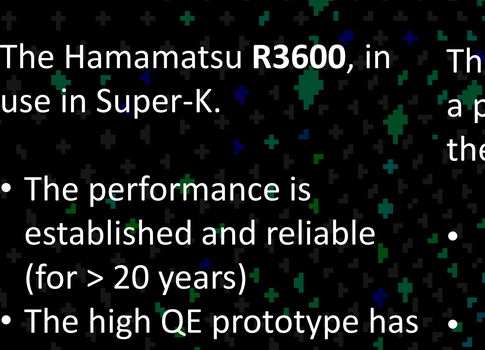
- PMT with a different type of dynode
- High collection efficiency
- Uniform drift path → High charge and time resolutions
- high QE
- Fast time response by linear focused dynode
- Double improvements on efficiency and resolution
- Established in 60-80 m water depth with an external cover

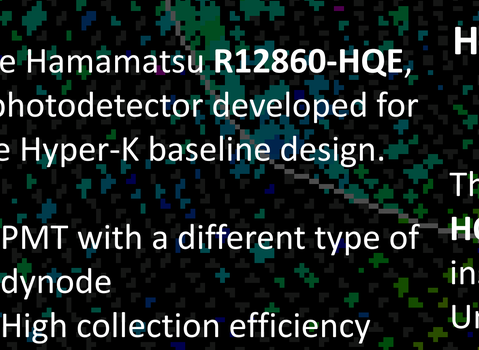


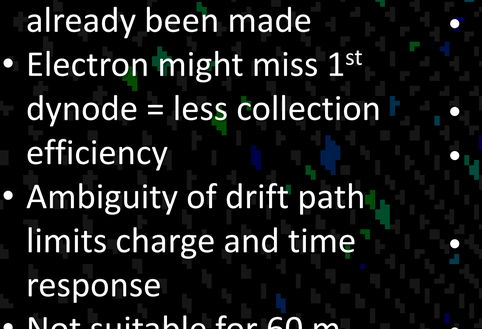
Hybrid PhotoDetector (HPD) (50 cm Ø)

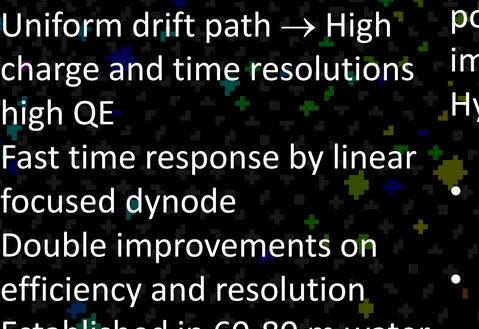
The Hamamatsu **R12850-HQE** avalanche diode (AD) instead of dynode.
Under development for possible further improvements of the Hyper-K.

- Simple structure inside and low cost
- The high voltage (HV) is higher than PMT
- Good signal resolution





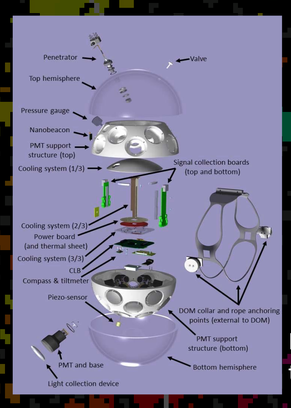




	HPD w/o Preamp	B&L	SK
1PE resolution (σ/μ)	16%	35%	53%
Peak/Valley	3.9	4.3	2.2
TTS FWHM (ns measured)	3.4	4.1	7.3
TTS FWHM (ns calculated)	0.75	2.7	5.5
Rise Time (ns)	7.4	6.2	10.6
Fall time (ns)	11.5	6.3	13.1
Pulse Width (ns)	25.5	16.7	31.4

The multi-PMT detector

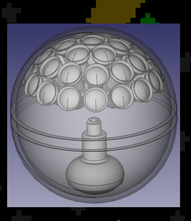
Based on the KM3NeT experience, a mPMT photodetector system is candidated to be placed in combination to large single PMTs. It consists of an acrylic spherical vessel with 26 3'' PMTs inside.



Left: Exploded diagram of the KM3NeT optical module

KM3NeT DOM

R12199 PMT used for the first HK vessel prototype



Concept design 3'' PMT × 33

- **Small PMTs** are commercially available and more performant PMTs are corrently under development → Looking into 3" PMTs with superior timing resolution
- Better resolution, photon counting and directionality wrt one large PMT
- PDs and electronics arranged within a pressure resistent vessel
- Ongoing mPMT optimization studies based on simulation
- R&D on PMT read-out system under way

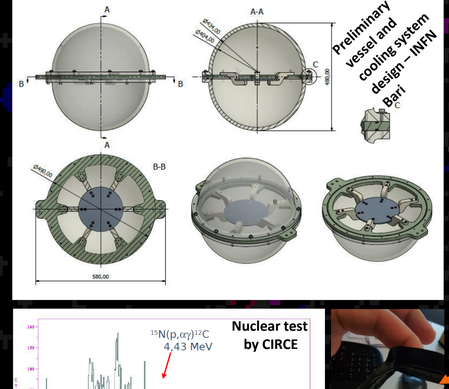
An initial prototype is being realized in INFN-Napoli, in collaboration with the INFN and the Polytechnic of Bari. It will be ready by summer 2017.

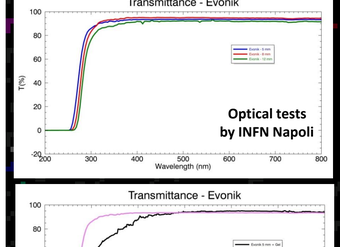
Vessel studies

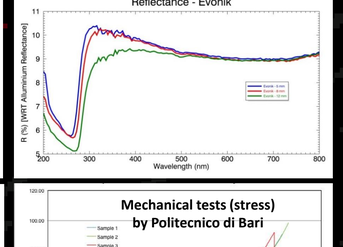
Tests on acrylic samples from several companies

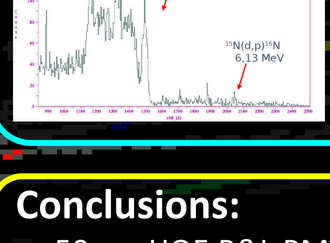
- No radioactive contamination (e.g., ^{40}K) due to acrylic instead of glass
- Optical and mechanical tests have been done
- Water-absorption nuclear and radioactive-contamination tests are ongoing in the CIRCE in Caserta (SUN) and in the Laboratori Nazionali del Gran Sasso (L'Aquila - Italy).

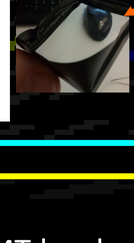
At this stage, selected the *Plexiglas GS UV Transmitting* by Evonik.

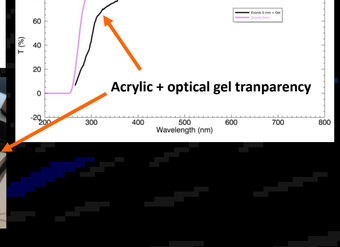


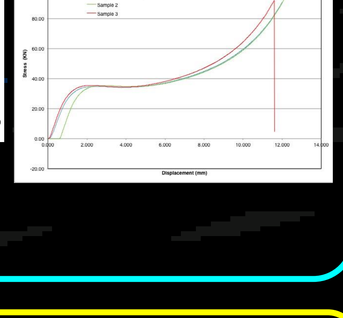












Reference
1) Poster background, credit by «Images of Super-Kamiokande events from tscan» (http://www.ps.uci.edu/~tomba/sk/tscan/tscan-pic-03-acs.gif)
2) Yuji Okajima, «Performance Evaluation of 50cm Photodetectors for Hyper--Kamiokande», poster for Neutrino 2014 at the GSU, Boston (US) (https://indico.fnal.gov/getFile.py/access?contribId=330&sessionId=30&resId=0&materialId=poster&confId=8022)
3) Y. Nishimura, «Development of a High-Resolution 50 cm Photodetector for Hyper-Kamiokande», poster for NNN16 at IHEP, China
4) G. De Rosa & T. Fuesels, «A multi-channel optical module for the Hyper-Kamiokande experiment», poster for Neutrino 2016, South Kensington, London

Conclusions:

- 50 cm HQE B&L PMT has been established for 60m-depth water tank as per Hyper-K baseline design
- 50 cm HQE HPD under development to improve resolutions
- mPMT under development → initial prototype ready by summer 2017