Large Area Photo-Detection System using 3-inch PMTs for the Hyper-Kamiokande Outer Detector

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5th International Workshop on New Photon-Detectors (PD18)

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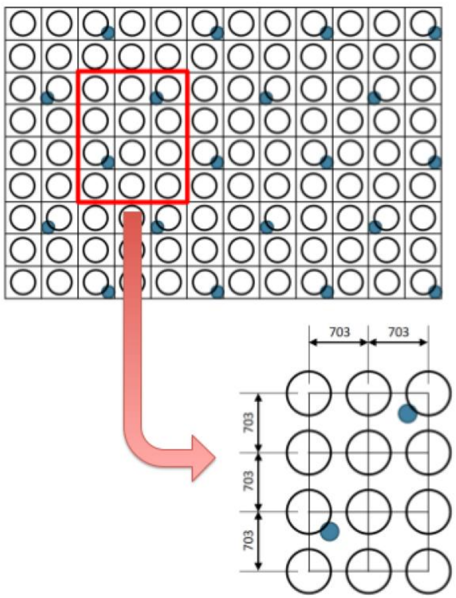
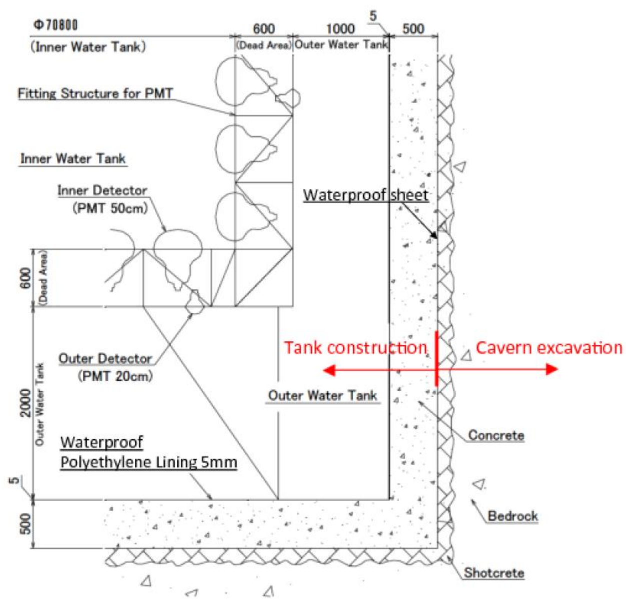
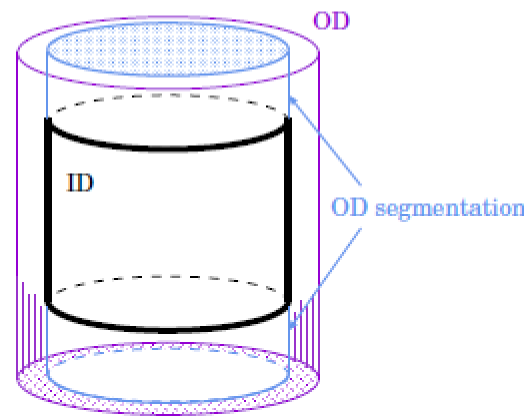
Hyper-K Outer-Detector

- Design based on Super-K Outer-detector
  - ~ 6700 20 cms (8”) PMTs facing outward
  - → 1% coverage
  - OD Water thickness : 1m barrel / 2m top and bottom

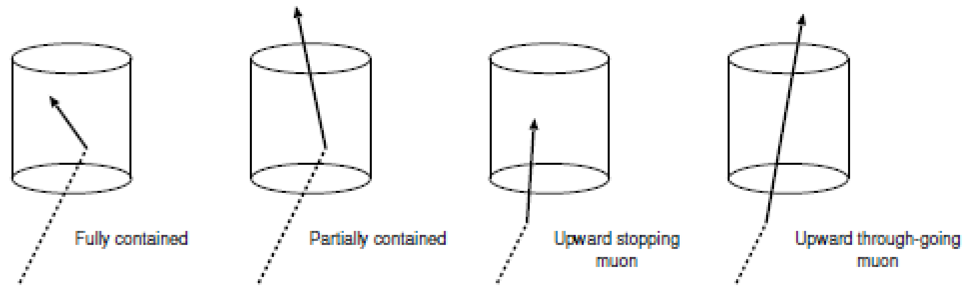






Physics requirements

- The outer-detector is a **veto** for background particles
  - Classify **Fully Contained** (FC), **Partially Contained** (PC), and **Upward-going** muons (UPMU)



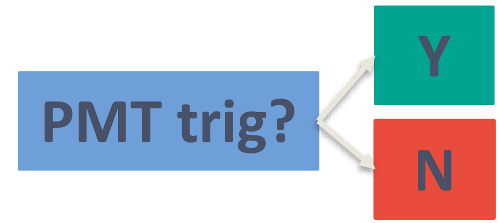
ATMnu analysis

  - Shield from **gamma** particles

- OD hits information are use in a “binomial way”
  - We want to know if they are clusters of hits → Nb of PE matters less

Physics requirements

- The outer-detector is a **veto** for background particles, based on **PMT triggers hits clusters above threshold**
- We can define the information entropy of our signal
  - $H = \log_2 2^N$ with N = # of **bits** of your system
  - In our case, entropy = Nb of PMTs !



- Using Super-K experience, we can study the minimum entropy required to classify events, which is directly related to the #PMTs
  - Increasing number of PMTs linearly increase the amount of information

Increase # of PMTs

- In order to make the system to work, we need to set a system with efficient trigger

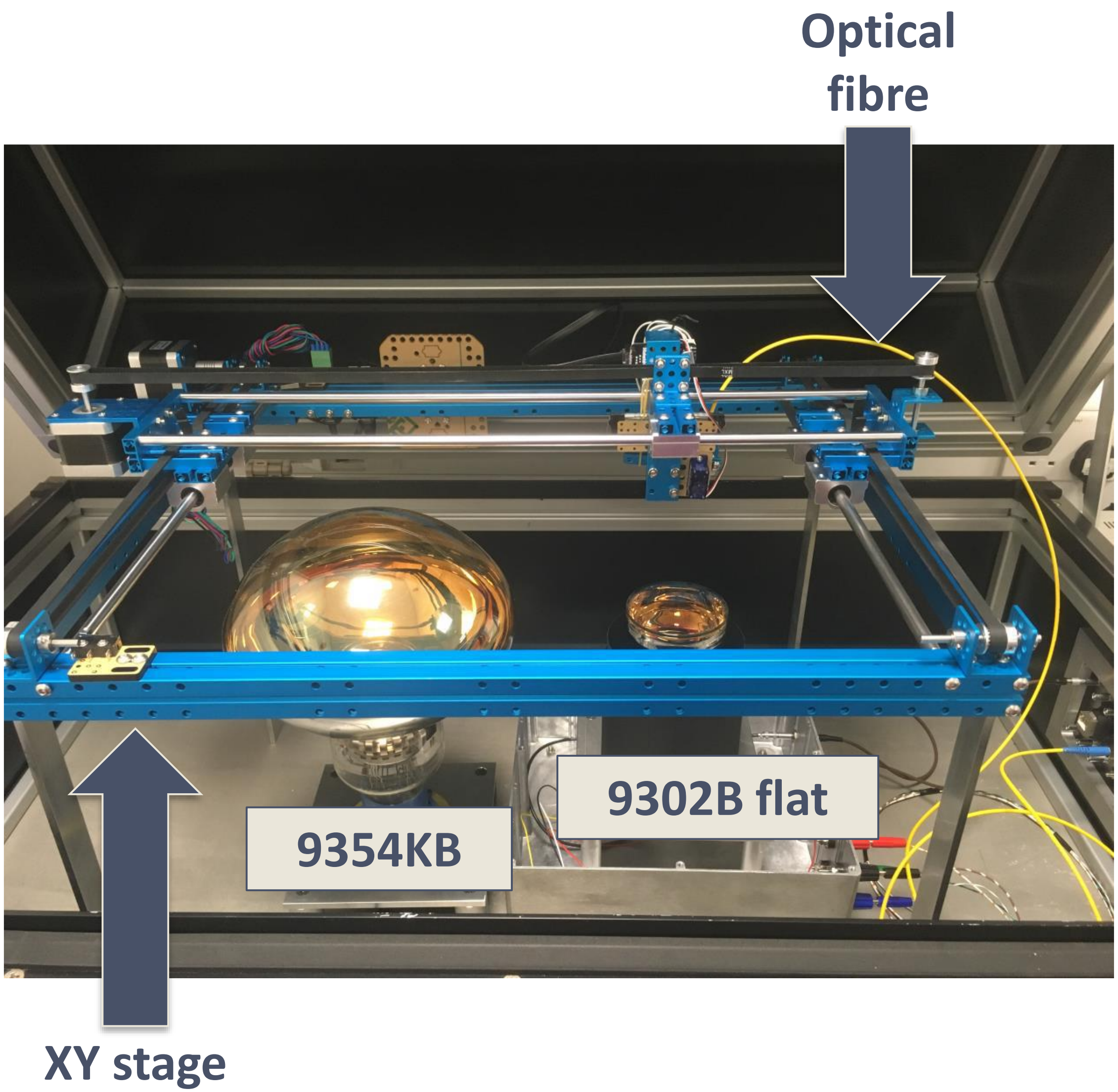
Good light collection

Low dark rates for low PE threshold

Measurements rig setup

Setup at QM : Dark box

- PMT connected to HV siting outside of the dark box with panel wires
- **Positive HV**
- Light injected with optical fibre at **1cm** height from the photocathode
- Optical fibre set **perpendicular** to the photocathode
- Measurements taken after a few hours with HV ON
- Dark rates measurements taken **24h** after HV ON



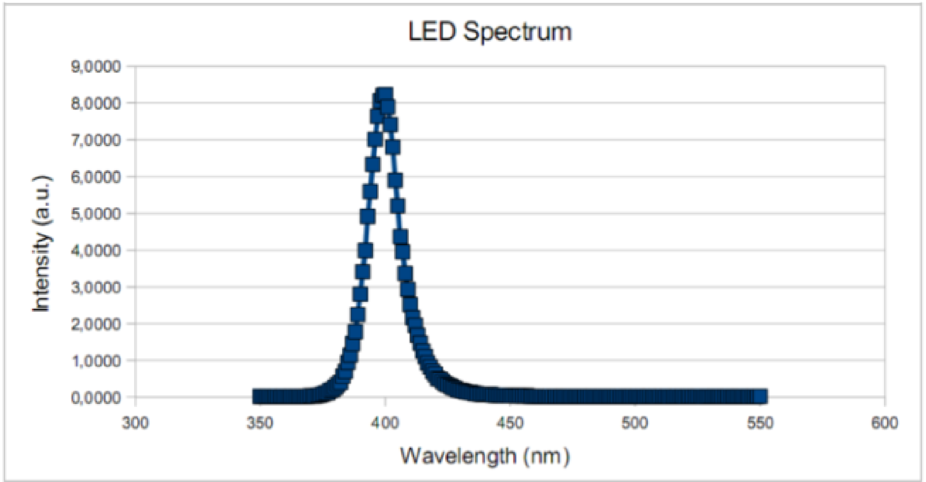
Setup at QM : Light Injection

- 400 nm LED
- From single photon to few thousands characterization
- Fast timing ~ 1 ns
- 2 trigger mode :
  - Low frequency ~kHz
  - High frequency ~MHz
- Acquisition taken with trigger mode both w/ and w/o optical fibre connected

Caen SP5601 Led Driver
with a OSSV5111A High Power LED

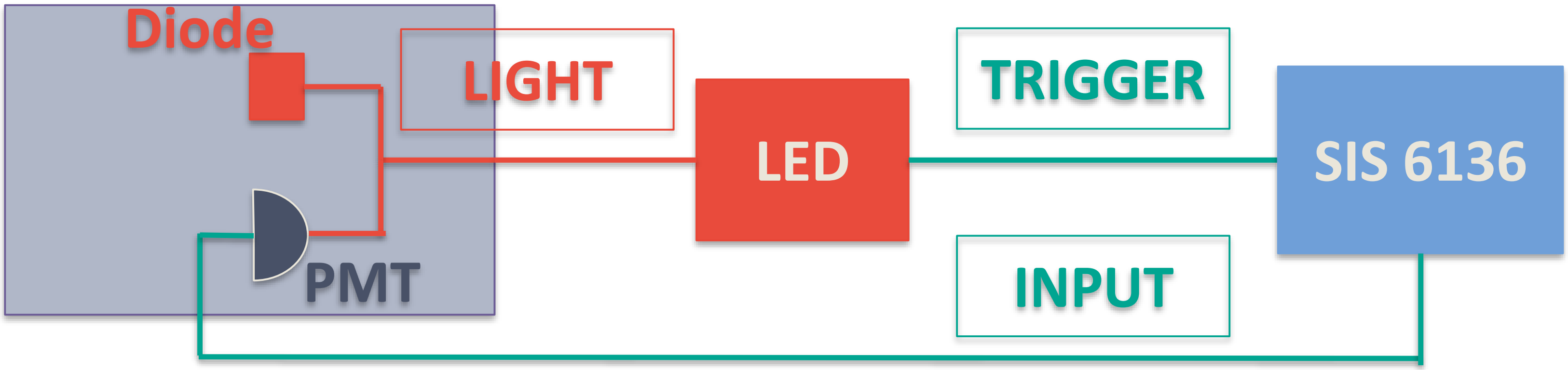
Setup for dark counts

- LED driver used as **external trigger**
- Optical fibre **NOT** connected



Emitted light spectrum. The peak is at 400 nm

Setup at QM : Acquisition procedure



- LED injection system also use as external trigger for the DAQ
- Photodiode connected with a 1:99 coupler for **timing** reference
- Waveforms are saved on a VME SIS 6136
  - Signal sampled at 250MHz and recorded on 1024 samples (4096ns)
- Waveforms are converted from ASCII format to friendly ROOT format
- Signal search and charge histogram are performed after in software

Dark rates measurements

Dark count algorithm

- We want to measure the dark counts without prior knowledge of the PE position
- In Hyper-K, there is no hardware trigger on the OD system :
  - Counting hits in a time window from an external trigger

Search dark pulses signals

- FOR loop on all signals :
  - Perform a sliding window integration
  - N_{window} : 16 samples (64ns)
  - Create and fill histogram H_{window} with integral of sliding windows
  - Get mean value of H_{window} to define dark count threshold

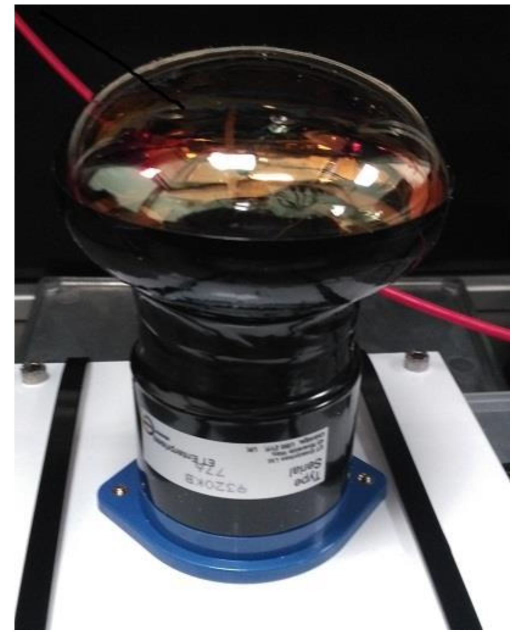
Fit charge histogram

- FOR loop on all signals :
  - Perform a sliding window integration
  - N_{window} : 16 samples (64ns)
  - IF Int(Window) > mu
    - Extract signal window
    - Compute integral
    - Fill charge histogram Hcharge
  - ELSE
    - Divide signal in windows of Nwindow
    - Compute integral
    - Fill charge histogram Hcharge

Ultimate goal of this method would be to provide calibration and dark count measurements at the same time !

PMTs candidates for the OD

Hamamatsu 3” and 3.5”	HZC XP82B20	ETEL 9302KFL

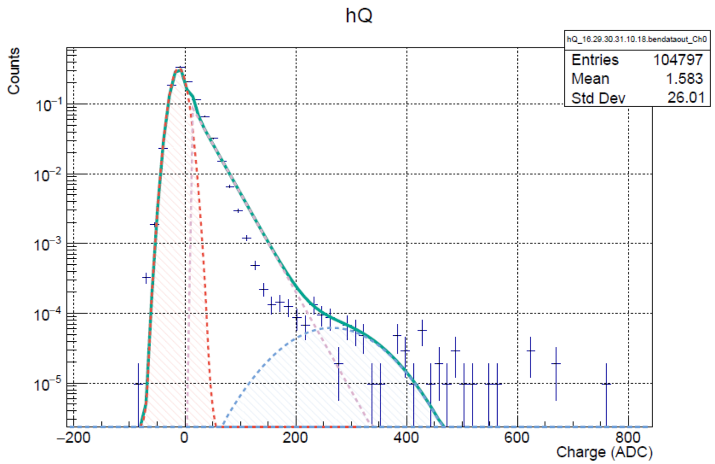


- R14374(HA)
- R14689(HA)

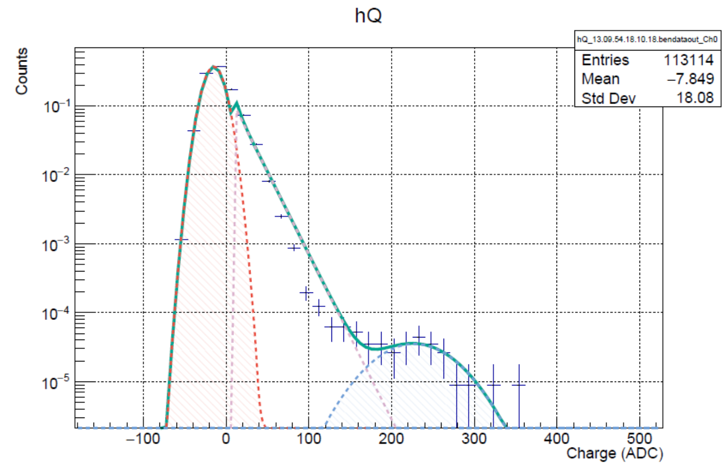
Dark rates measurements for Hamamatsu PMTs

3”

R14374

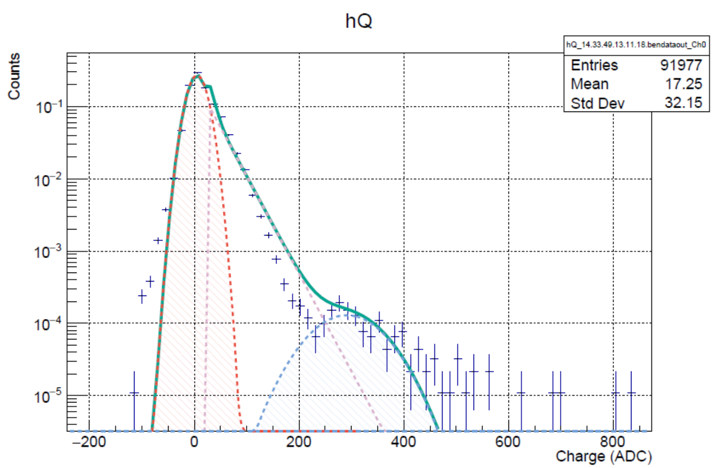


R14374HA

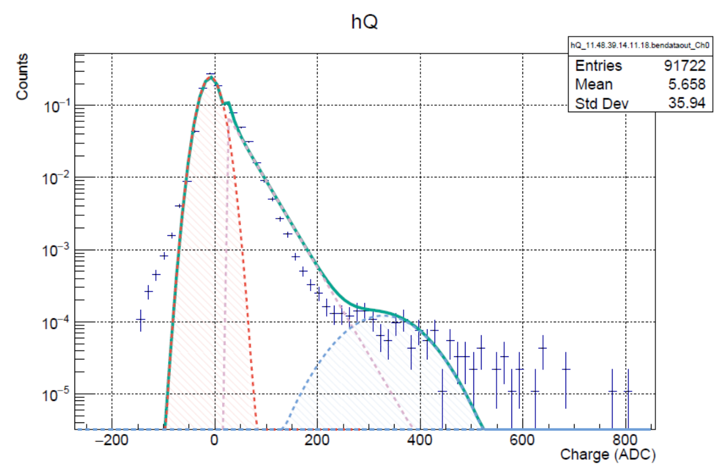


3.5”

R14689



R14689HA



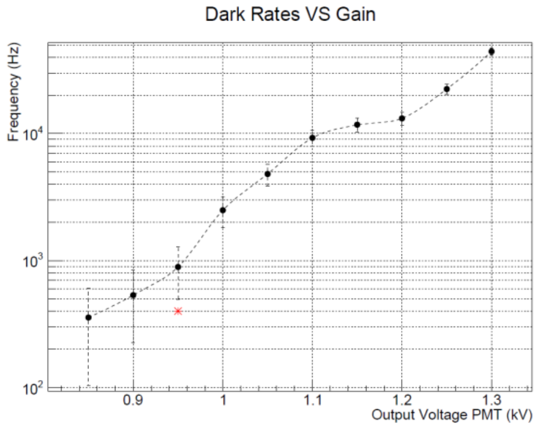
Dark rates measurements summary

Model	Gain	Dark rates	PE Res
R14374	$2.7 \pm 0.1 \times 10^6$	210 ± 80 Hz	30%
R14374HA	$3.3 \pm 0.1 \times 10^6$	290 ± 60 Hz	21%
R14689 (3.5”)	$2.8 \pm 0.1 \times 10^6$	250 ± 100 Hz	17%
R14689HA (3.5”)	$2.9 \pm 0.1 \times 10^6$	240 ± 90 kHz	18%

- PMTs meet requirements for dark counts in Hyper-K OD
  - Up to 6 - 3” PMTs per supermodule, or 15k for the whole detector
- Other candidate : 3” ETEL 9302KFLB
  - Measurements agrees with quoted constructor value of 400Hz at gain 3×10^6
- All these measurements have been taken at 20°C, need to define procedure to measure dark counts at ~10°C

Preliminary results to demonstrate the new algorithm method, need more measurements to assess robustness

3” ETEL 9302KFLB



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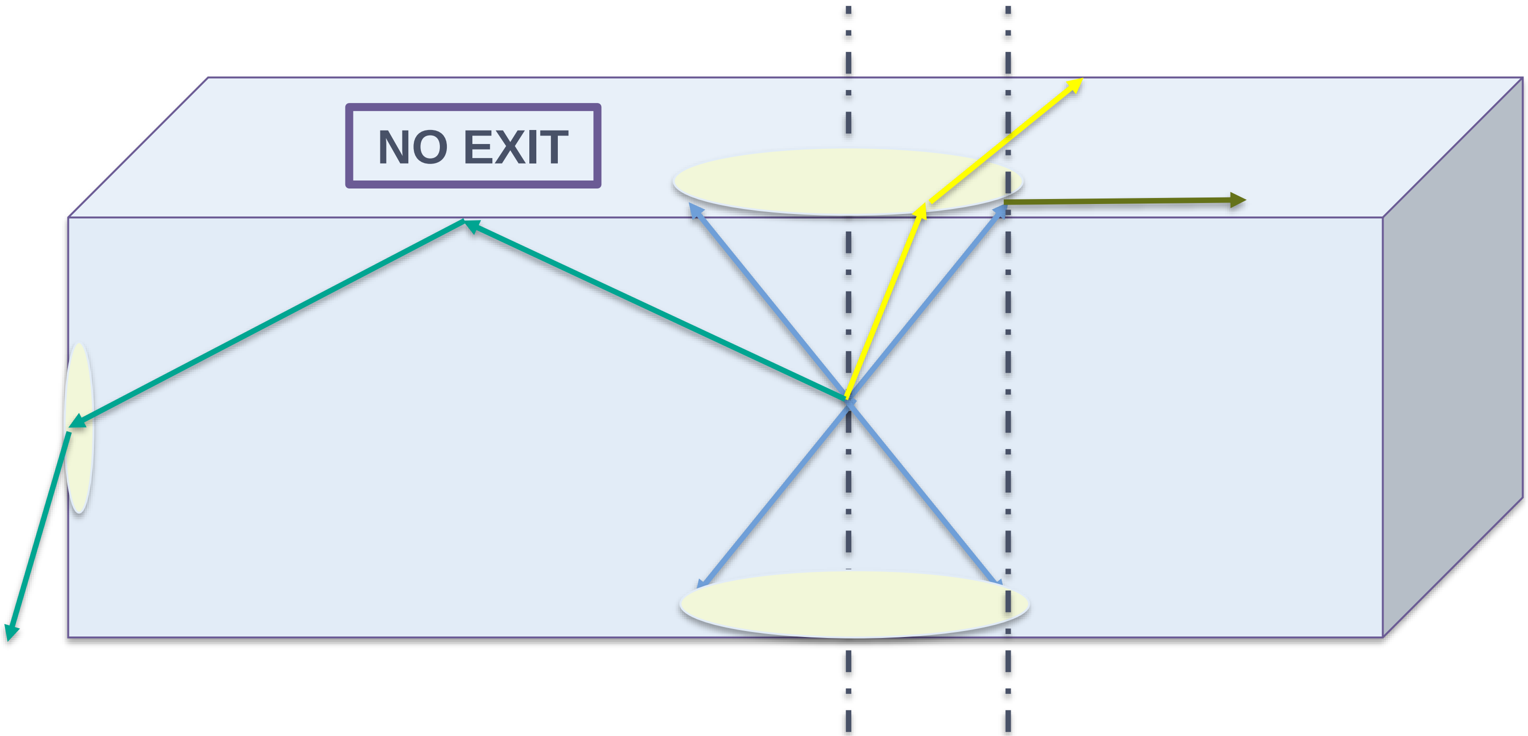
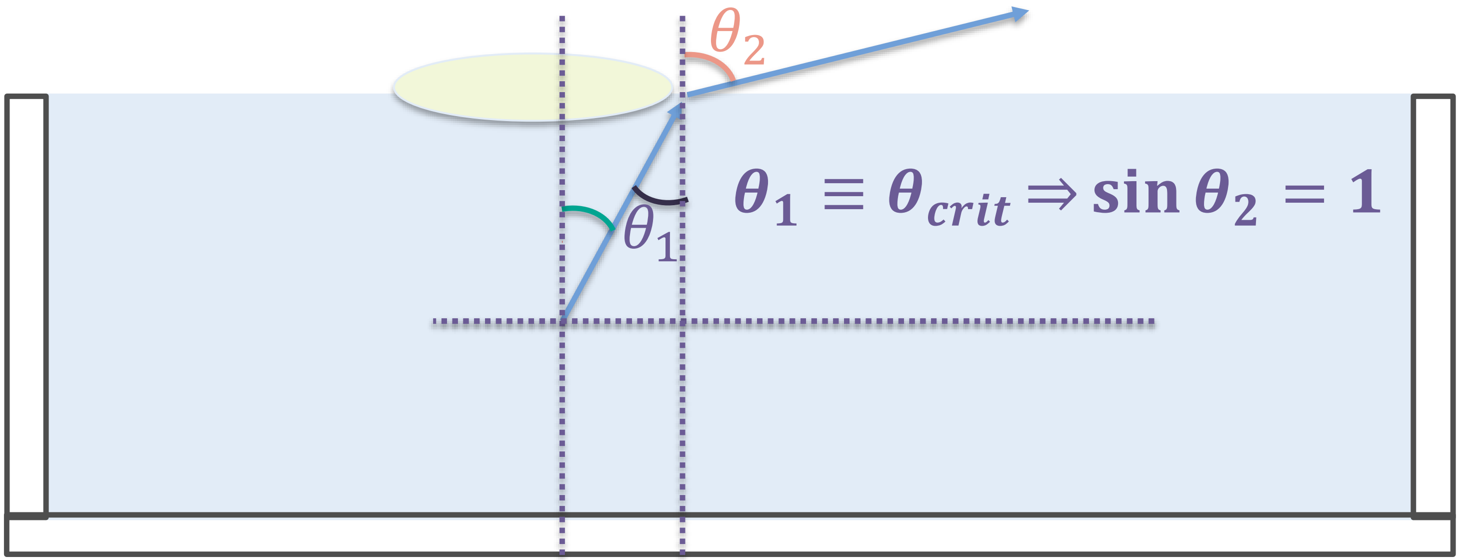
Light collection enhancement system

Photons traps

- WLS plates are made of plastic, with $n_{WLS} = 1.58$
- They are at the interface with water, $n_{water} = 1.33$
  - When photon exit the plastic they bend **towards** it !



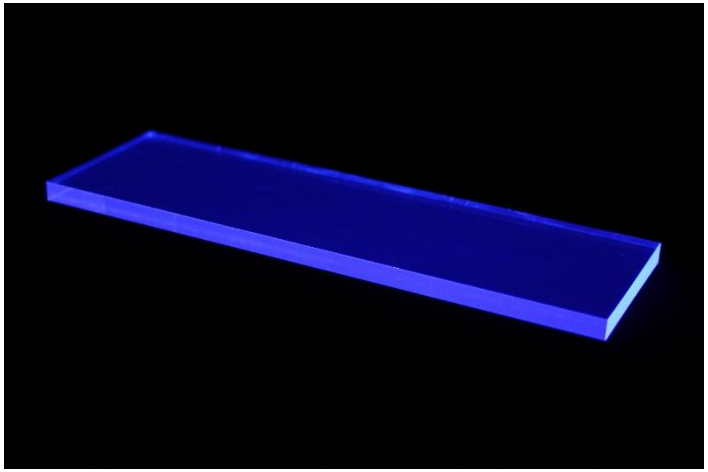
Photons traps

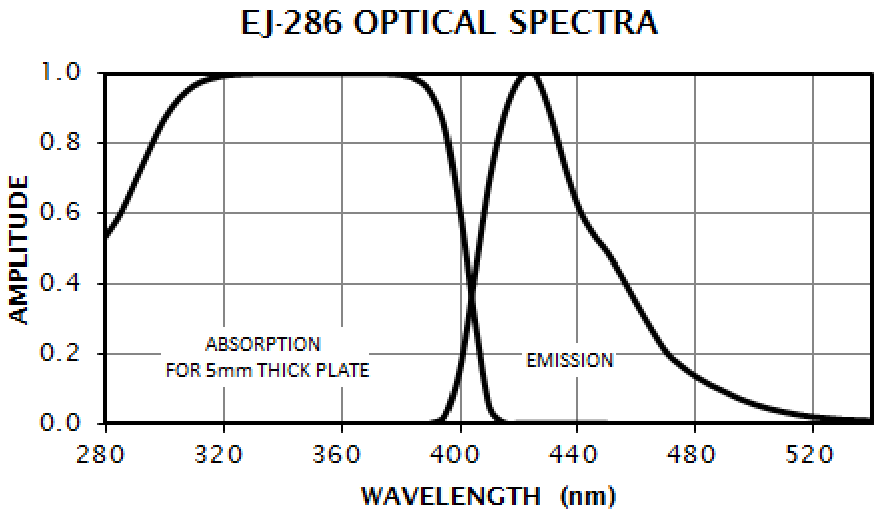


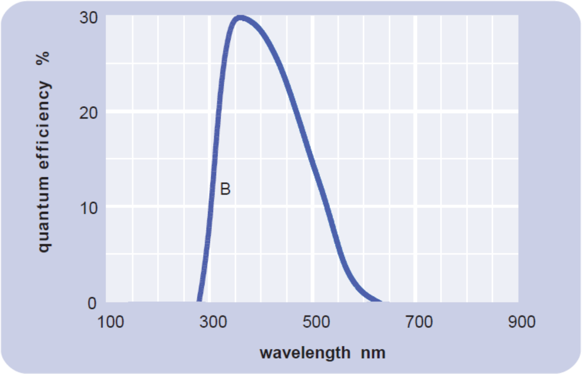
- Compute critical angle when light is trapped
  - $\theta_{crit} = \sin^{-1}(^{n_{water}}/_{n_{WLS}}) = 57° \cong 1$rad
- Then compute the “collection probability” by ratio of solid angle
  - $P_{\mathrm{CE}} = 1 - \frac{2\pi(1-\cos\theta_{\mathrm{crit}})}{2\pi} = \cos\theta_{\mathrm{crit}}$
- P_{CE} corresponds to the amount of light trapped inside the plate, i.e. the light reemitted after absorption → **54% in water**
- Add convolution with plate area and PMT QE → **300% light enhancement**

Candidates WLS plates

- Eljen EJ-286

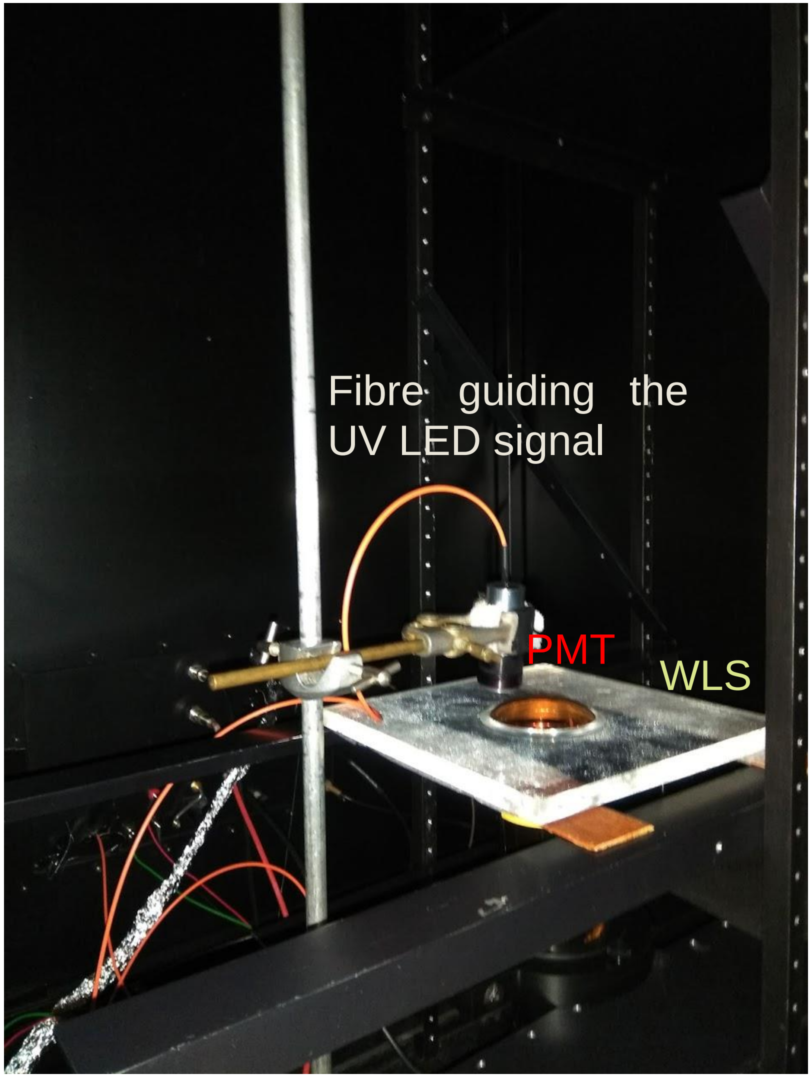






- Max absorption in UV (Cerenkov photons)
- Max emission at **420 nm**
  - Matches well quoted PMTs QE
- Material **defines** critical angle
  - Light collected = f(Area)

Setup measurements

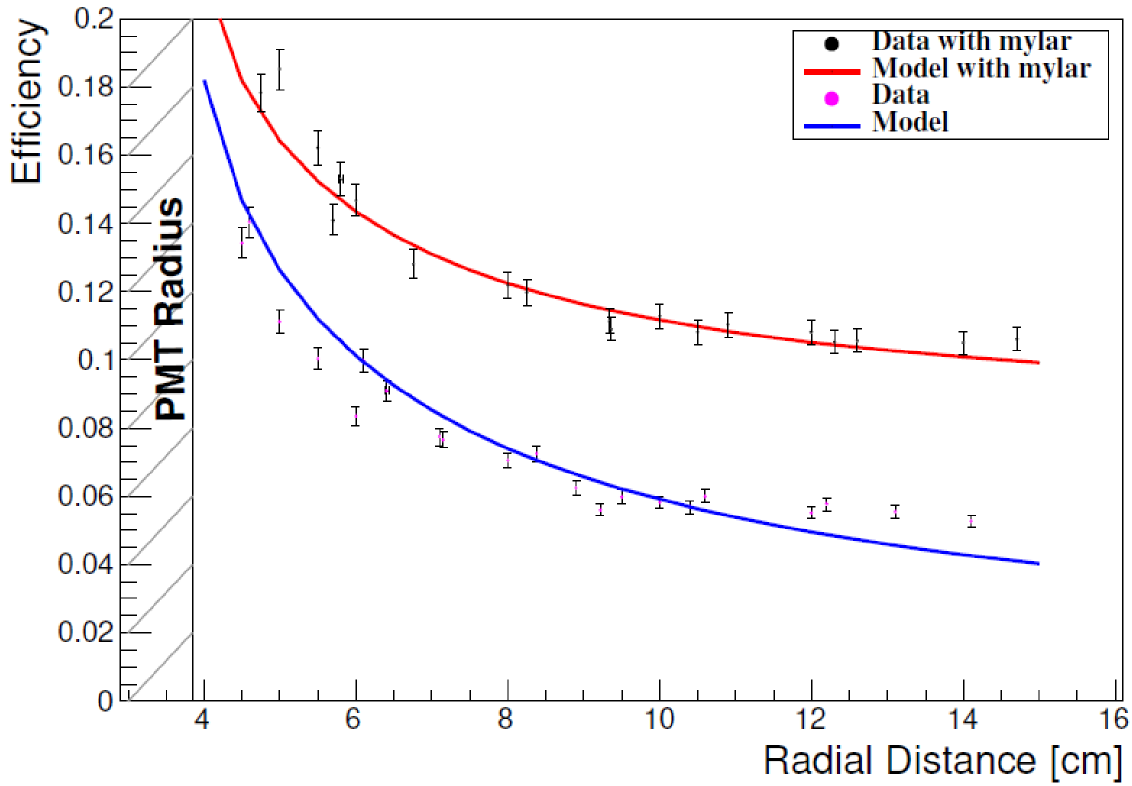


- 3“ PMT (9320KFLB) and Wavelength Shifter Plate (WLS – EJ286)

- UV LED @ 375 nm
- Neutral Density filter @ 2.0
- A pulser provides signal to the UV LED with rate: ~ 10 kHz
- A fibre is used to guide the LED signal to the PMT.

Measurements

- Fits come from model of light reflexion inside the WLS plate

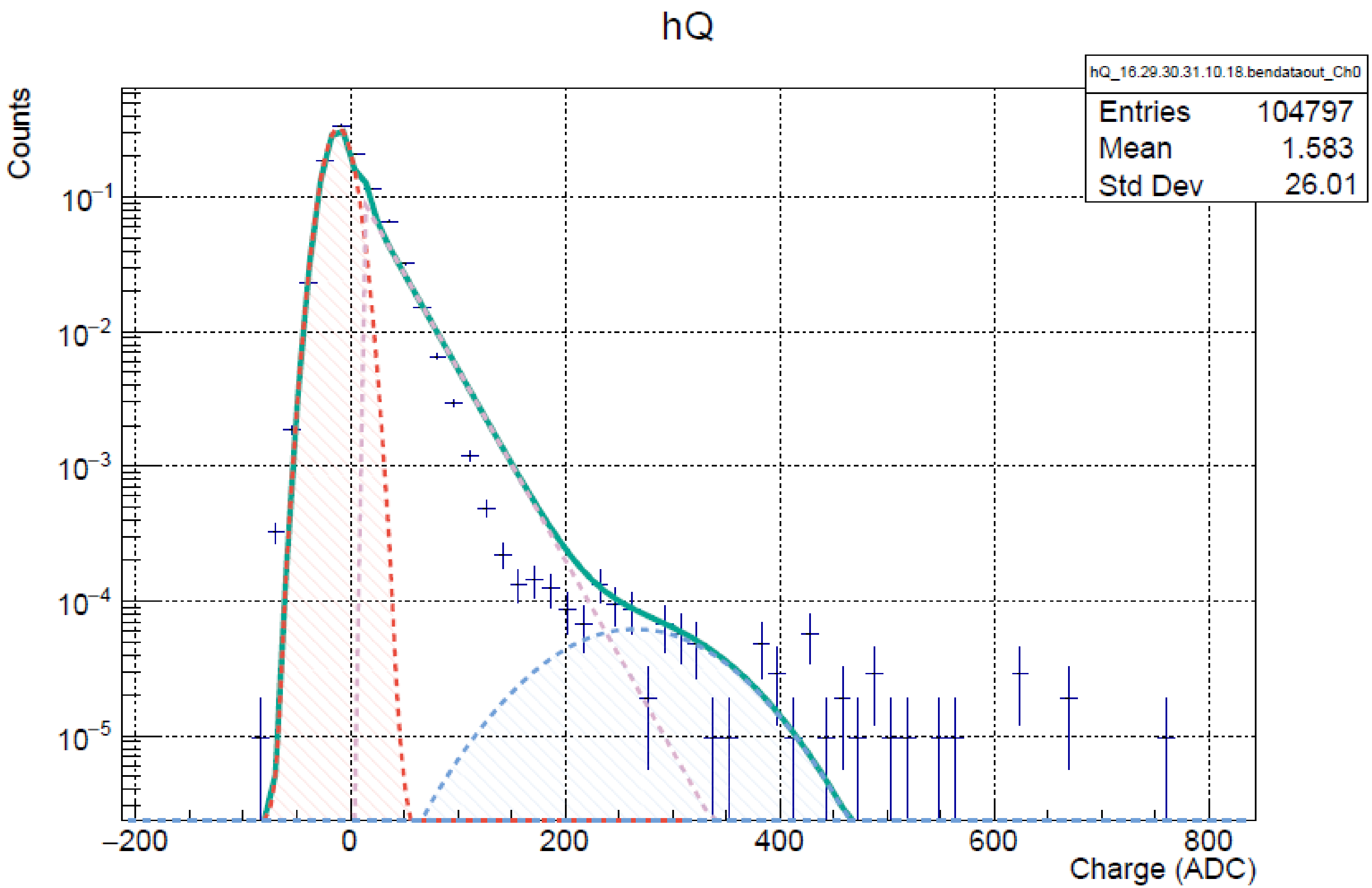


Summary

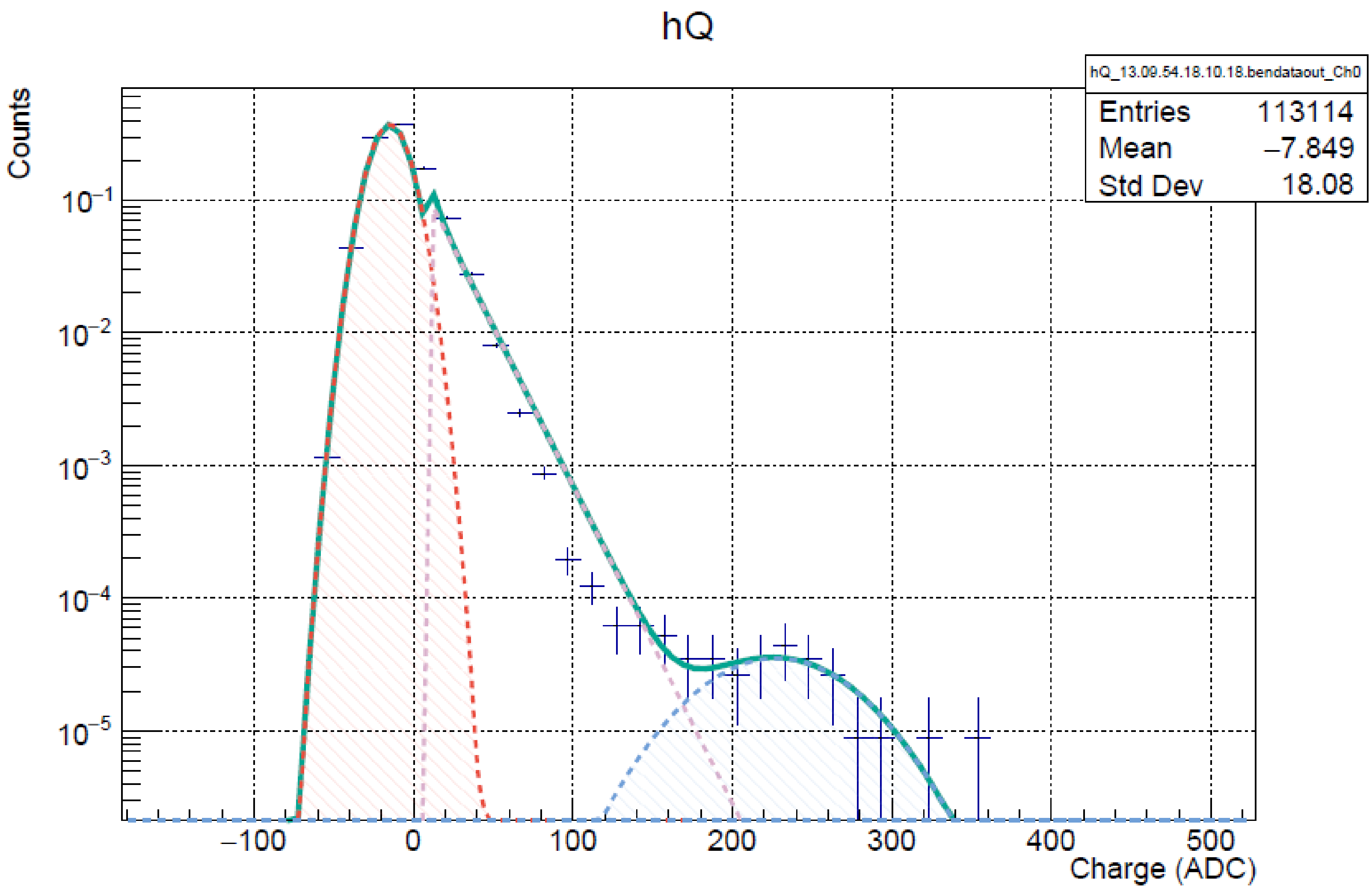
- 3” and 3.5” Hamamatsu PMTs candidates for the OD matches the requirements for dark counts, as well as the ETEL9302KFL
- Awaiting delivery for HZC 3.5” PMTs for characterization
- A new method of measurements dark counts while calibrating the PMTs is explored and show promising results
- More measurements to come :
  - Noises : afterpulses, undershoot
  - Light : Light collection, relative quantum efficiency
- Light collection enhancement system is expected to provide +300% photons per PMTs
- The Hyper-K OD is implemented inside the **WCSim framework** (Geant4 simulation of Hyper-K) with the according dark rates measurements for small PTMs system

BACKUP

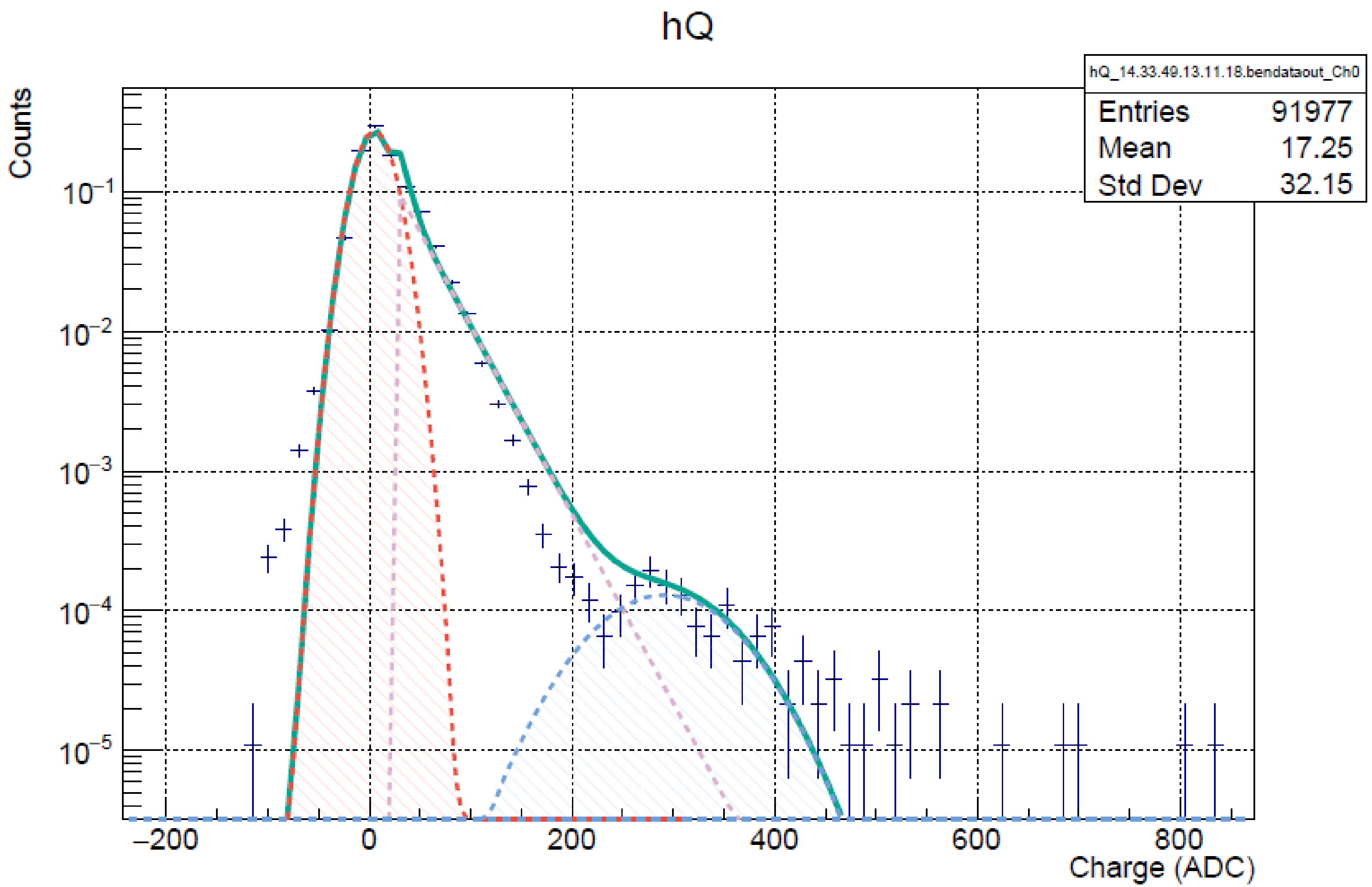
Dark rates : R14374



Dark rates : R14374HA



Dark rates : R14689 3.5”



Dark rates : R14689HA 3.5”