

Outer Detector (OD) calibration

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- Review of SK calibration
- Toward HK

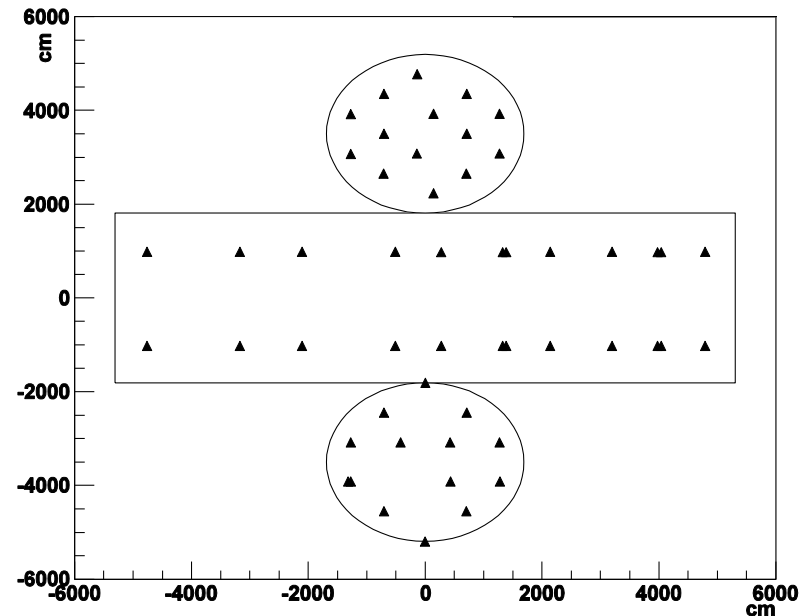
Review of SK OD calibration

Introduction

- OD is used primarily to identify incoming cosmic rays and ν interactions with particles leaving ID. OD is also important for:
 - rough reconstruction of very high energy events which saturate ID
 - separation of partially contained (PC) stopping and through-going events for atm.- ν oscillation analysis
 - selection of beam events with light in OD for T2K analysis
- OD is not used for precision reconstruction unlike ID:
 - OD charge reconstruction accuracy of about 10-20% and timing to 5-10ns are generally sufficient for SK-IV physics needs at this moment
 - OD calibration and simulation parameter tuning is done differently than for ID

OD calibration hardware

- Nitrogen-dye laser output goes to 52 optical fibers which go to OD
 - most OD PMTs see at least two fibers
- Light from fiber ends is diffused by mixture of optical cement and titanium dioxide
- Also, movable 70m optical fiber + diffuser ball ($\phi 5\text{cm}$, acrylic with MgO) occasionally connected to laser

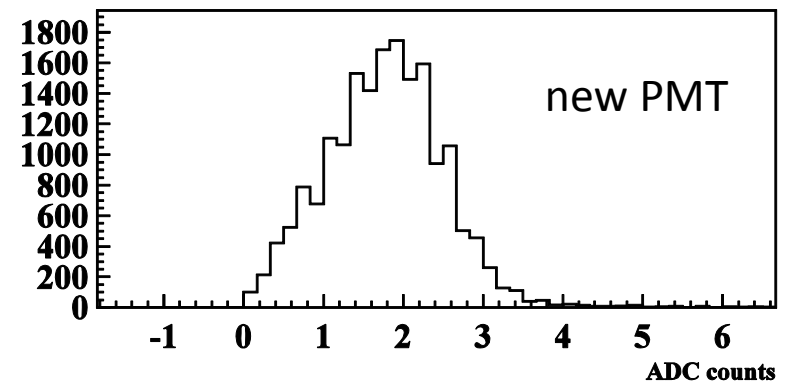
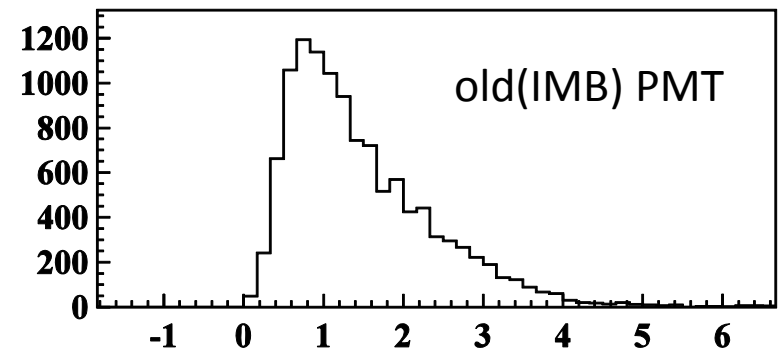


OD fibers mounted to outer walls

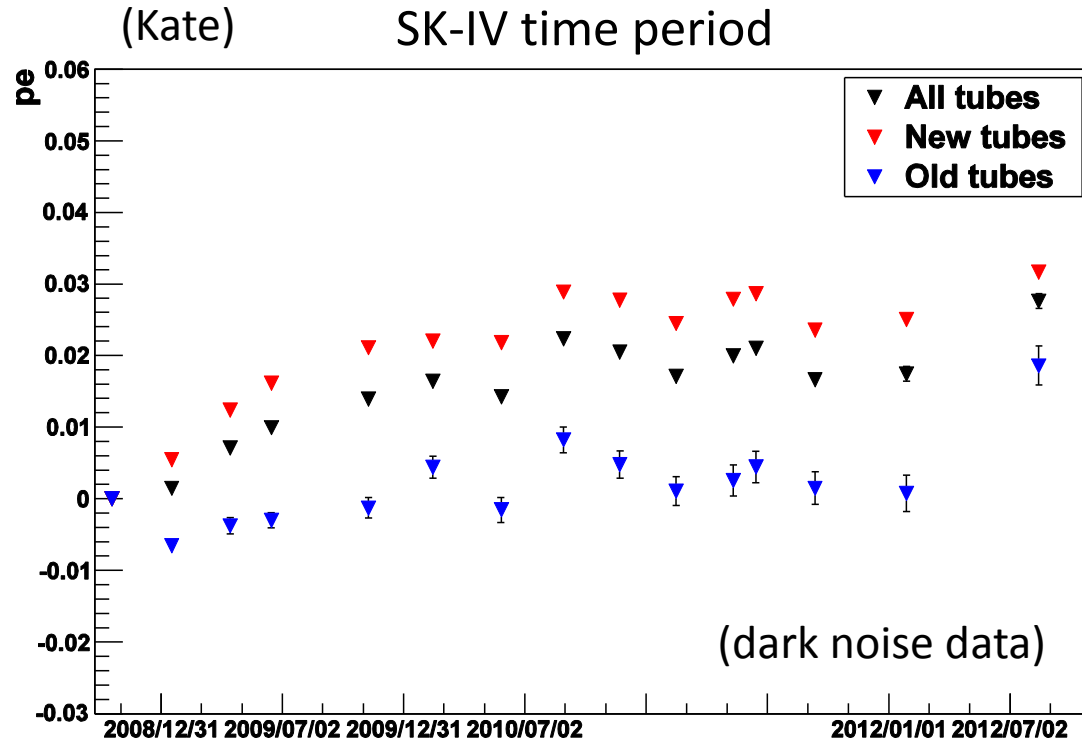
OD PMTs

- 1,884 8-in PMTs mounted on outside of steel structure dividing ID and OD :
 - 1,293 new PMTs (toward bottom)
 - 591 old(IMB) PMTs (toward top)
- New tubes showing generally much better peak-to-valley ratios
- Typical counts-per-pe values range from 2-6 determined with dark noise data, confirmed with lower intensity laser data
- SPE shape is implemented in SK detector simulation PMT by PMT

Single photoelectron (SPE) distributions



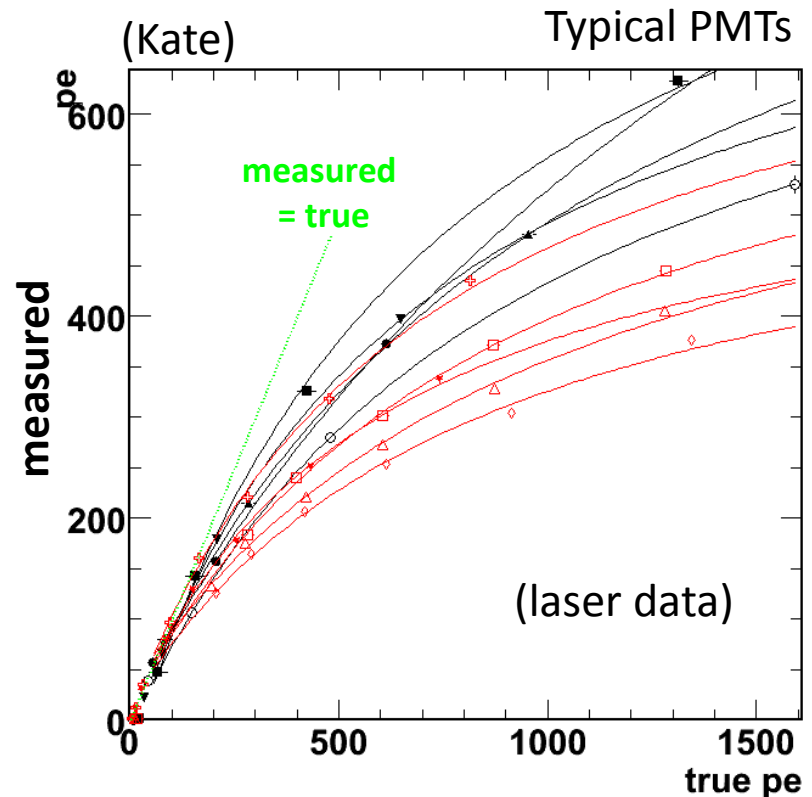
PMT gain drift



- Upwards drift effect is more pronounced for new PMTs
- Spread of old PMT counts-per-pe distribution tends to increase with time
- New counts-per-pe values are determined on approximately yearly

OD PMT nonlinearity

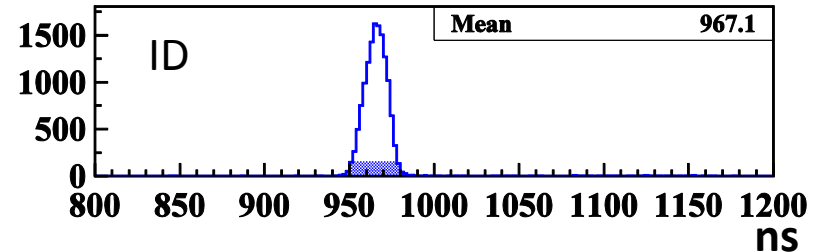
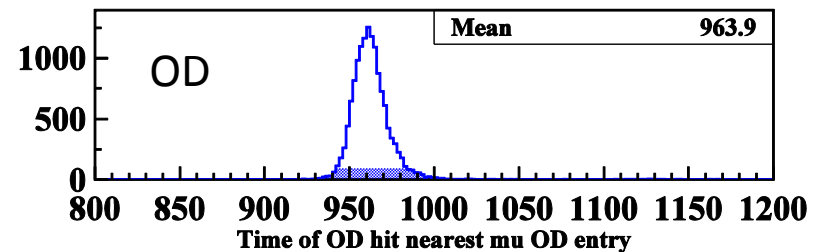
- Saturation effect is seen above a few hundred pe
- fitted with $Q_{meas} = Q_{true} / (1+k \cdot Q_{true})$ and implemented in detector simulation
- k is common for old PMT (~ 0.002) and new PMT (~ 0.001), respectively
- Due to lack of sufficient working fibers, k is determined with cosmic ray muons for SK-IV



OD timing calibration

- For relative timing offset, difference of PMT cable length is taken into account
- Global timing offset between ID and OD was determined with laser, and checked with cosmic ray muons
- Both relative and global offsets were determined to be within several ns

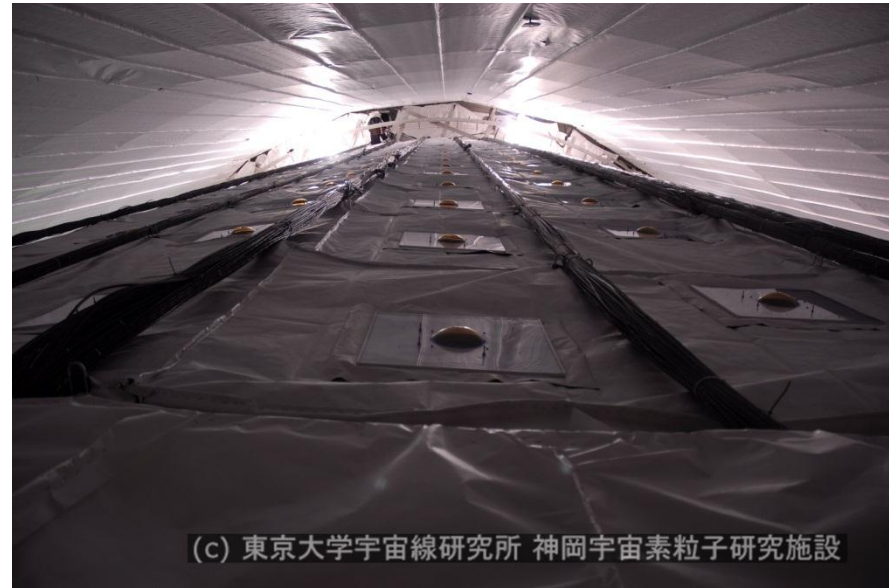
time for nearest hit PMT
(Kate) to cosmic ray muon track



(cosmic ray muon data in 2010)

Optical properties of OD

- Optical properties of OD materials are treated as parameters to be tuned in SK detector simulation:
 - reflectivity and transmissivity of Tyvek for top, bottom and barrel, respectively
 - light collection efficiency (QE and photon collection)
 - (water quality parameters are common between ID and OD)
- They are given nominal values based on measurements and tuned to match to cosmic ray muon data



Toward HK

- Should achieve better calibration than current OD calibration for any future better physics analyses using OD in HK
 - ex. T2K has shown that better OD reconstruction would be desirable for beam events with light in OD
- Necessary improvements:
 - longer lifetime light source and optical fiber with diffusing material
 - installation of collimated light source with known charge profile especially with bottom-to-top directionality for better detector simulation tune
 - better peak-to-valley photo sensor
 - implementation of structures of OD region in detector simulation
 - etc.