# Instrumentation and Calibration of a Water Čerenkov Detector

# Super-Kamiokande


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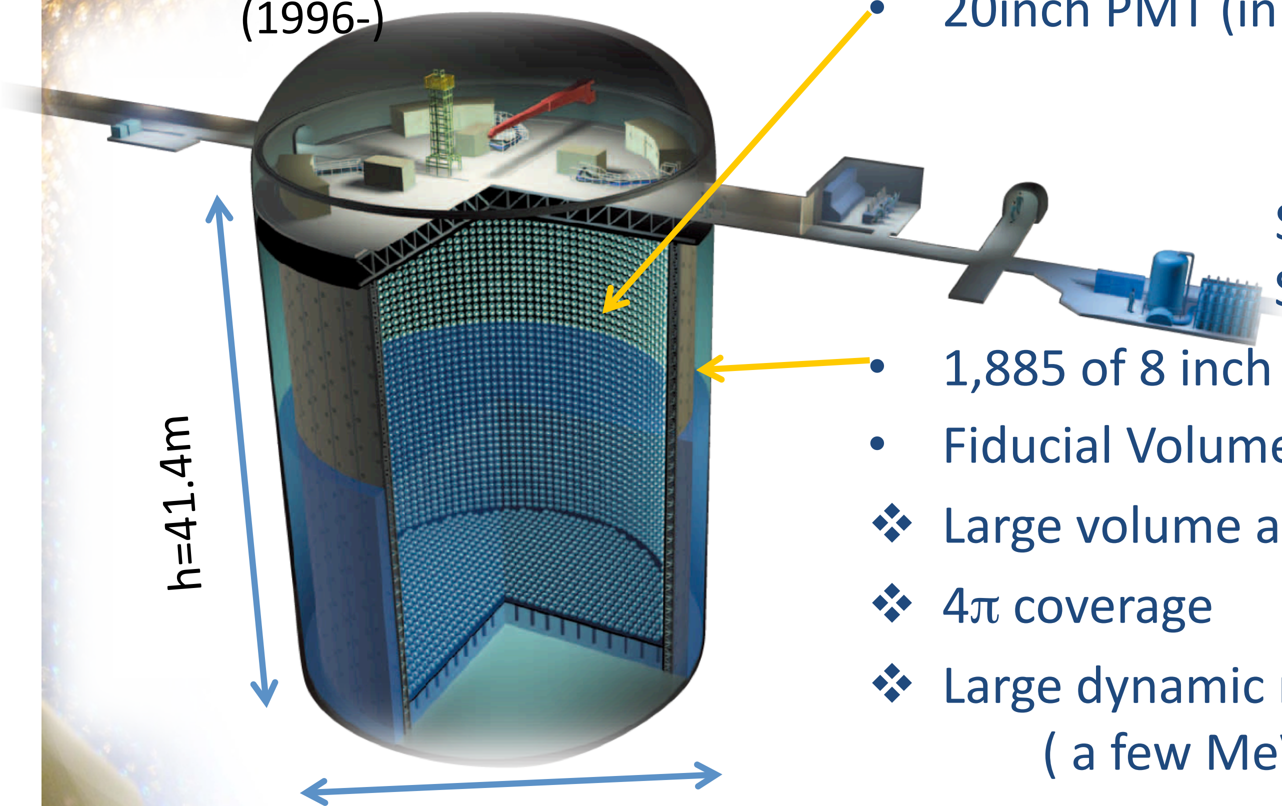
# Super-Kamiokande

Super-Kamiokande
(1996-)



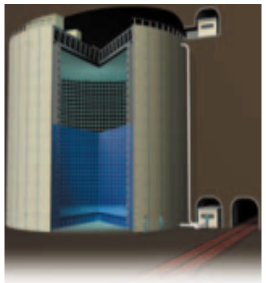

- 50,000 tons of Pure Water
- 20inch PMT (inner detector) #PMT, coverage

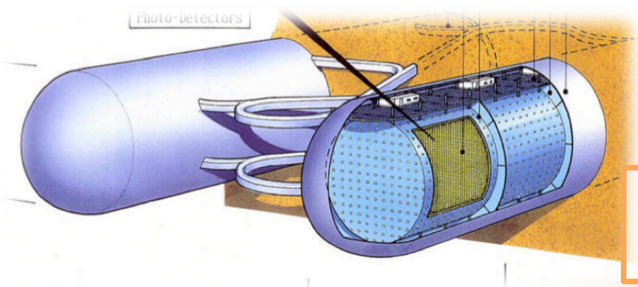
SK-I(1996-2001): 11146, 40%
SK-II(2001-2005): 5182, 20%
SK-III(2006-2008): 11129, 40%
SK-IV(2008-): New DAQ Elec.

- 1,885 of 8 inch PMT (outer detector)
- Fiducial Volume (>2m from wall) =22,500 tons

❖ Large volume active neutrino target
❖ 4π coverage
❖ Large dynamic range on neutrino energy ( a few MeV – TeV )

Kamiokande
(1983-1996)





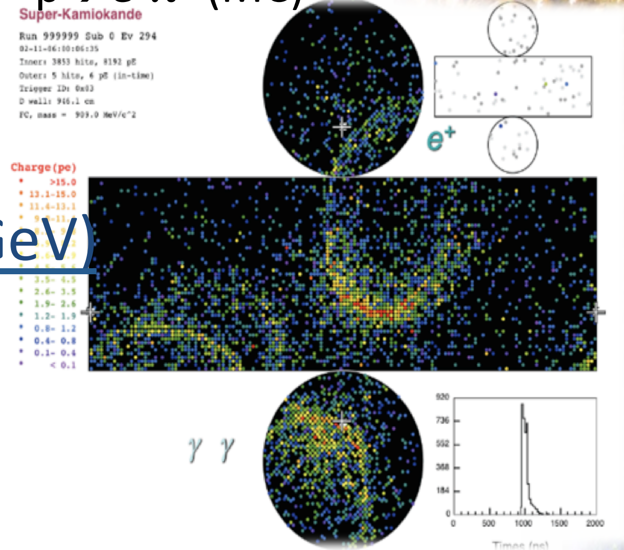
Hyper-K
(201X? -)

→M. Yokoyama
Friday 14:30

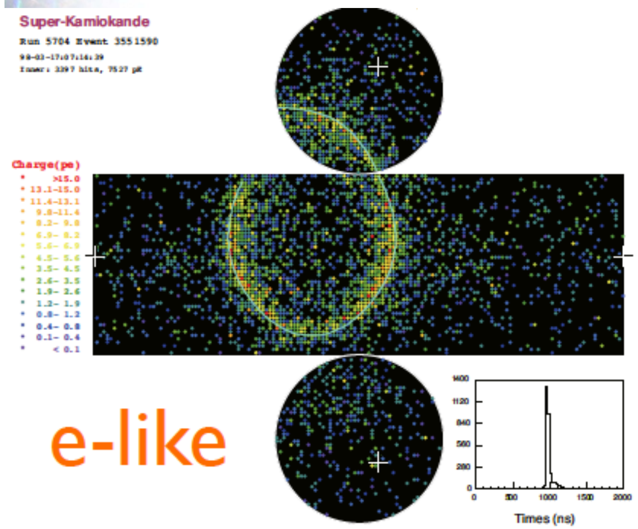
# Physics Targets of Super-Kamiokande

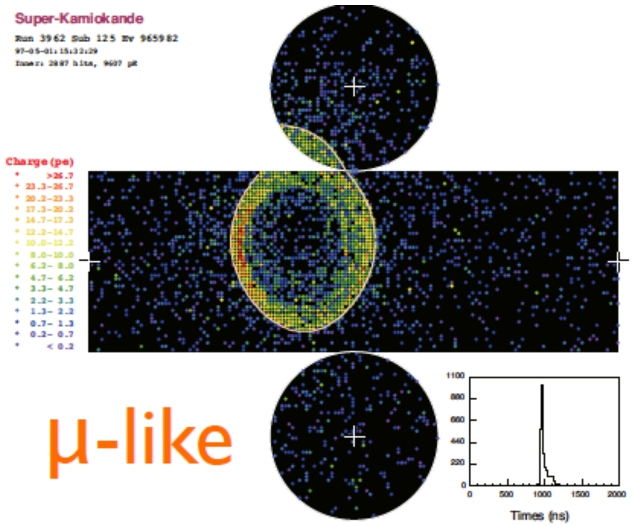
- Nucleon Decay ($M_p$~1GeV)
- Atmospheric Neutrino (Eν=100MeV~TeV+)
- Long baseline Accelerator Neutrino (Eν ~ 1GeV)
- Solar Neutrino (Eν= 4MeV ~ 10MeV)
- Supernovae Neutrino (Eν ~ 10MeV)
- WIMP, GRB, Solar Flare and more…

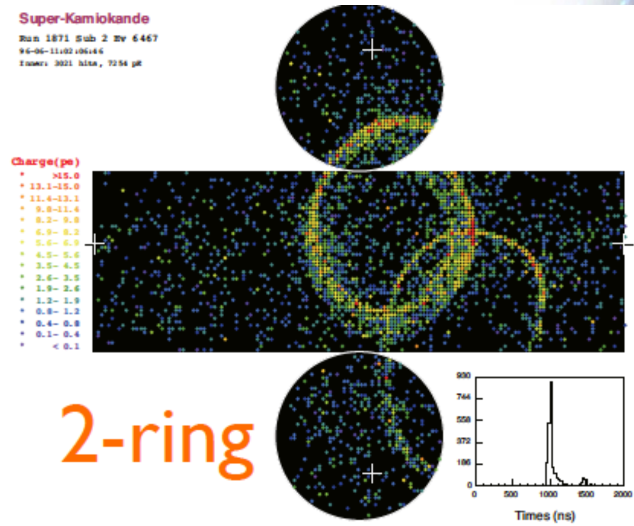
p→$e^+\pi^0$ (MC)



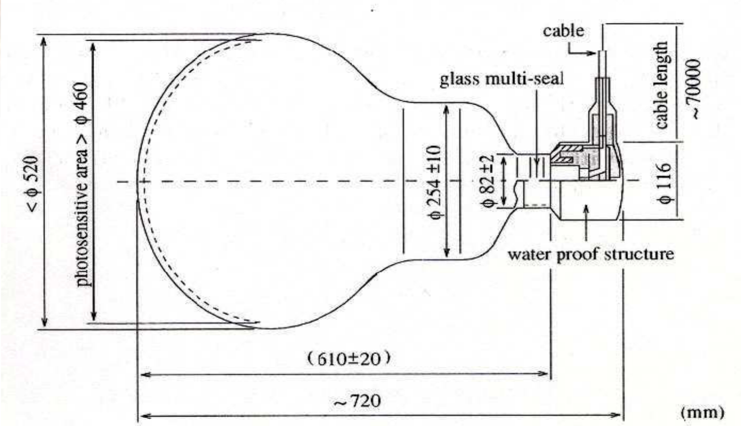

* This talk covers mainly on higher energy part



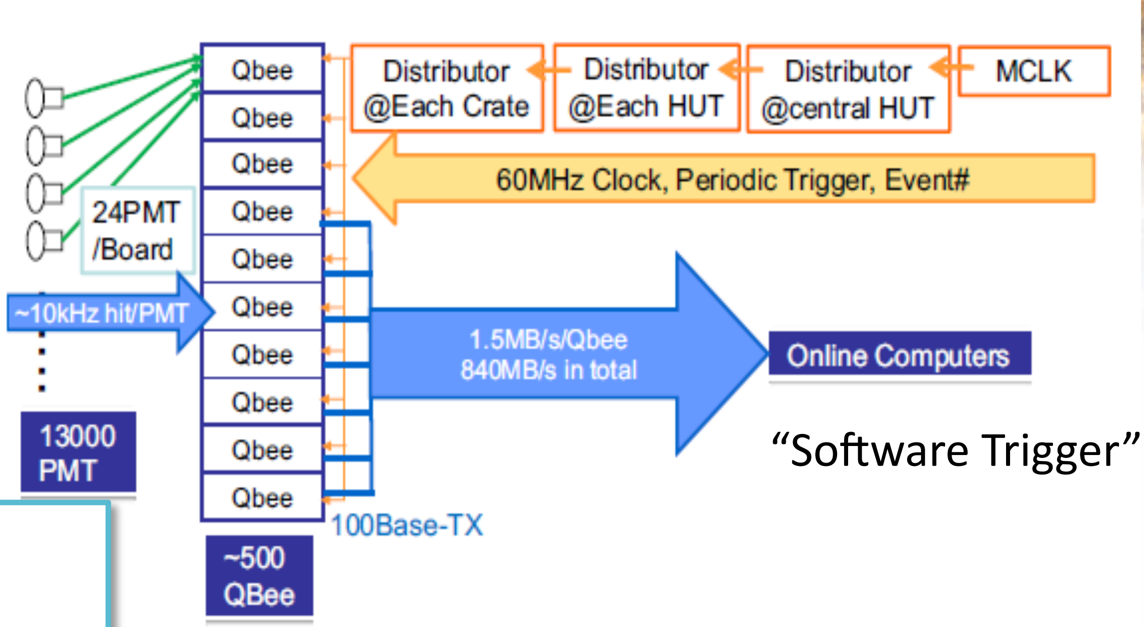
# Photo-Sensor: Hamamatsu R3600 20inch PMT




| | |
|---|---|
| Shape | Hemispherical |
| Photocathode area | 50 cm diameter |
| Window material | Pyrex glass (4 $\sim$ 5 mm) |
| Photocathode material | Bialkali (Sb-K-Cs) |
| Quantum efficiency | 22 % at $\lambda = 390$ nm |
| Dynodes | 11 stage Venetian blind type |
| Gain | $10^7$ at $\sim$ 2000 V |
| Dark current | 200 nA at $10^7$ gain |
| Dark pulse rate | 3 kHz at $10^7$ gain |
| Cathode non-uniformity | $<$ 10 % |
| Anode non-uniformity | $<$ 40 % |
| Transit time | 90 nsec at $10^7$ gain |
| Transit time spread | 2.2 nsec (1 $\sigma$) for 1 p.e. equivalent signals |
| Weight | 13 kg |
| Pressure tolerance | 6 kg/cm$^2$ water proof |

After the recovery of accident,
all the ID PMTs are
sheltered by FRP + Acrylic case
to prevent chain reaction of explosion

# DAQ Electronics (QBEE) after upgrade@2008




QBEE specification:

- QTC
  - A custom ASIC (0.35μm CMOS)
  - 3 input channel/chip,
  - 3 charge stage/channel
  - Dynamic range: 0.2pC – 2500pC (~0.1p.e. – 1200 p.e.)
- Multi-hit TDC
  - Atlas Muon TDC(AMT)
- Driven by 60MHz master clock and 60kHz periodic trigger
- TCP/IP readout
- On board calibration pulsar

Readout All hits above QTC threshold

→ Apply "Software Trigger" at Semi-Online

· Gate widthes

→ 40us for LowE/HighE events (solar/atm. nu)

→ 1000us for T2K spill trigger

→ 1.3us for super LE trigger (solar nu)

Redundant DAQ for very high trigger rate (nearby Supernova) will be implemented

→T. Tomura
Thu. 16:40

# Event Reconstruction for Atmospheric/LB ν & Proton decay

- Vertex Reconstruction

  ↓ PMT hit timing

- Ring Count

  ↓ PMT hit pattern

- Particle Identification

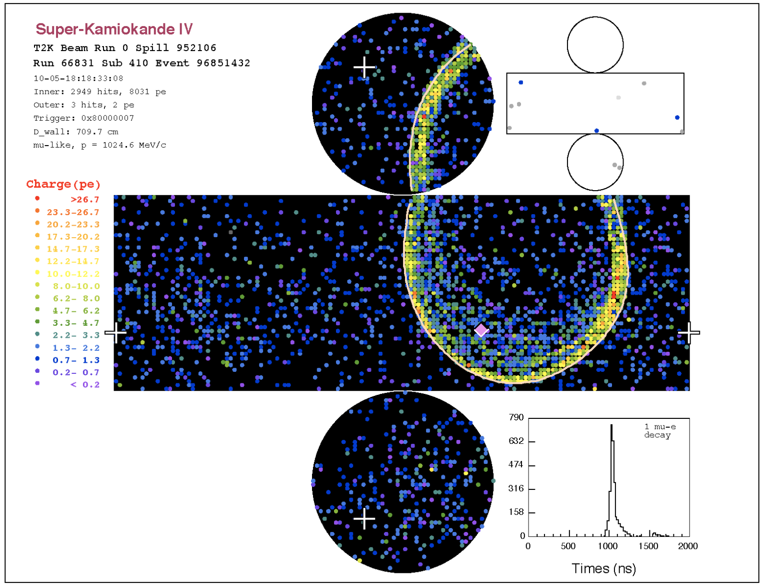
  ↓ PMT hit pattern & Cherenkov opening angle

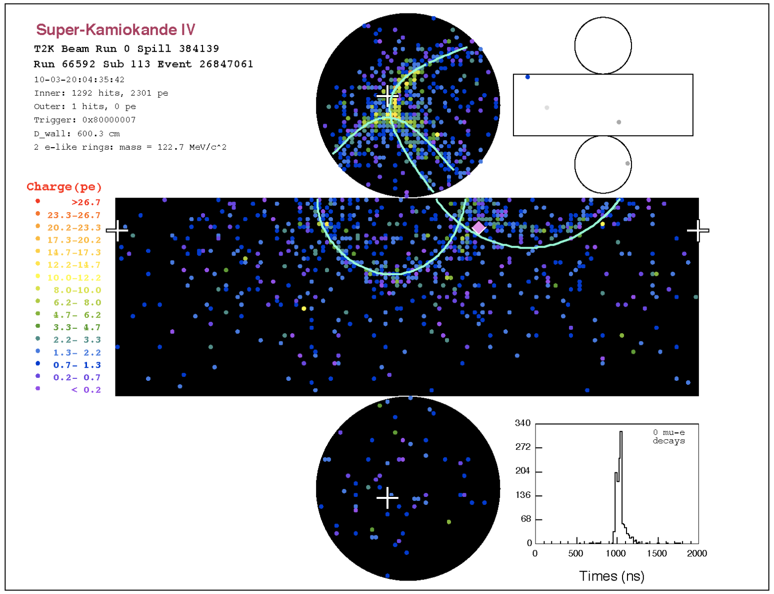
- Energy Reconstruction

  ↓ PMT charge sum in a ring + Correction for water transp.

- Muon Decay Electron Finding

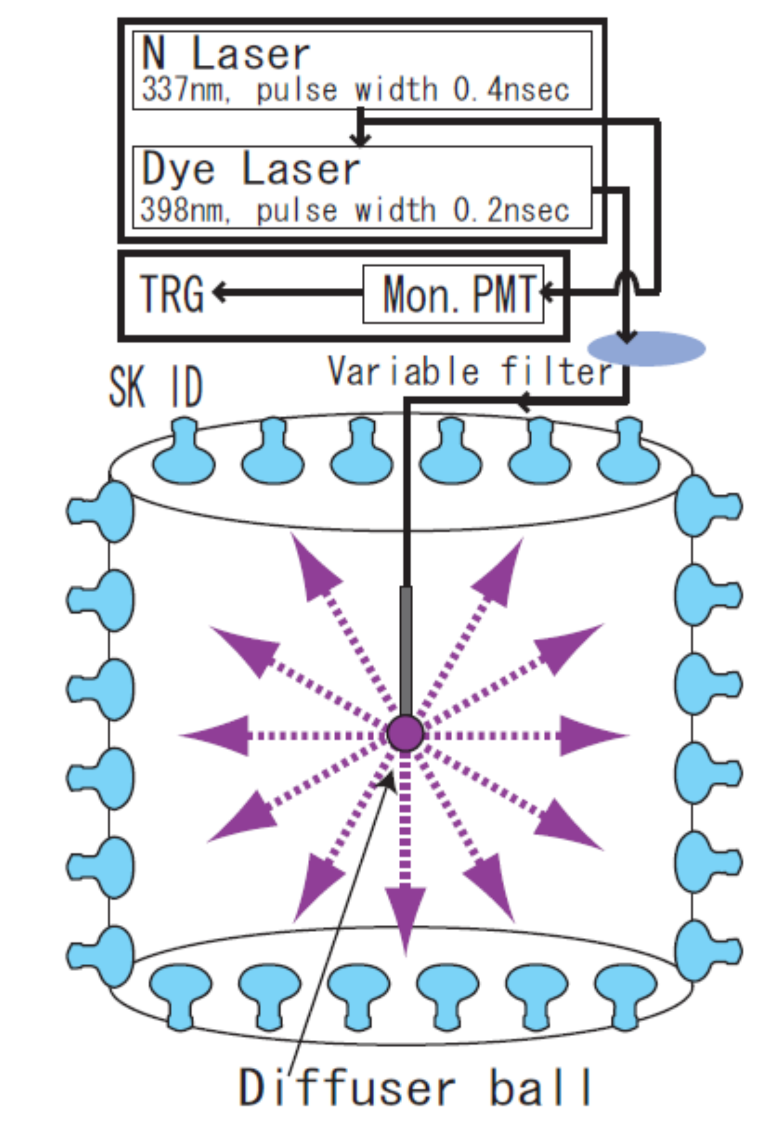
  PMT hit time profile ($\tau_\mu$ ~ 2us)

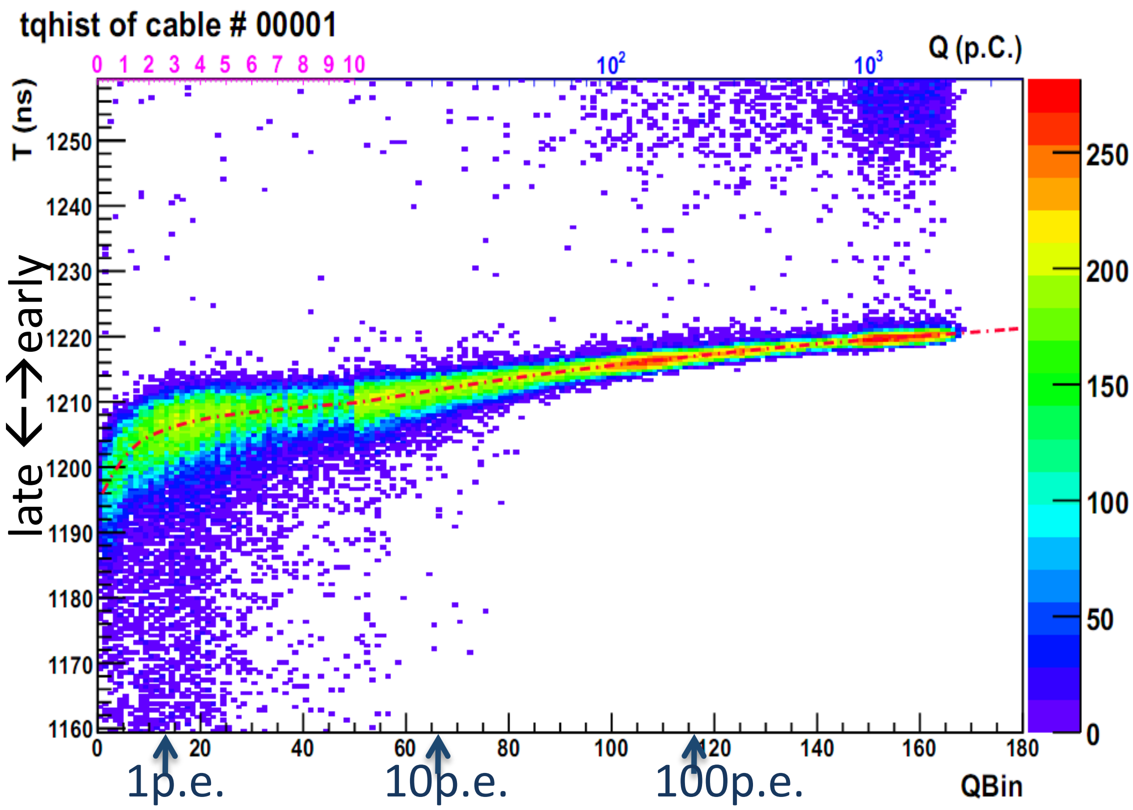


# Detector Calibration

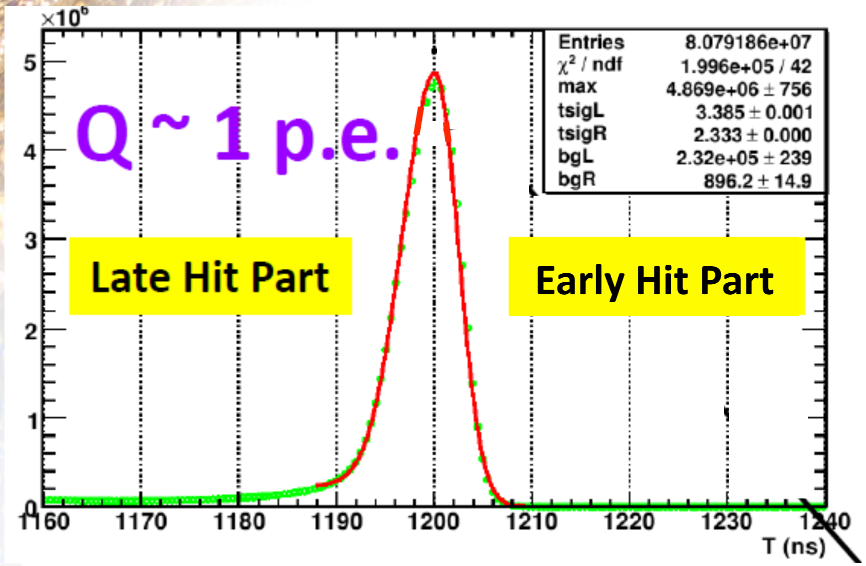
# Timing Calibration (Time walk & Offset)



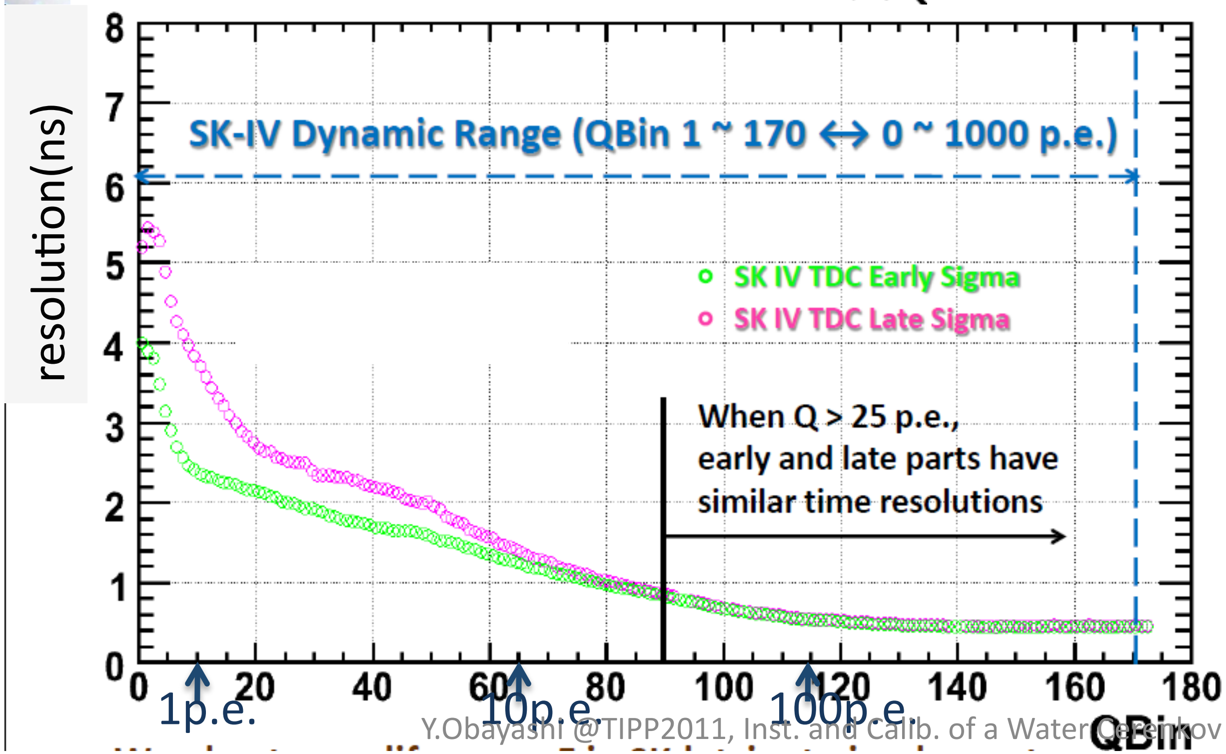




- Make T-Q curve for all the PMTs and use as correction functions for data

# Timing Resolution




Summed up T – T0 – ToF for all PMT.




$\sigma_t$ ~ 2.5 ns @ 1 p.e.

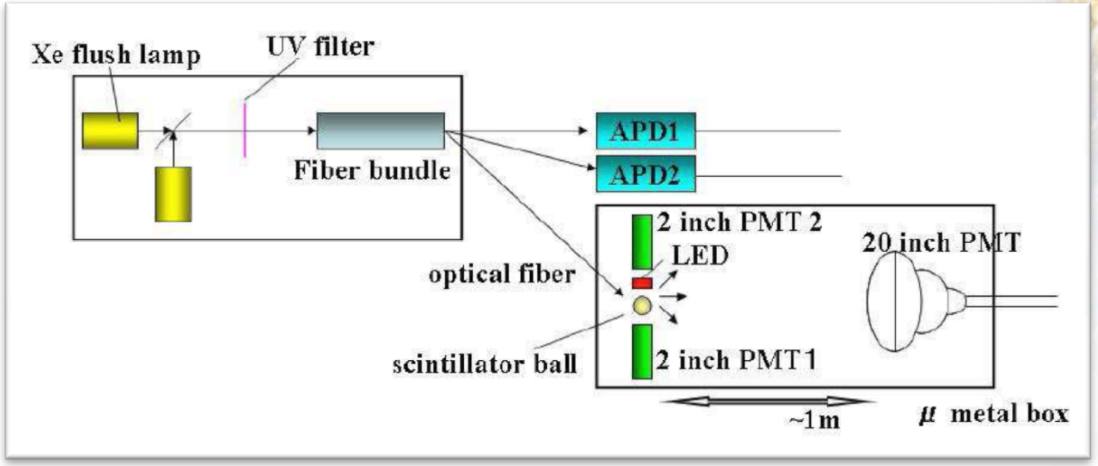
0.5 ns @ >100p.e.

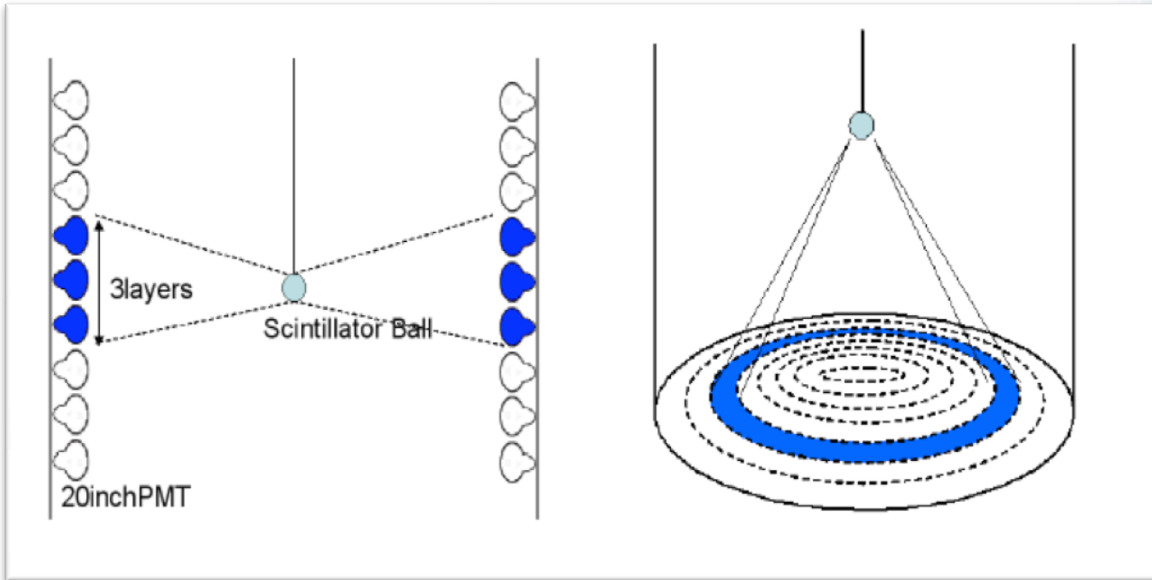
# PMT Gain Calibration (HV adjustment)

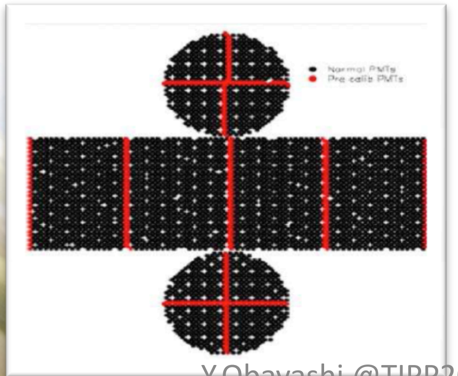
- Make 420 “Standard” PMTs at OUTSIDE of the tank before install
- Place these standard PMTs in the tank to cover all geometry
- Adjust HV of each PMTs comparing standard PMT charge

$$Gain(i) = \alpha_i \times HV(i)^{\beta_i}$$

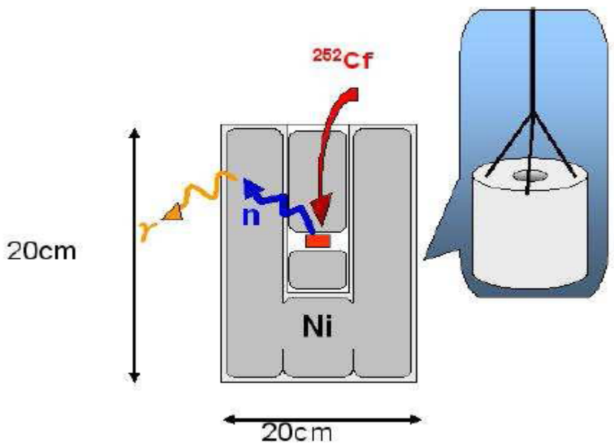
$\alpha_i$,$\beta_i$: *i* th PMT’s param.



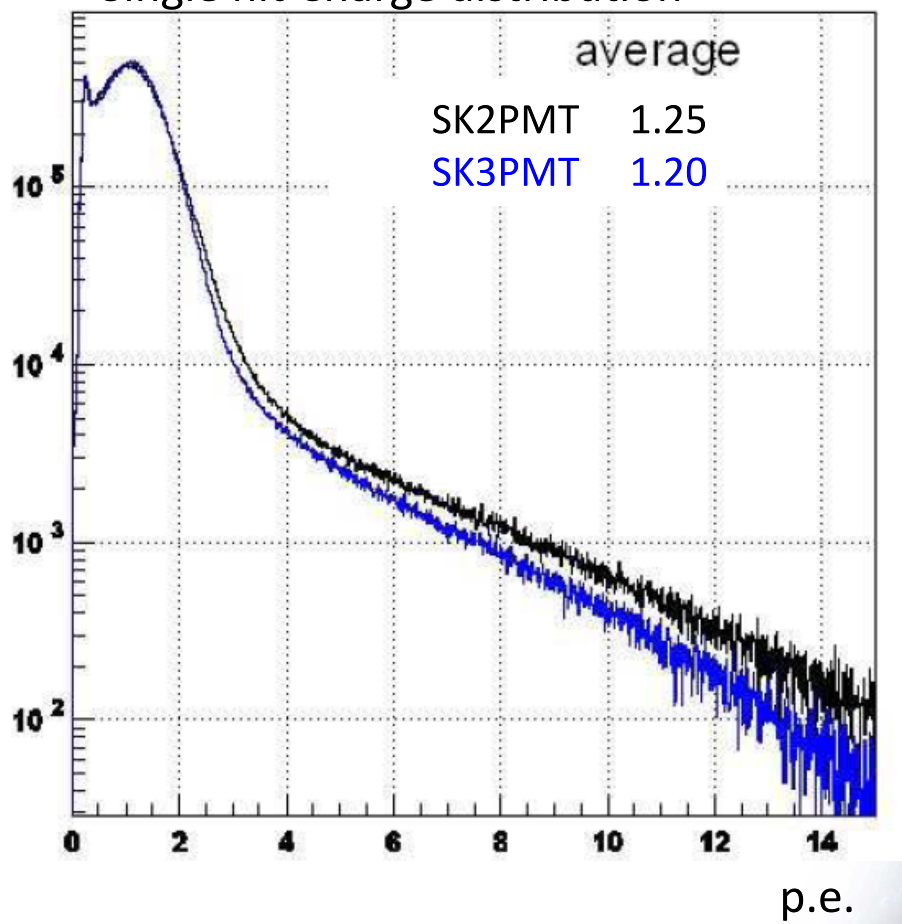



# Ni + Cf gamma source



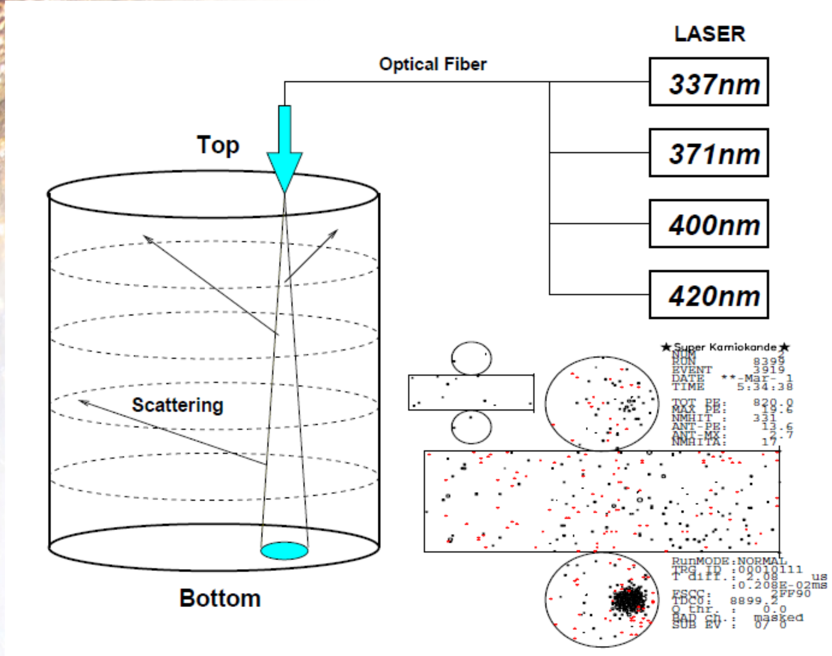

- Neutron from $^{252}Cf$ is converted to 6-9MeV gamma in Ni
  → ~single hits on PMTs
- Measure
  - 1p.e. distribution
  - Q.E. of each PMT
- Used as input of detector simulator

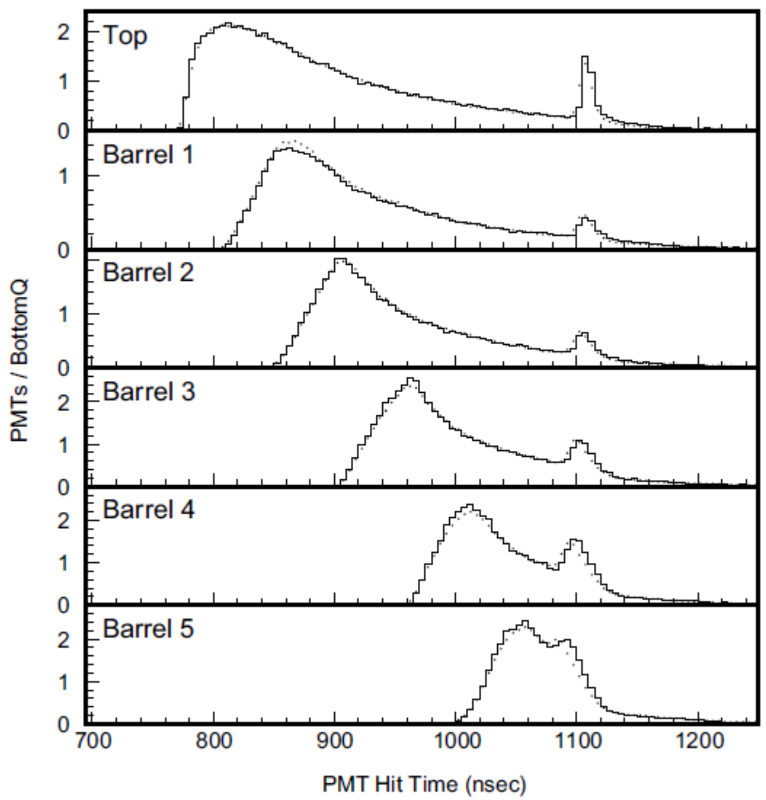
Single hit Charge distribution

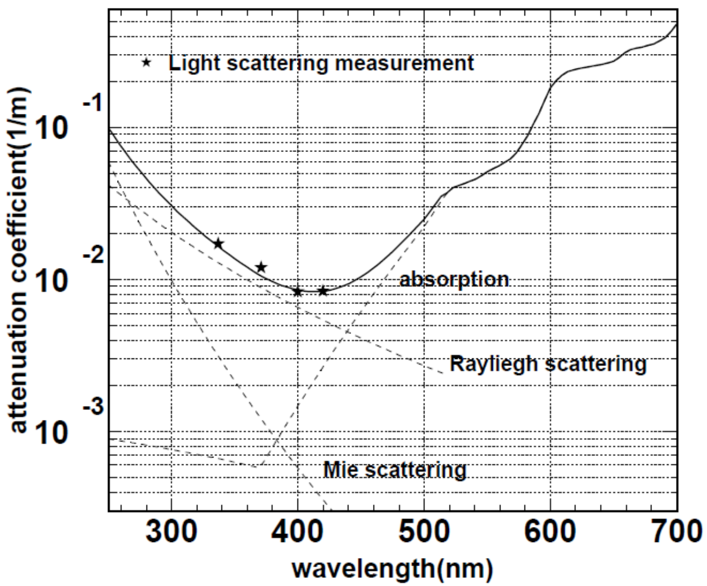



"SK2PMT": PMT used from SK beginning
"SK3PMT": Newly produced PMT after accident in 2001

# Attenuation and Scattering in Water



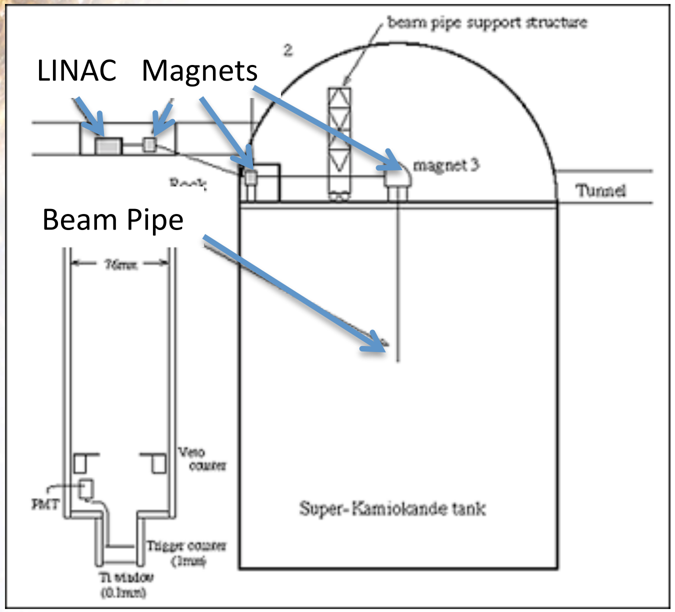




Fitting with parameter:
absorption, Rayleigh scattering and Mie scattering for each wavelength
→ Input of Detector Simulator

# LINAC / DT Calibrations for Solar ν analysis

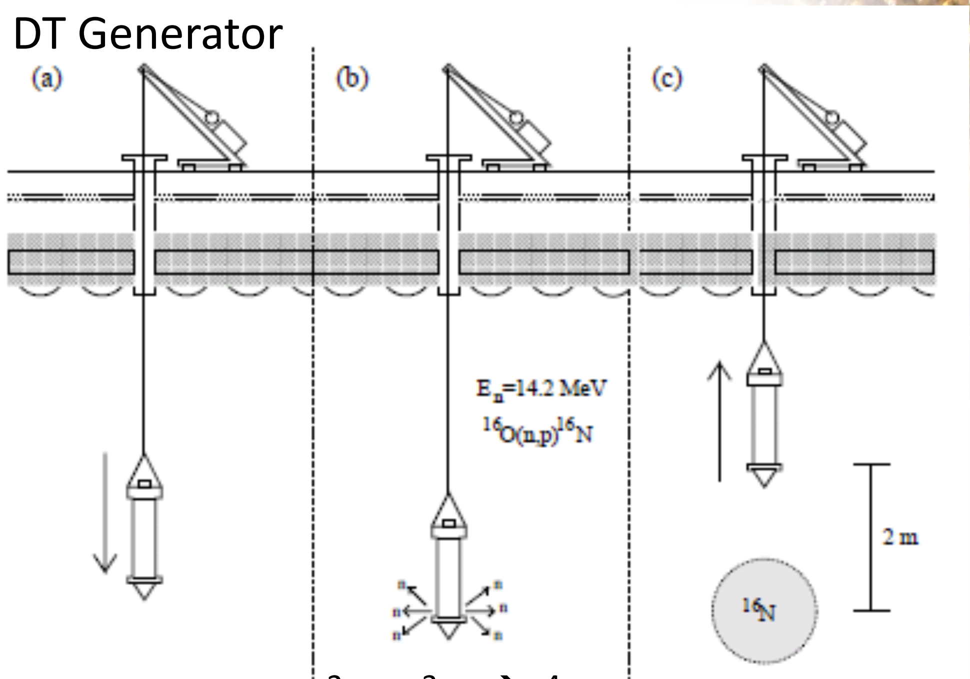
LINAC system




Accelerate and inject electrons:

Pe = 5 – 18 MeV/c

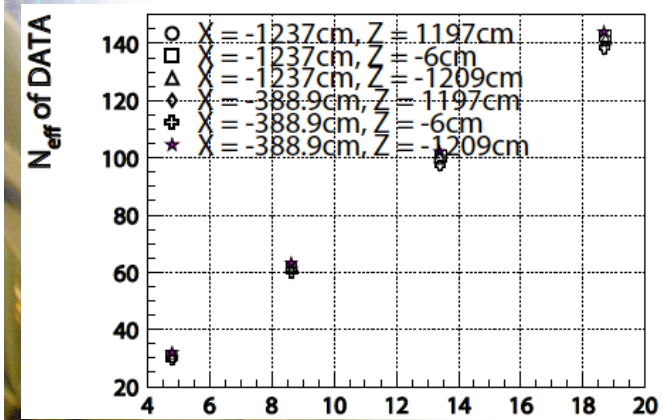
DT Generator

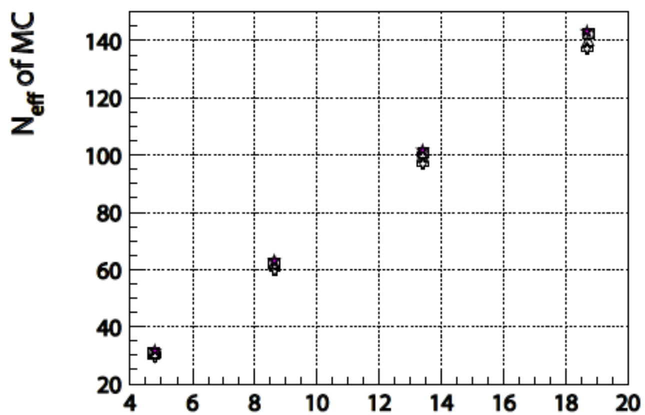


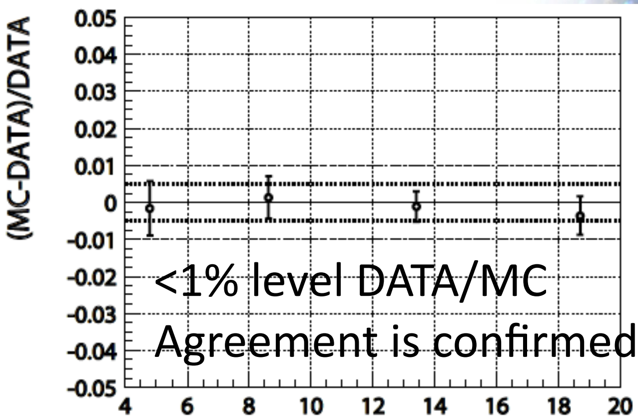

$^{2}H + ^{3}H \rightarrow ^{4}He + n$

$^{16}O(n,p)^{16}N$

$^{16}N \rightarrow \gamma(6.1MeV), e(4.3MeV)$ etc.



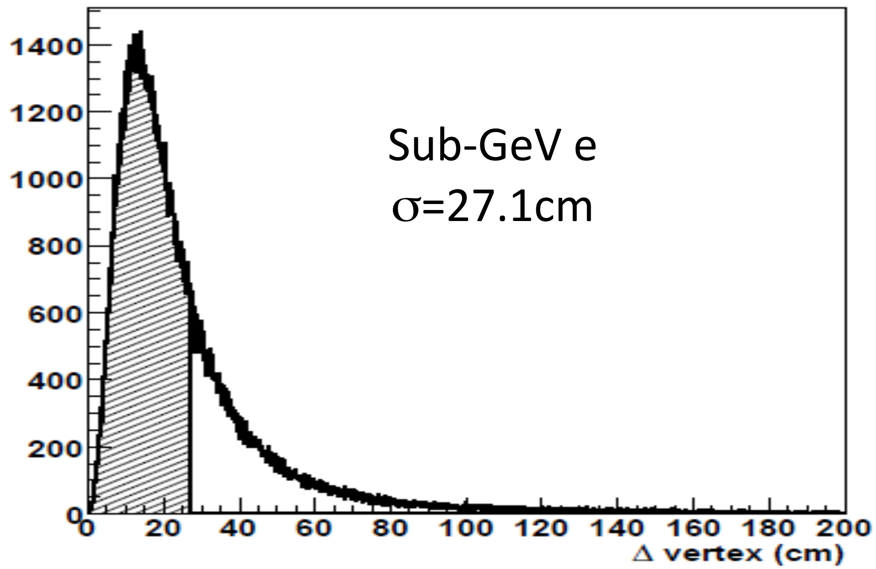



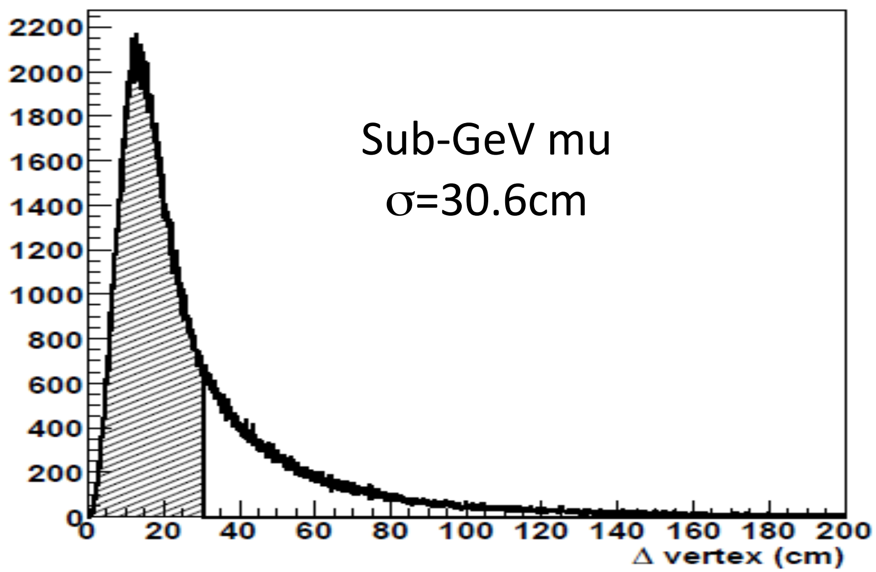




<1% level DATA/MC Agreement is confirmed

# Detector Performance

# Vertex Resolution

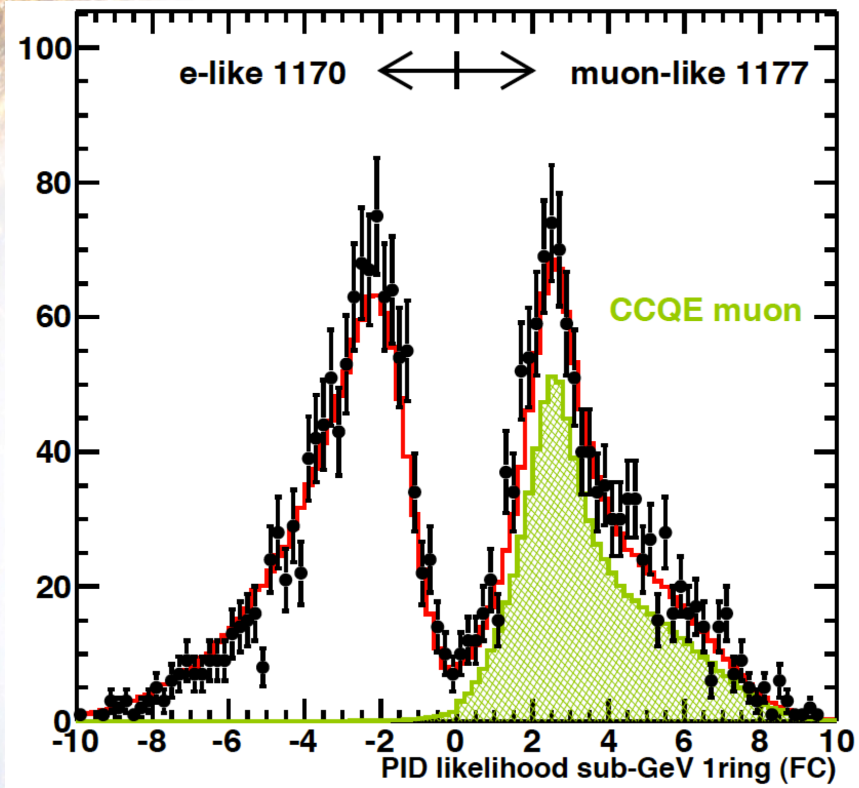


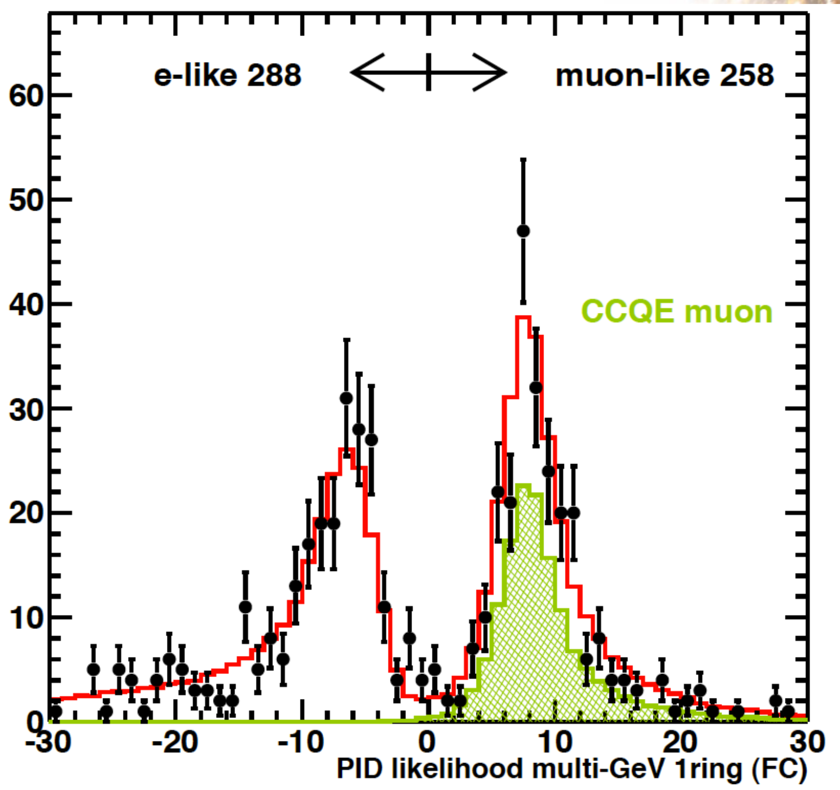

- Evaluated by Δ(rec. vtx – true vtx)
- ~30 cm resolution @ Sub-GeV region

# Particle Identification

Sub-GeV (Evis < 1.3GeV)




Multi-GeV (Evis > 1.3GeV)



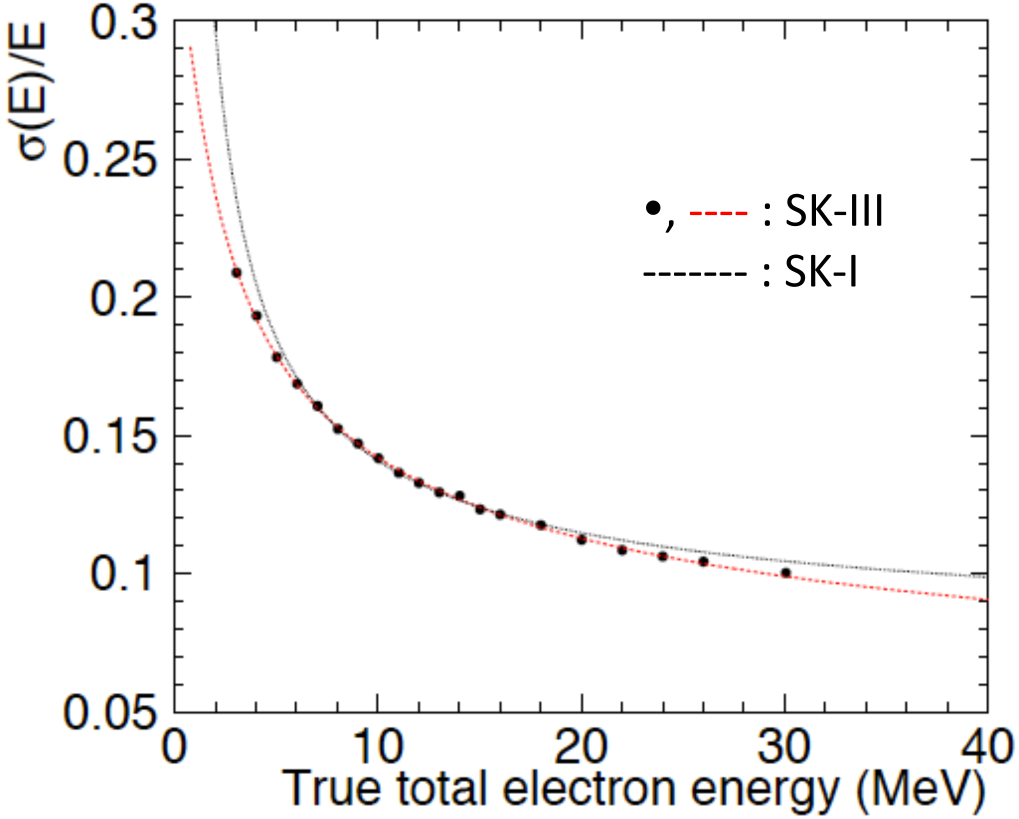

- Identify e or mu using Likelihood with Cherenkov light pattern and Opening angle.
- MissID rate:

$\nu\mu$ CCQE missID as e-like: 0.5%

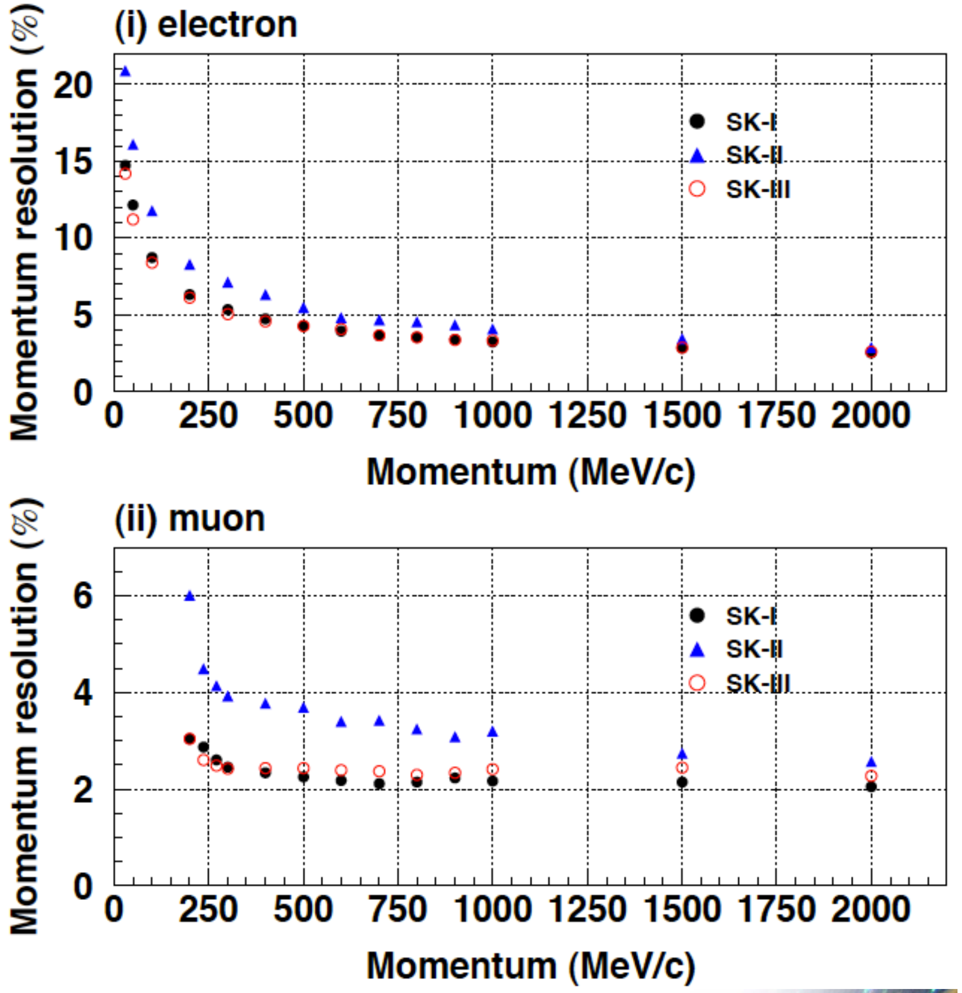
$\nu e$ CCQE missID as $\mu$-like: 1.5%

# Energy Resolution

Solar neutrino analysis

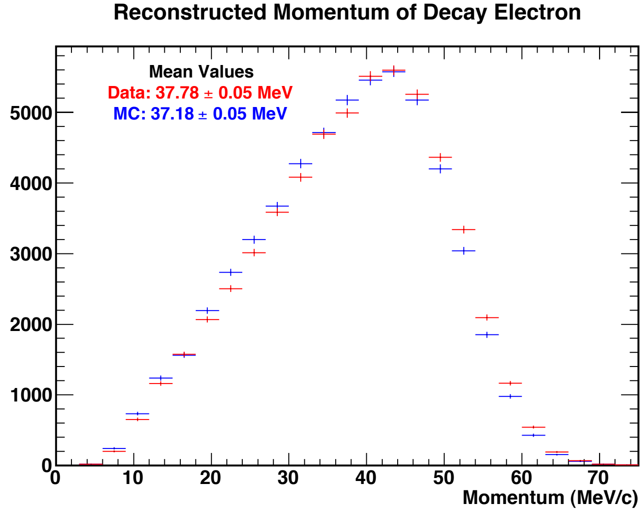



Atmospheric neutrino analysis

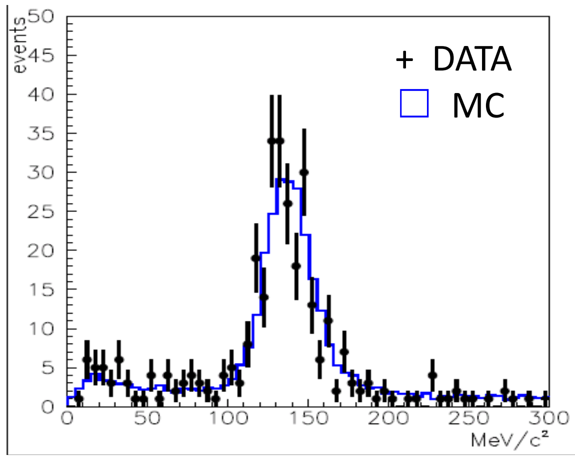



- ~15% @ Solar neutrino energy, 2~3%@1GeV (SK-I,III)
- SK-II shows worse resolution due to low PMT coverage(~20%)

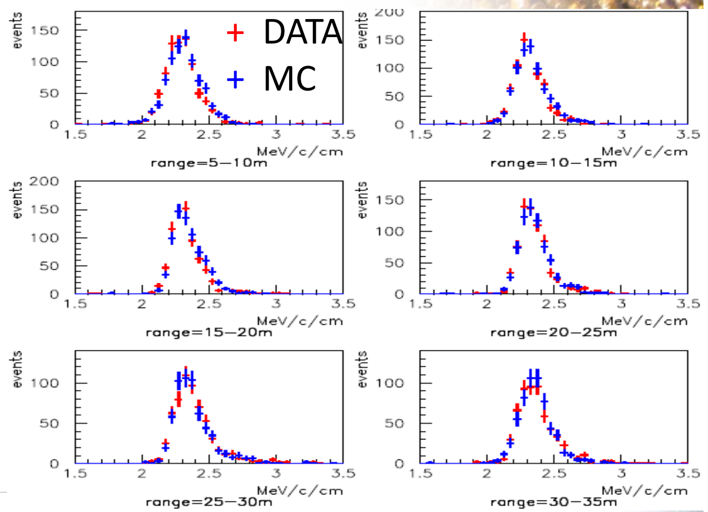
# Absolute Energy-Scale



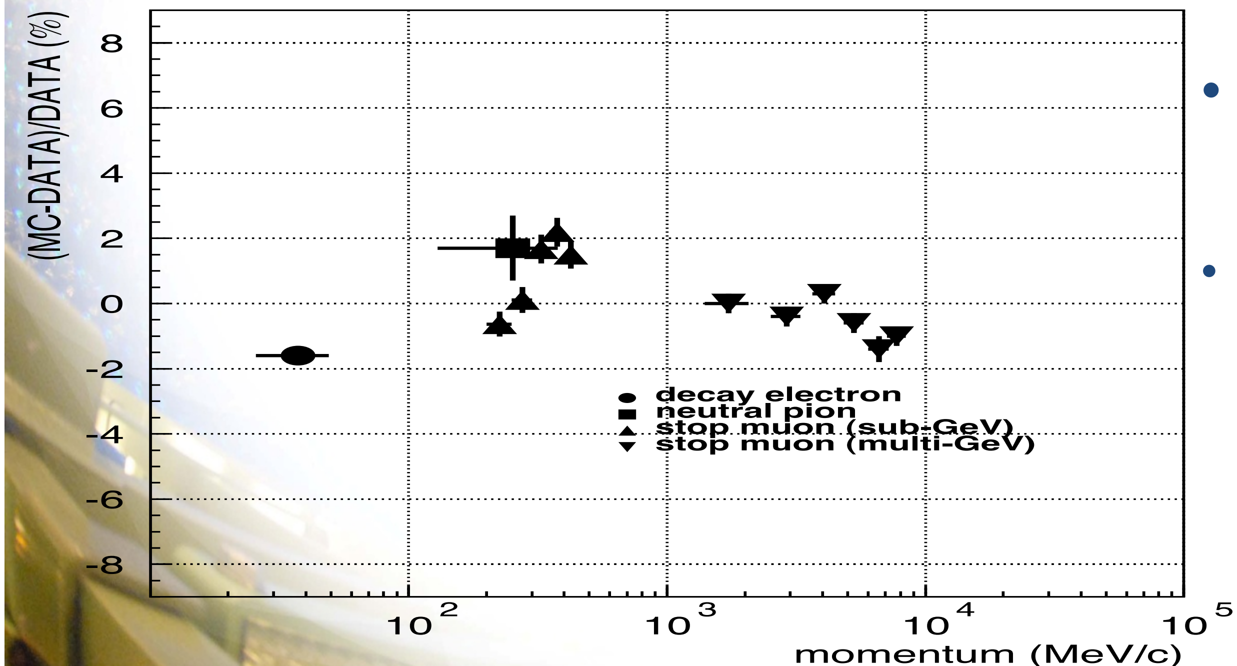

Muon decay electron momentum




invariant mass of $\pi^0 \rightarrow \gamma\gamma$



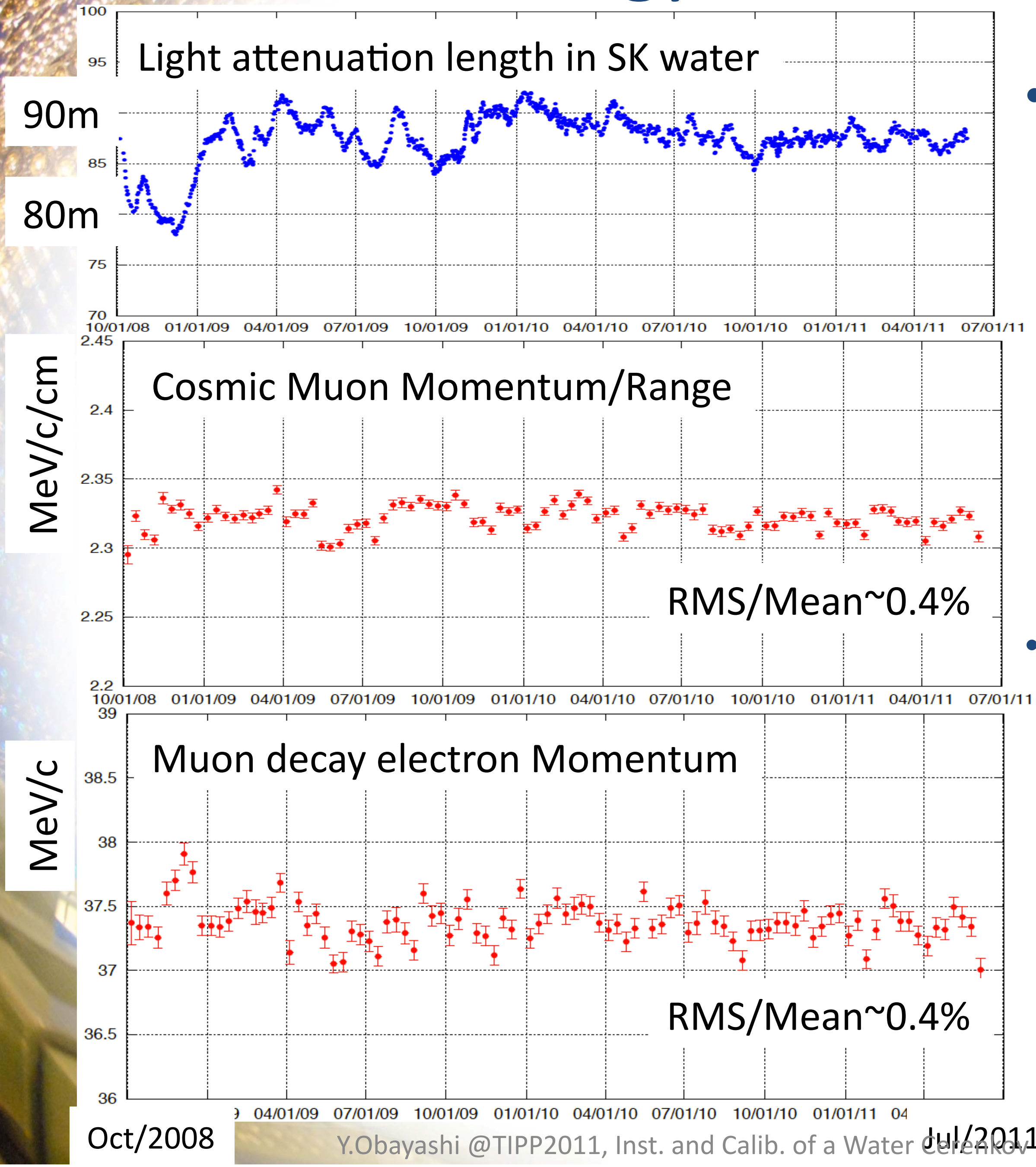

Momentum/range of cosmic muons




- Evaluated with MC-DATA comparison with several physics samples
- Absolute energy scale error is

within ±2%
through
30MeV ~ 5+ GeV

# Energy Scale Stability




- Despite that light attenuation length varies ~80m to 90m, reconstructed momentum after water attenuation correction is quite stable with RMS/Mean ~0.4%.
- (Monitored attenuation length is used in the momentum reconstruction)

# Summary

- 50,000 ton Water Čerenkov detector Super-Kamiokande
- Well calibrated with various calibration sources
- Nice performance
  - Vertex resolution ~30cm @ sub-GeV
  - MissID rate of νμ CCQE as electron-like: ~0.5%
  - Energy Scale error <2%, stability ~0.4% RMS/mean
  - Energy resolution: ~15%@solar, ~3%@1GeV
- Well established technique
- Keep effort to improve its performance → Applicable for Next Generation WČ discussion