# Hyper-K Event Reconstruction

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6th Hyper-K Meeting

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# Hyper-K Reconstruction Packages

- **BonsaiFit**
  - Based on hit time likelihoods only
    - Assumes ≤ 1 hit per PMT per event
  - Used for low energy analysis
- **FiTQun**
  - Based on charge and time likelihoods
  - Used for high energy analysis
- Both packages work for Super-K (based on skdetsim)
  - Now being adapted for Hyper-K (based on WCSim)

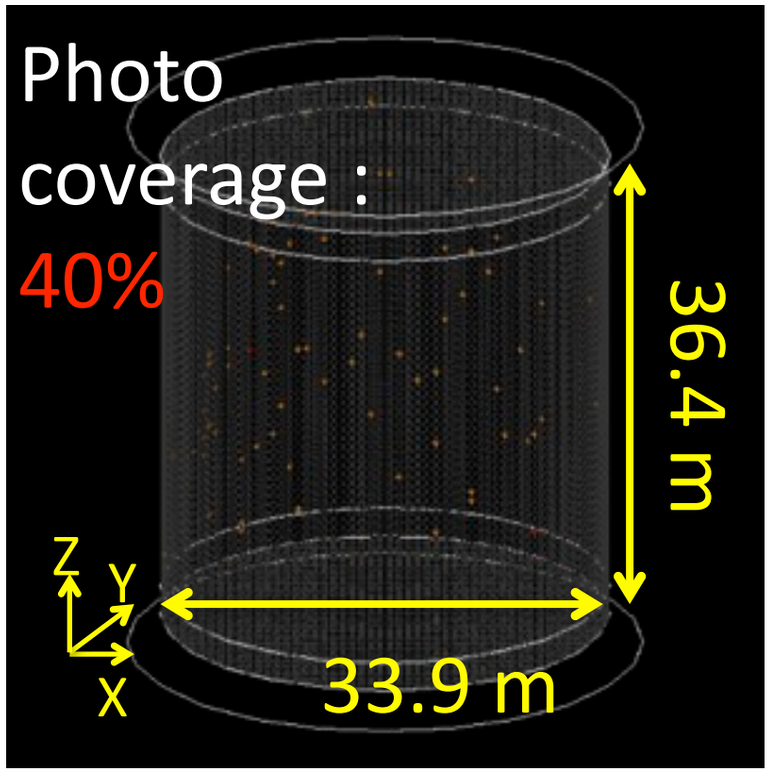
# Low-E Reconstruction with WCsim (T.Yano)

## Low Energy Reconstruction with BONSAI

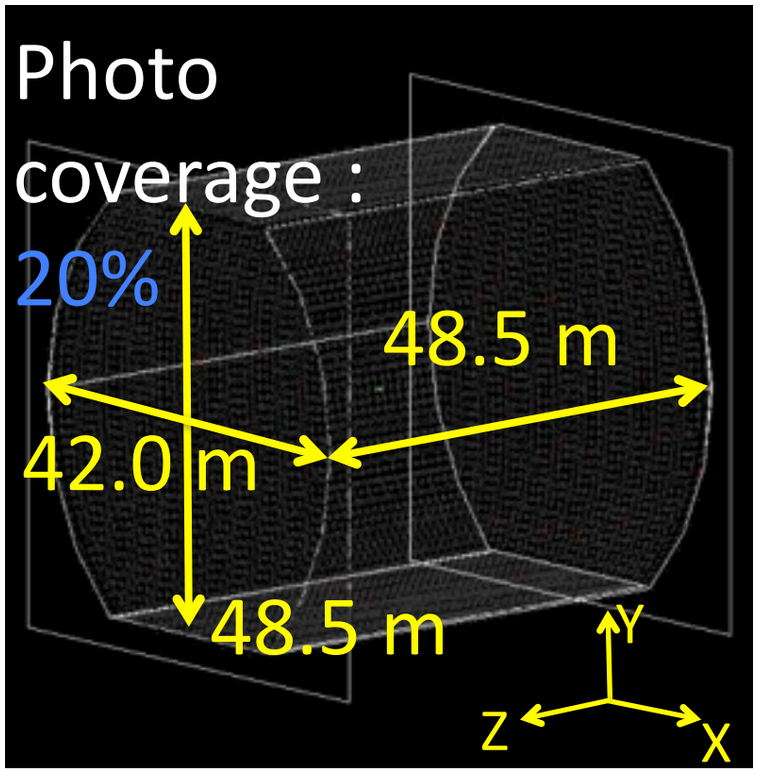
- SK's algorithm, BONSAI is brought into WCsim for 3 to a few tens MeV. (libWCsimBonsai)
- The reconstruction is demonstrated at 5$^{th}$ HK open meeting.

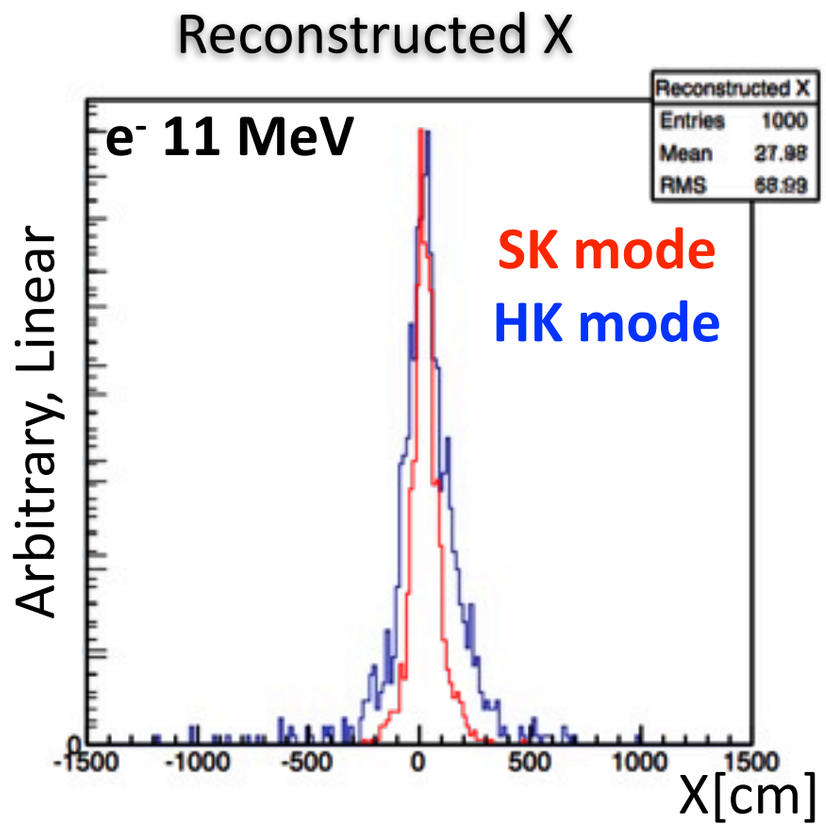
T. Yano 5$^{th}$ HK Open Meeting

**WCsim Super-K mode**




**WCsim Hyper-K mode**



# Status and Plan for Low-E Reconstruction

## Status

- First version of "libWCSimBonsai" is working with WCSim, for Hyper-K low-E reconstruction.
- This package will be applied for the study of several Hyper-K detector configure, including the cavity shape.

## Future Plan

- To take libWCSimBonsai package into hk-hyperk git.
- To improve this interface to fit the WCsim format. e.g. reading geometry and some other information.
- To tune Bonsai and WCSim for low energy study, with realistic HK photosensor QE, timing resolution and after pulse.

# Reminder: The FiTQun Likelihood Fit

$$L(\mathbf{x}) = \prod_{\text{unhit}} P(i\text{unhit}; \mathbf{x}) \prod_{\text{hit}} P(i\text{hit}; \mathbf{x}) \boxed{f_q(q_i; \mathbf{x})} \boxed{f_t(t_i; \mathbf{x})}$$

- A single track can be specified by a **particle type**, and **7 kinematic variables** (represented above as the vector **x**):
  - A vertex position **(X, Y, Z, T)**
  - A track momentum **(p)**
  - A track direction **(θ, ϕ)**
- For a given **x**, a charge and time PDF is produced for every hit PMT
- The **charge PDF** is factorized into:
  - PMT & electronics response
  - Number of photons reaching the PMT
    - **Predicted charge (μ)**
- All 7 track parameters **fit simultaneously**

**Time PDF**

**Charge PDF**

Will be different for each PMT (20”, 12”, etc)

Will be different for each geometry (size and shape)

PMT Charge Response:

Property of the electronics and PMT properties

Predicted Charge (μ):

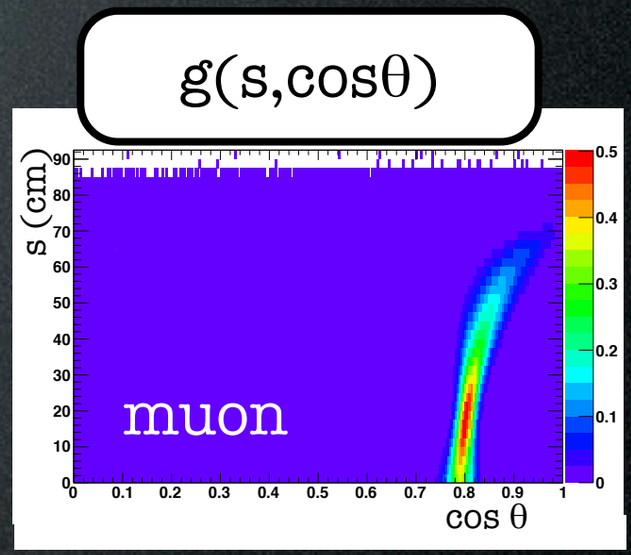
- Number of photons that reach the PMT
- Depends on detector properties (scat, abs, etc.)

# FiTQun Parameters

- FiTQun was originally designed to work with Super-K
  - skdetsim + specific cylindrical geometry + 20” PMTs
- FiTQun should be adaptable to changes in these conditions:
  - The direct light predicted charge (80% of all charge in Super-K) depends on relatively few parameters

$$\mu = \Phi(p) \int ds\, g(s, cos\theta) \Omega(R) T(R) \epsilon(\eta)$$

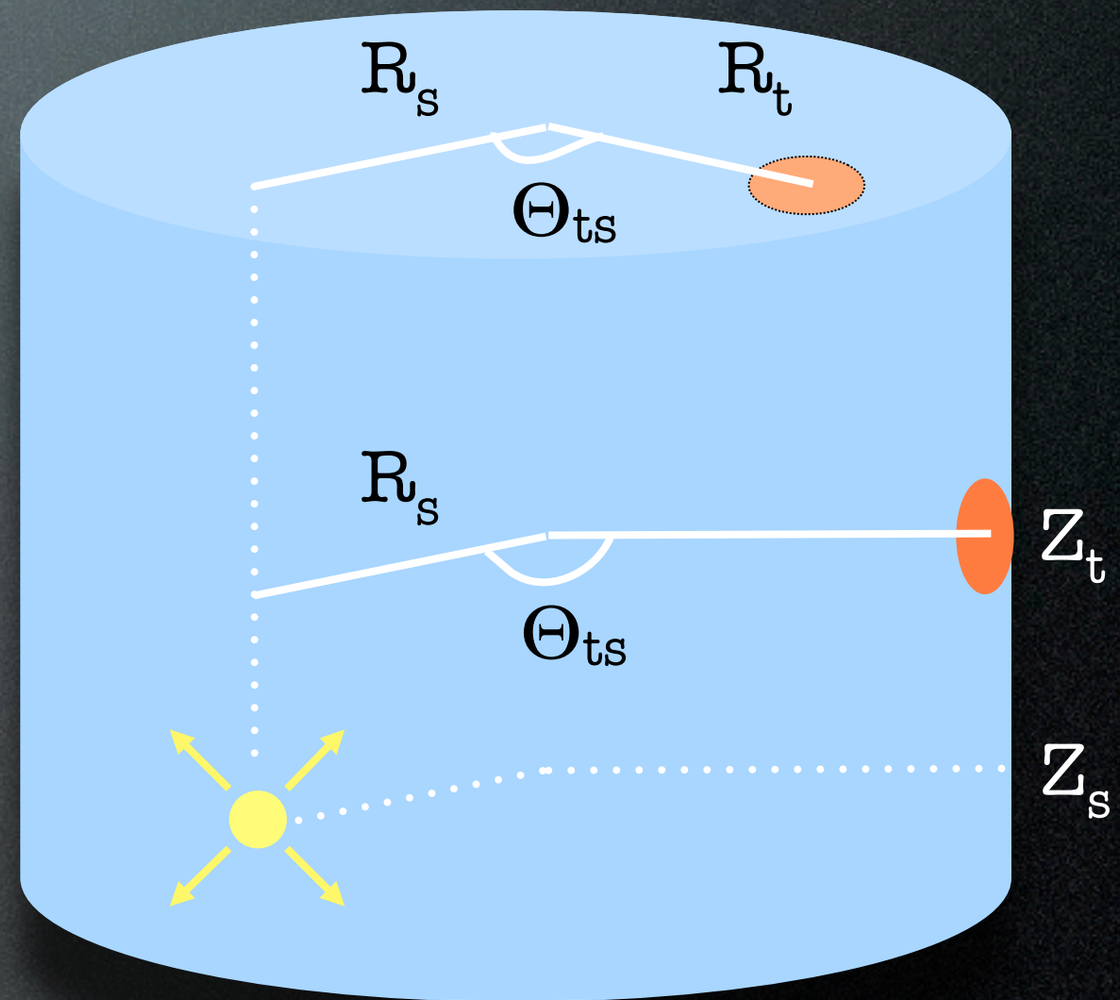
- Light Yield (normalization)
- Integral over track length
- Chrenkov emission profile
- PMT solid angle
- Water attenuation
- PMT angular response




  - Cherenkov emission profile should not change
  - PMT solid angle is easily adjusted for different sized PMTs
  - Water attenuation is just an exponential function with a single parameter
- PMT response (angular acceptance, QE, pulse shape, time likelihoods) could be different
  - This is likely to be a bigger problem when the PMT size is changed
- Scattered & reflected light tables need to be recalculated for each new geometry

# Scattered Light

- Currently assume a **cylindrical geometry**
- Tabulate $\frac{d\mu^{indirect}}{d\mu^{direct,iso}}$ (= $A_{scat}$)
  - Source direction ($\theta_s$, $\phi_s$)
  - Source position ($\Theta_{ts}$, $R_s$, $Z_s$)
  - $Z_t$ for PMTs on the sides
    - $A_{side}(\theta_s, \phi_s, \Theta_{ts}, R_s, Z_s, Z_t)$
  - $R_t$ for PMTs on the ends
    - $A_{end}(\theta_s, \phi_s, \Theta_{ts}, R_s, Z_s, R_t)$




- Must tabulate 6-dimensional scattering tables every time the geometry or optical properties are changed

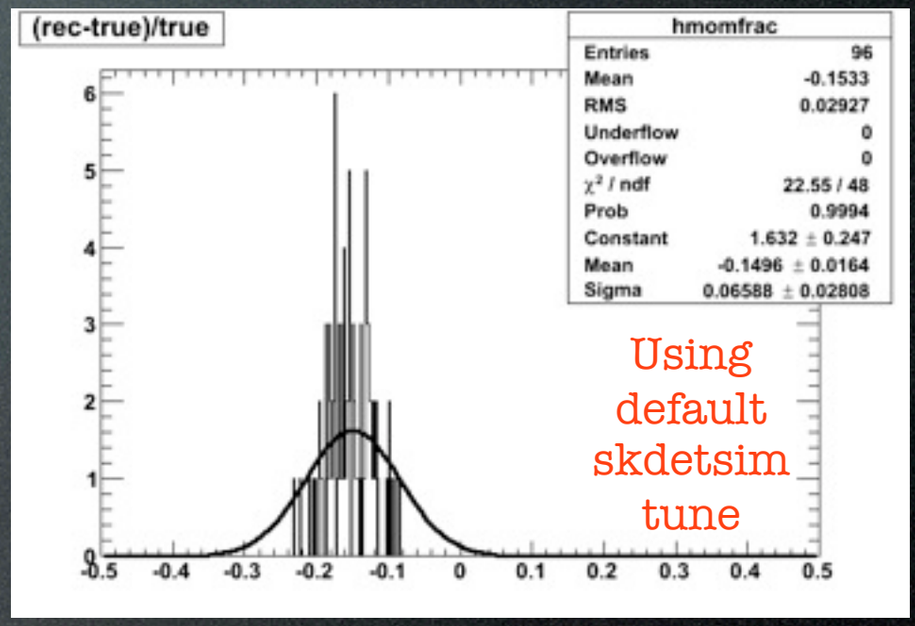
# FiTQun Tuning

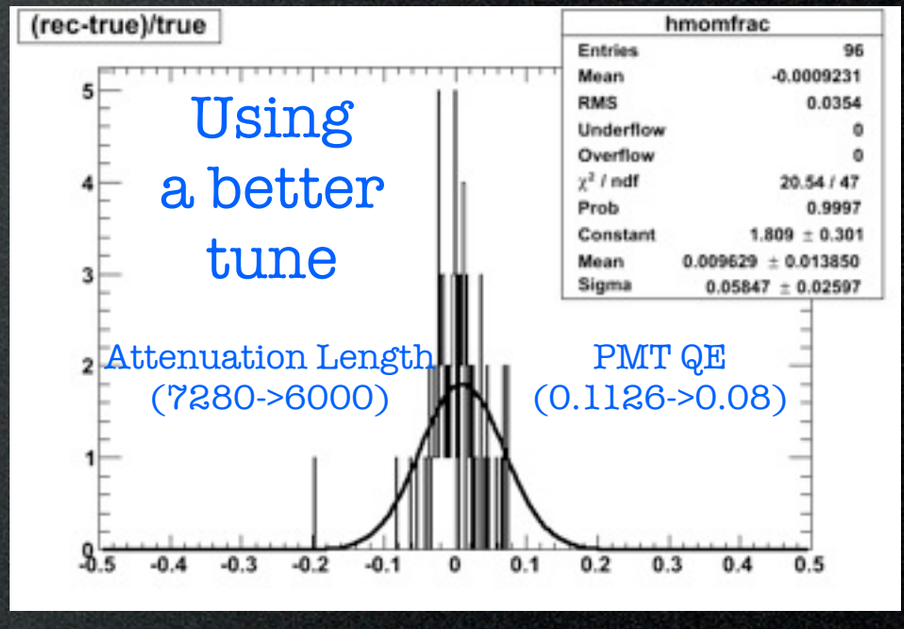
- 2-stage fiTQun tuning strategy
  1. Quick and approximate
     - Tune just the PMT QE and attenuation length, and generate a new scattering table
       - Assume PMT angular acceptance, pulse shapes, discriminator thresholds, time likelihoods, etc. are identical in WCSim and skdetsim
  2. Complete retune
     - Tune every input parameter using WCSim, as was originally done using skdetsim
- Next slides show the “quick and approximate” tuning for WCSim run with the Super-K geometry
  - All other parameters are fixed to skdetsim SK1-mode values

# Tuning Procedure

- Use SK geometry
- Run many WCSim particle guns
  - Electrons and muons in the x-direction (96 events per configuration)
  - Several energy bins:
    ke (MeV): 100, 300, 500, 1000, 1500
  - Several vertex positions:
    x (cm): -1500, -750, 0, 750, 1500
  - Several QE values:
    0.07, 0.08, 0.09, 0.1126
  - Several Attenuation Lengths:
    4500, 5000, 5500, 6000, 7280.73
- In each case, plot momentum mis-reconstruction: (rec-true)/true
  - Fit with a Gaussian

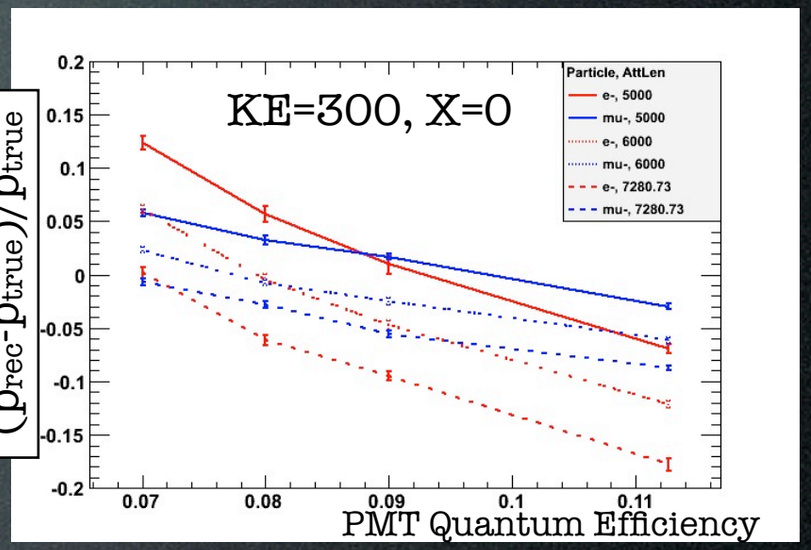
500 MeV electrons starting at the center of the tank

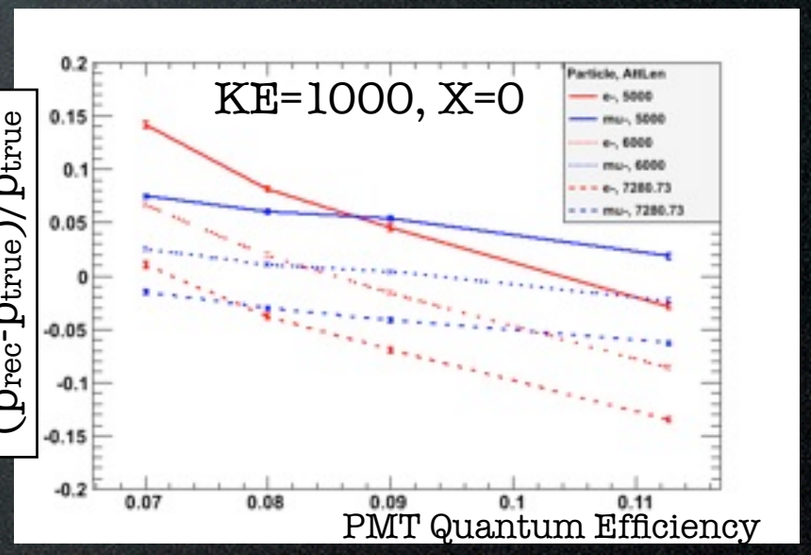


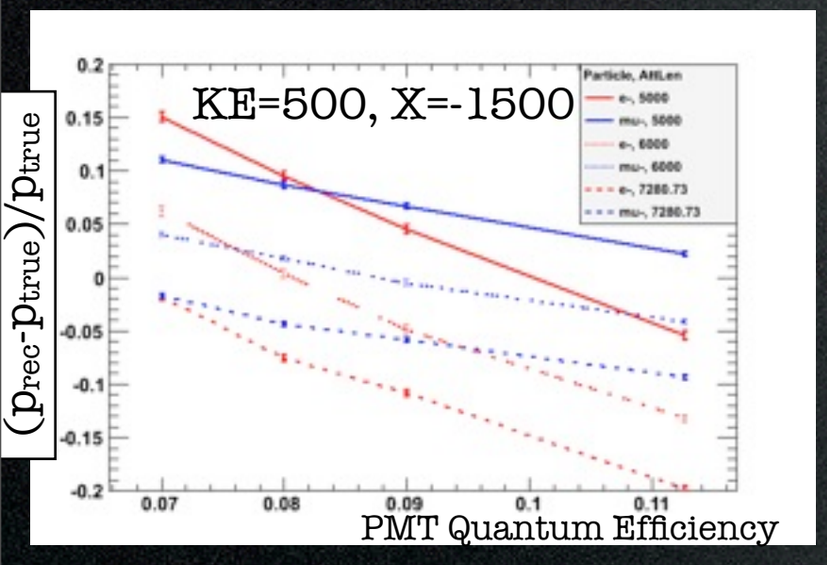



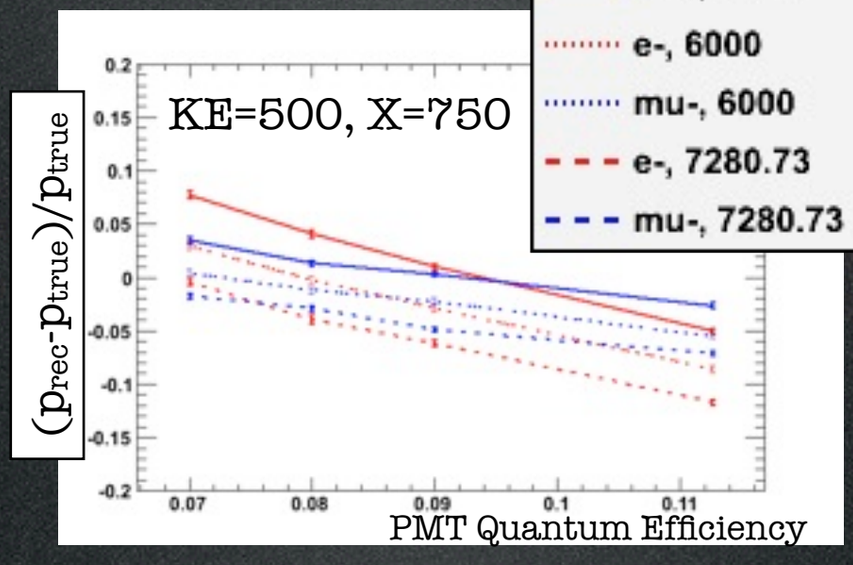
# Sample Results

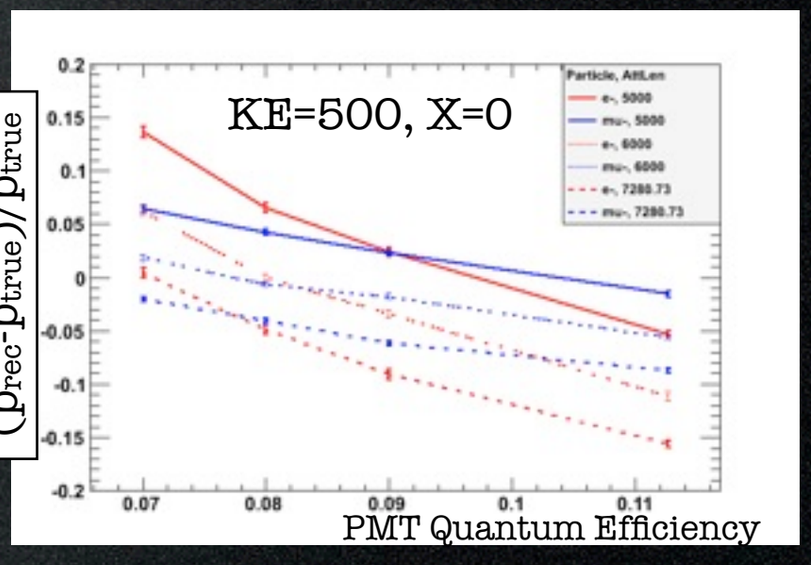
- Look at how electrons and muon momentum reconstruction varies
  - Best parameters are at y = 0
    - i.e. $(p_{rec}-p_{true})/p_{true} = 0$
- Need to consider as a function of position and momentum



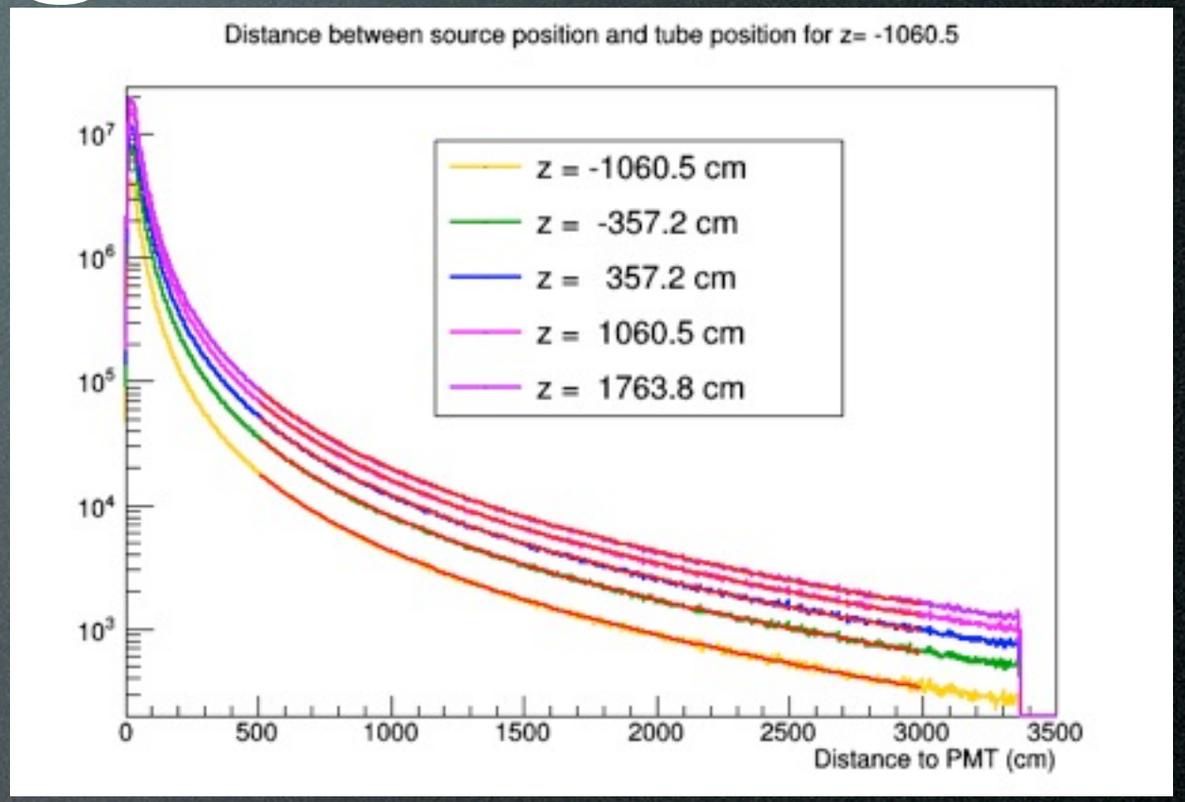



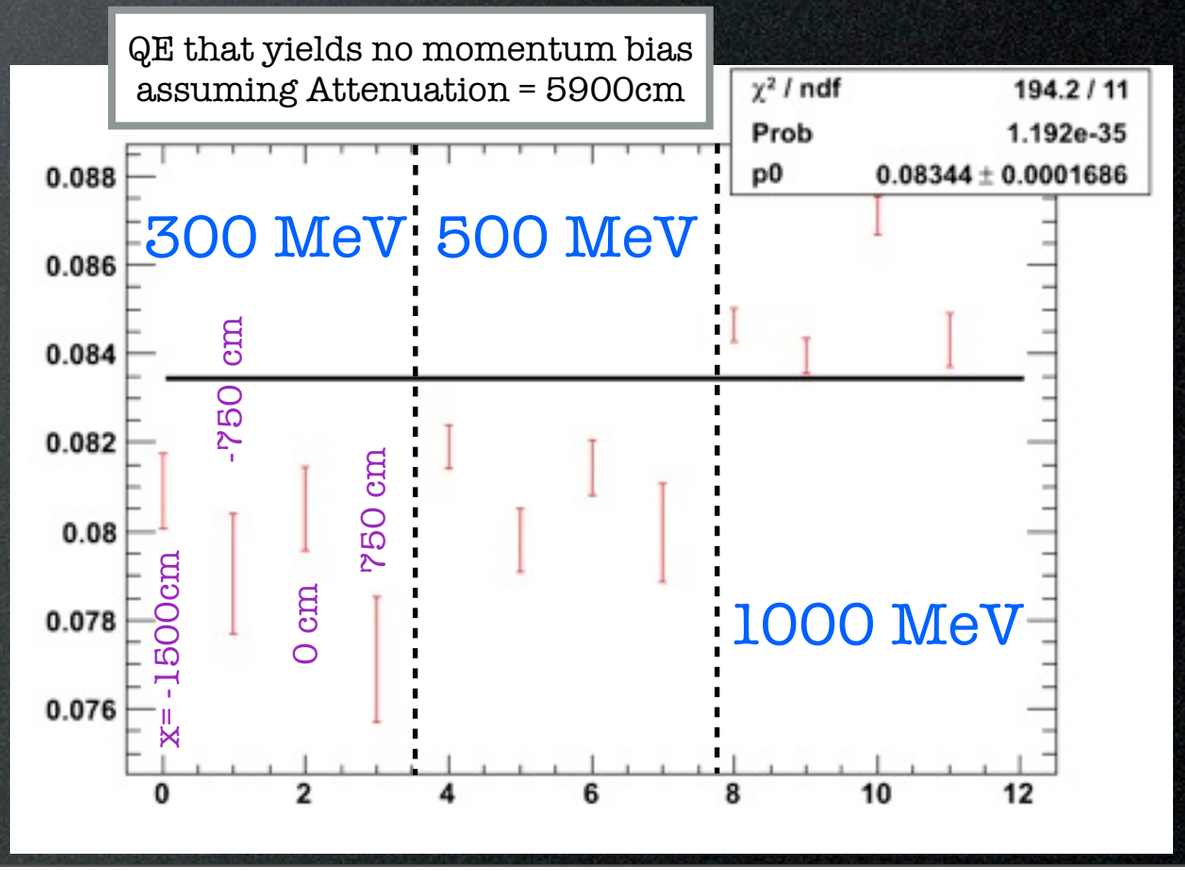



# Best Tuning Values

- Attenuation length studies using scattering table data have previously indicated a value of ~5900 cm
- If that value is used, can determine the value of QE that gives zero bias
  - Electrons shown on the right
  - Muons have larger errors (due to flatter slopes)
- Reasonably consistent results across the tank and across energy
  - Slight higher preference at higher energy
- Recommend we go forward with these values for now



# Current Status

- A workable version of fiTQun is now available for WCSim with Super-K geometry
- These “quick and approximate” tunes of QE and attenuation should work for Hyper-K mode as well
  - A few versions of Hyper-K scattering tables have been produced, and are being tested
- Detailed tuning has begun, and will ramp up in February
  - New undergraduate and postdoc are starting on this project
  - Goal is to develop a procedure that can be quickly adapted to changes in PMTs, photo-coverage, and geometry (e.g. cavern length)
    - Needed for precision studies of all the new Hyper-K detector configurations, NuPRISM, and TITUS

# Summary

- Both BONSAI fit and fiTQun can now be run with WCSim
  - FiTQun Hyper-K scattering tables are now being finalized
  - BONSAI fit is being modified to accept different detector geometries using the fiTQun WCSim interface code
- Work is now beginning on a streamlined detailed tuning procedure for fiTQun
  - This will allow us to test several different HK detector configurations, and to simulate NuPRISM and TITUS
  - New manpower has recently been identified for this, but more people can certainly get involved
    - ...especially given the tight timescales involved to study the different detector configurations

# Supplement

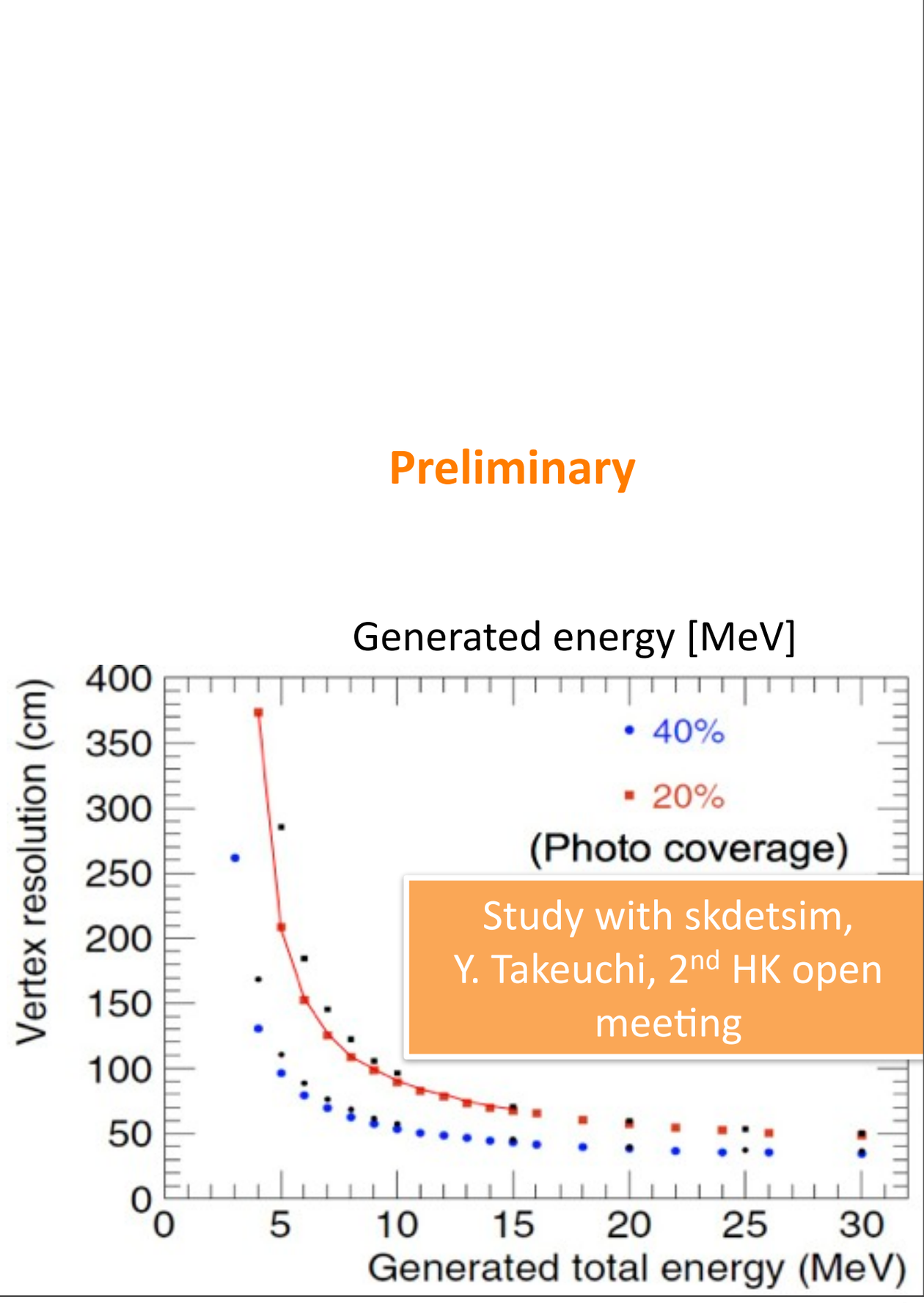
# Appendix

# Vertex resolutions

**Three-dimensional Vertex resolution** of WCsim HK and WCsim SK are compared.

The vertex resolution of WCsim SK and WCsim HK with BONSAI are ~50% larger than skdetsim ones.
The relation between vertex resolution and energy is similar for these cases.

The vertex resolution and other characteristics of one Hyper-K compartment is expected to be similar to SK-II. We need more tuning for further studies.



# Next Tuning libWCsimBonsai

WCsim executable

WCsim ROOT output

Hit info.
PMT ID, T, Q

PMT Geometry

Primary Track

etc.

Optimization for WCsim, new photo detectors and Hyper-K geometry.

Configuration files from skdetsim

Fit parameters
(Cherenkov angle etc,)

Timing Likelihood

libWCsimBonsai on ROOT

BONSAI

Tuning for HK

Reconstruction result:
Vertex, Goodness, etc.