
# WBS 1.4 Optical (Laser) Calibration

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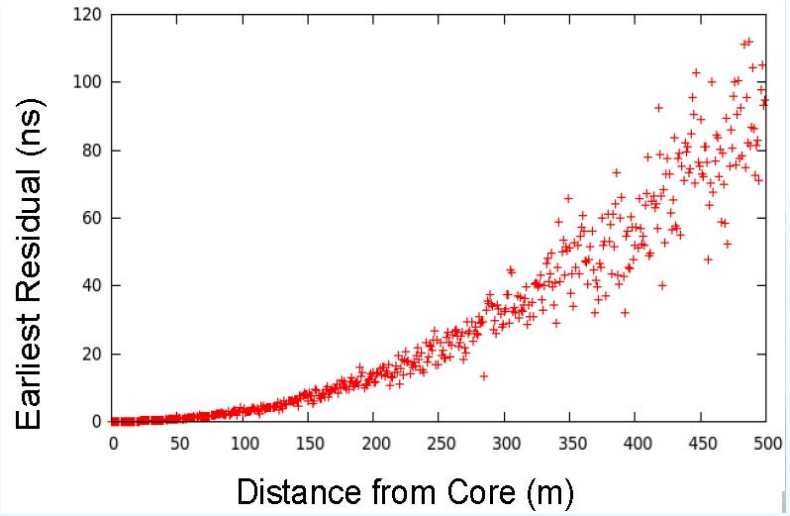
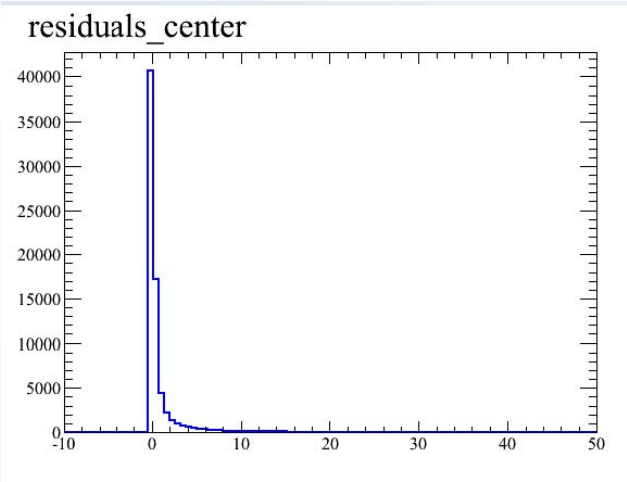
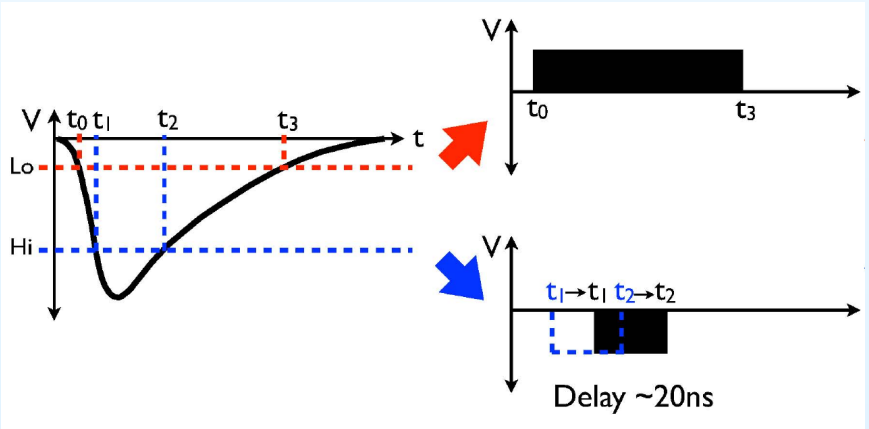
**FOR**

HAWC Calibration Team at: Colorado State U. (CSU), George Mason U., LANL, Michigan Technological U. (MTU) and U. of New Mexico (UNM)

# HAWC challenges ...

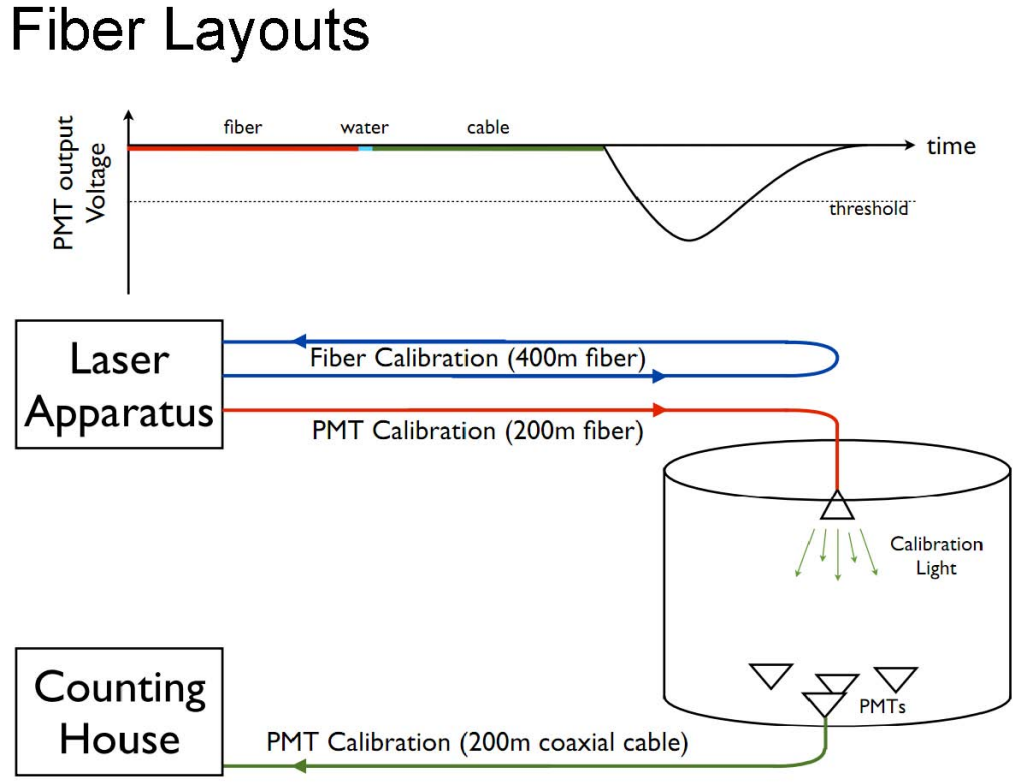




- (Top Left) Shower front timing residuals *VS* distance from shower core; (Top Right) Timing residuals (nsec) near the shower *core*.
- Precision angular reconstruction then needs the PMT timing offsets (errors) to be $< 1$ns.
- DAQ emphasis on precision timing (Bottom Left) results in the signal amplitude being *coded* as Time over Threshold (ToT).

# HAWC calibration *design* ...

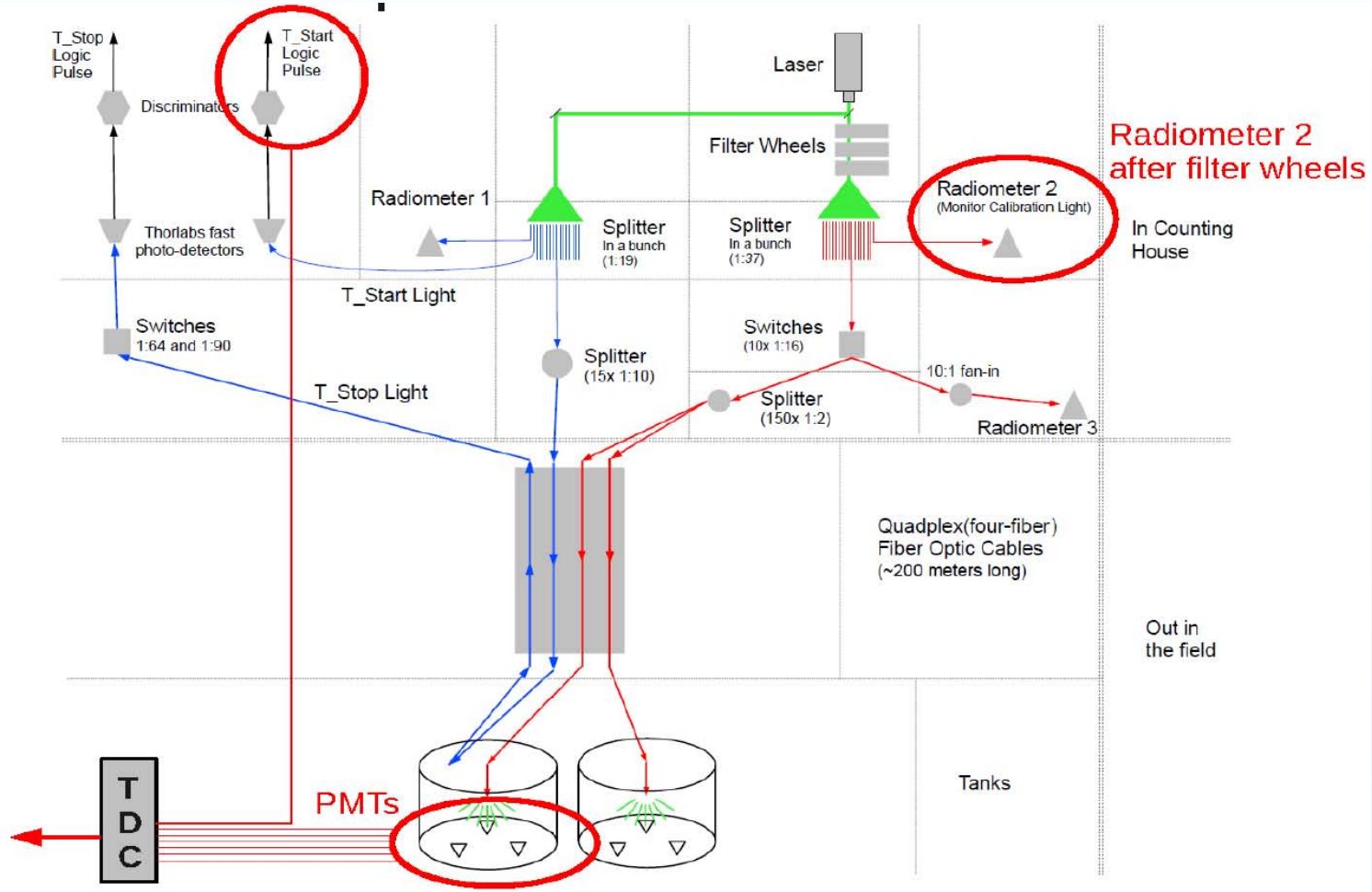




- Use a pulsed (300ps, 532nm laser) light source of known intensity and with known light transit time to the PMTs.
- Adjust the source intensity (using neutral density filters) over the (required) PMT dynamic range of $\sim 0.1$PE to $\sim 10^4$PEs.
- Repeat 300 times (for 300 WCDs). Begin with the HAWC WCD prototype at CSU

# HAWC calibration *calibration at CSU WCD* ...

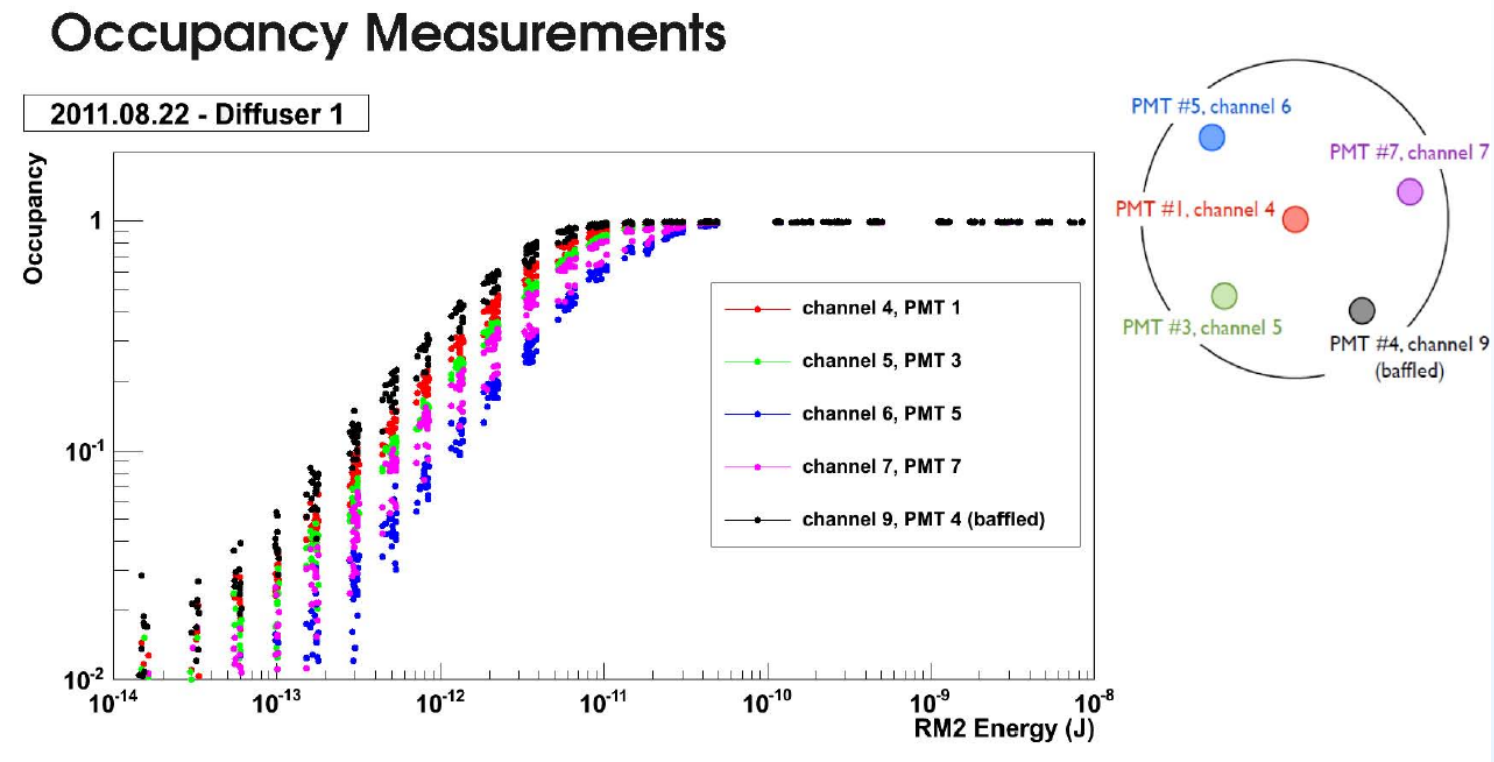

- The prototype HAWC WCD at CSU has allowed R&D on all components (hardware, control software and analysis) of the calibration system.
- Major group calibration responsibilities include:
  1. CSU: calibration data analysis, muon calibration
  2. George Mason U: muon calibration
  3. LANL: DAQ for TDCs
  4. MTU: calibration control software and data analysis
  5. UNM: calibration hardware, control software and data analysis

# HAWC calibration *schematic* ...

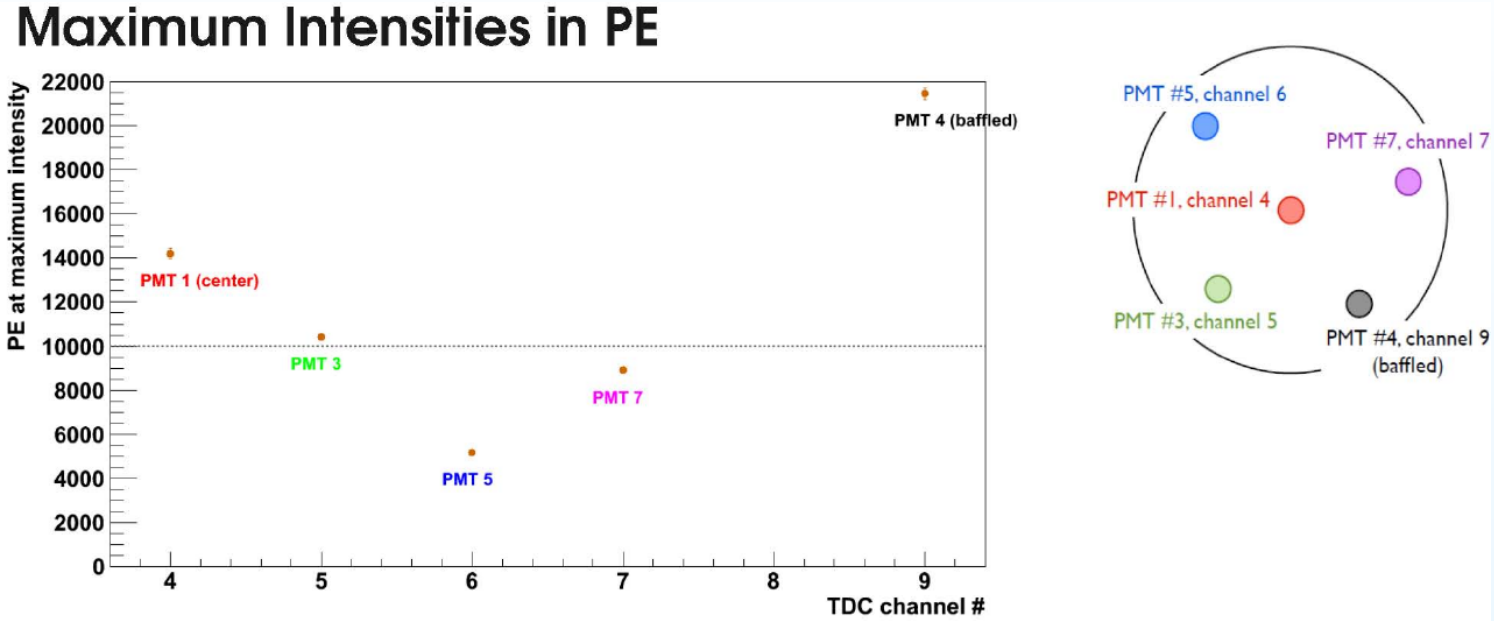

- The *ingredients* for a calibration include: the light-to-WCD Intensity (Radiometer 2), and digitization of the laser pulse time ($T_{start}$) and the PMT (time and ToT).

# HAWC calibration *cycle* ...

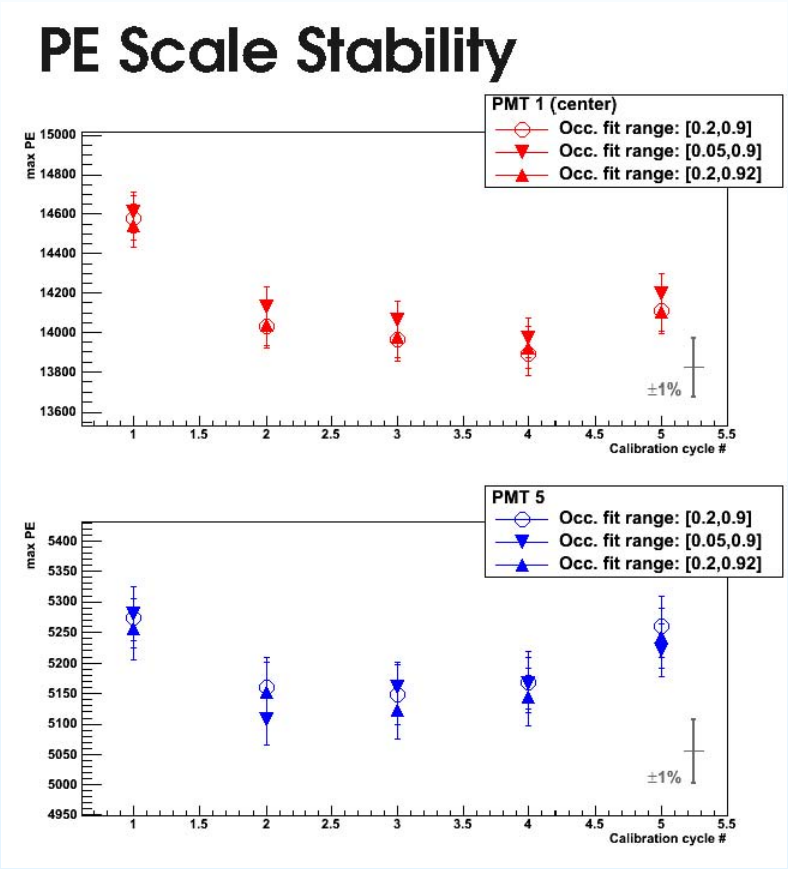

- A calibration cycle involves $\sim 2000$ light pulses/intensity at 150 discrete intensities.
- The PMT occupancy (*i.e.* fraction of laser pulses with PMT signal $> V_{Lo}$) is related to the average number of PEs, $< n_{PE} >$, at that intensity (RM2 energy (J)).
- This is merged with the distribution of ToT (at that RM2 energy (J)) to obtain: ToT $\rightarrow n_{PE}$ for each of the PMTs (5 in this data from CSU) in the WCD.

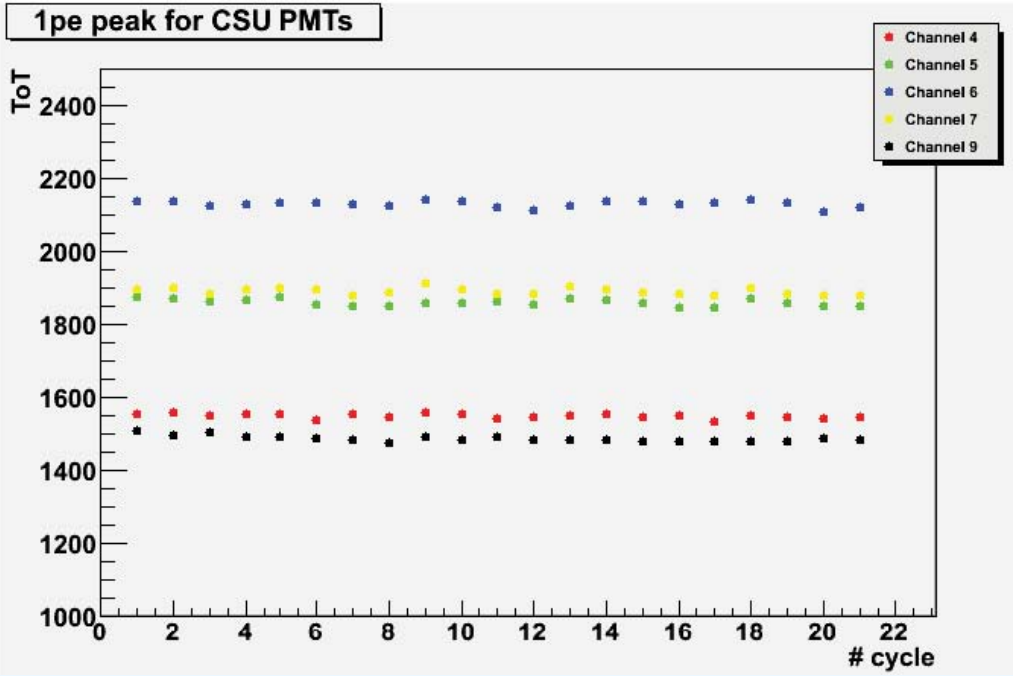
# HAWC calibration *"Maximum PEs" at CSU* ...


- The CSU prototype HAWC WCD has been in routine data taking for calibration R&D since spring 2011.
- This tank includes 5 (4 plus one with reflective baffle) PMTs and 4 selectable calibration light diffusers.
- Maximum PMT calibration signals (PEs), temporarily reduced by $\sim 4\times$, meet the design goal of $\sim 10,000$ PEs (dotted line in plot).

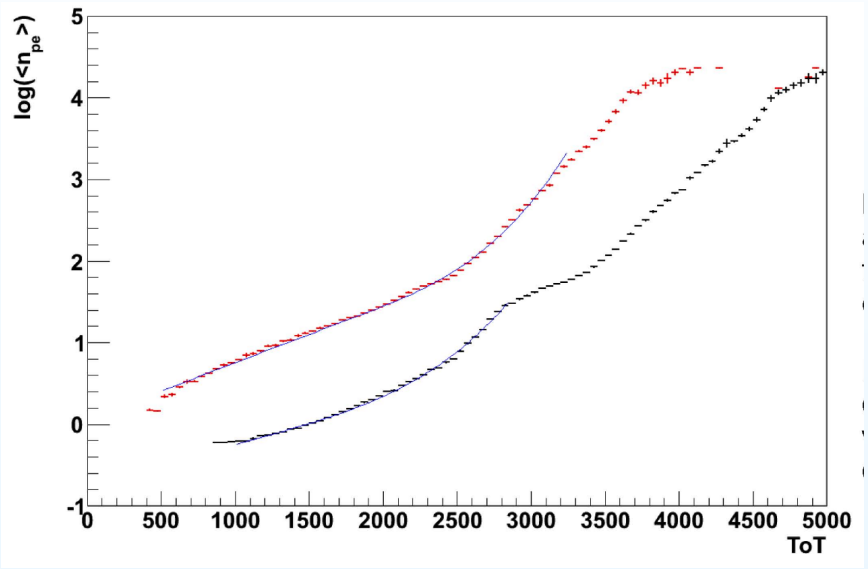
# HAWC calibration *stability at CSU* ...

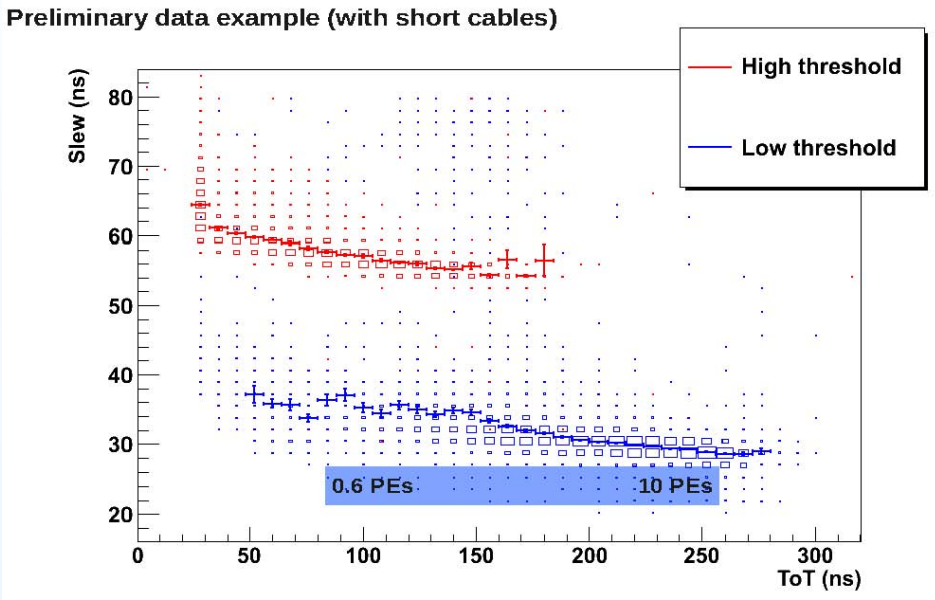




- (Left plots): Variation in the Maximum PE values for different analysis *fit ranges* and for two different PMTs *vs* calibration cycle.
- (Top plots): Variation in the 1PE→ToT values for all 5 PMTs *vs* calibration cycle.
- Both Maximum PE and 1PE calibration results show variations of $1 \sim 2\%$.

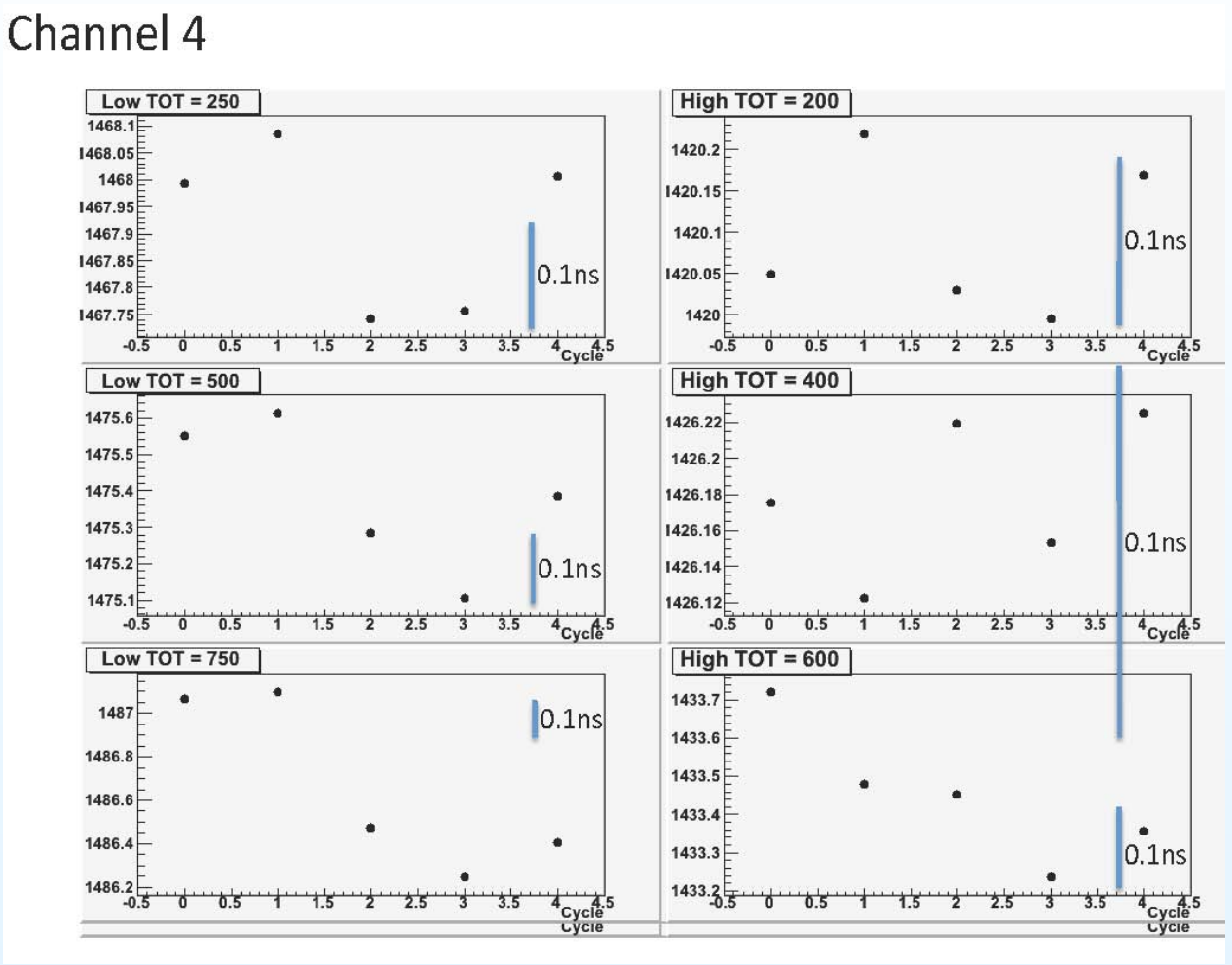
# HAWC calibration *deliverables (from CSU) (I)* ...

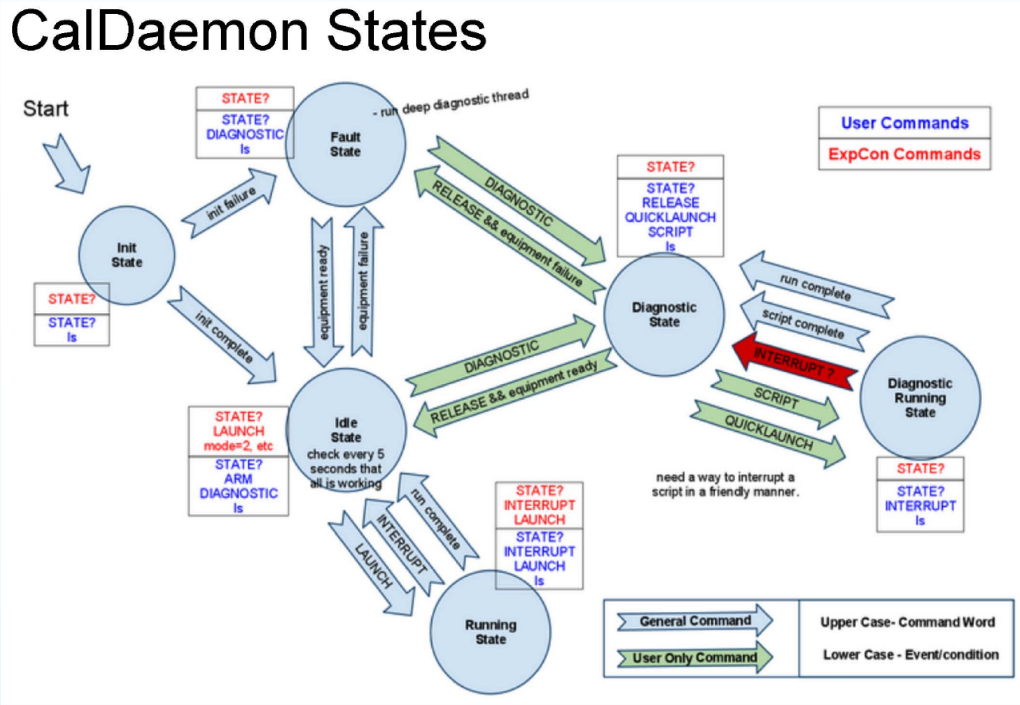

- (Top Left) Relation between what HAWC measures: PMT ToT and the PMT signal in PEs. The PMT signal in PEs is needed for shower plane reconstruction and $\gamma$-hadron separation.
- (Top Right) Time slewing correction (nsec) *vs* the measured PMT signal in ToT. The slewing correction is needed for shower plane reconstruction.
- Note: Time slewing $\equiv$ time between laser and PMT pulses; ToT(ns) = ToT/10.24.

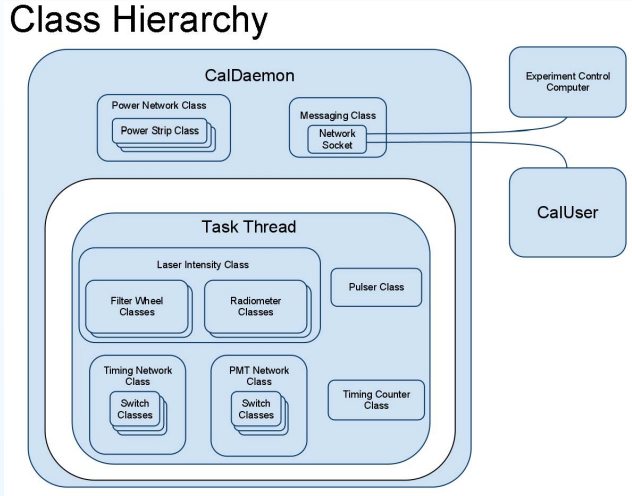
# HAWC calibration *deliverables (from CSU) (II)* ...


- A first look at the stability of (one) PMT's slewing correction is encouraging ...

# HAWC calibration *final control software* ...


- The HAWC calibration control software, developed at MTU, is now mature.
- The MTU HAWC software (and control computer) will move to CSU soon.
- Development of the *calibration* and *experiment control* software, optimization of the calibration parameters, debugging problems from the HAWC site, and extensive calibration studies will continue at CSU for the foreseeable future.

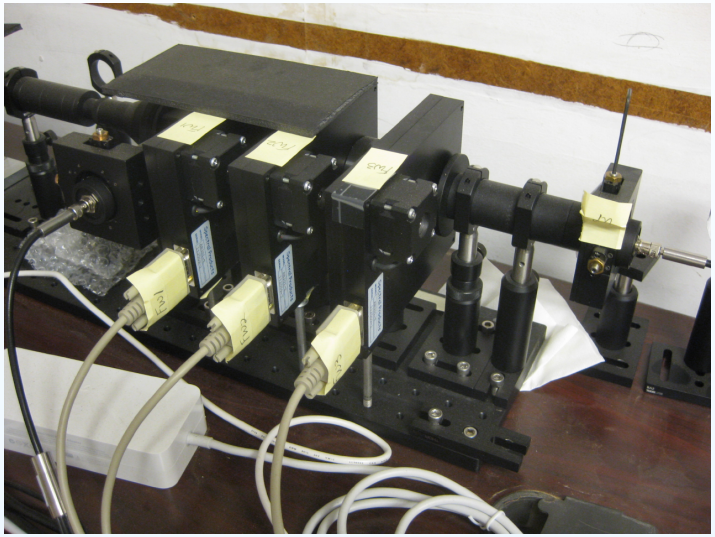
# HAWC calibration *status/plans (I)* ...


- Calibration studies have benefited from essentially complete *HAWC calibration systems* at CSU and MTU. A small subset of the studies are reported in this talk.

- What has been demonstrated includes:
  1. the successful, automated (continuous), remote operation of the calibration and DAQ at CSU:
     - the light pulses span the PMT dynamic range of 0.1 $\sim 10^4$ PEs
     - the monitoring of light pulse intensities (over the full dynamic range)
  2. calibration-to-calibration differences of calibration constants show only small variations (at the few percent level)

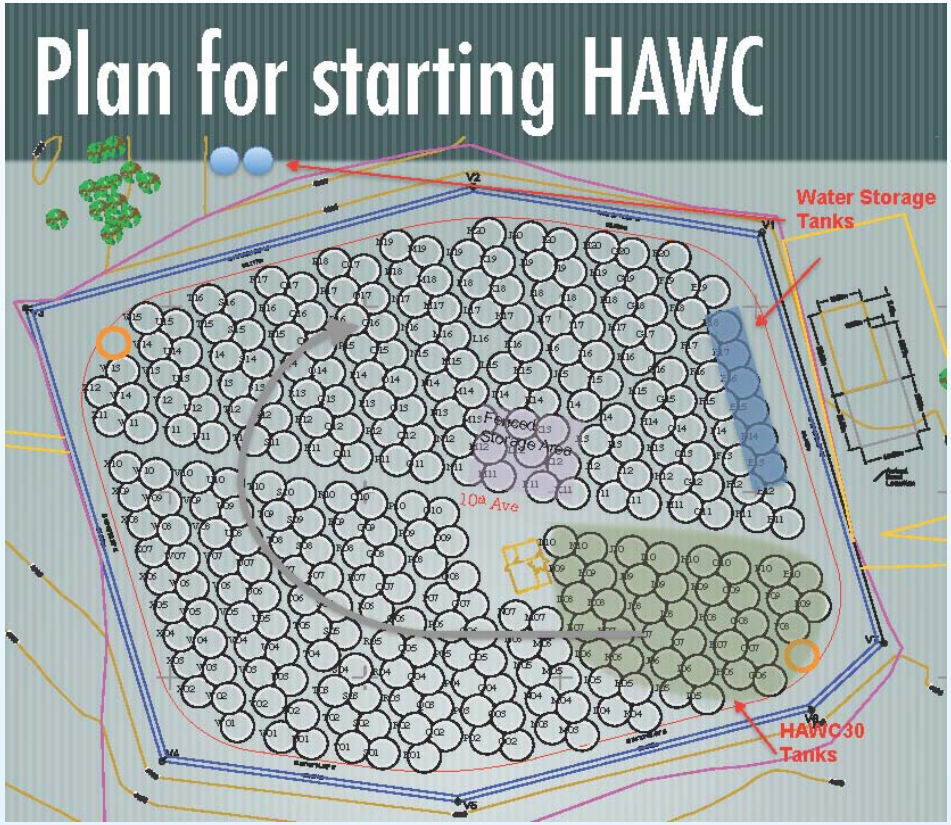
- What is still in progress includes:
  1. automated, remote operation of the *round-trip-timing* monitoring of the light delivery times to the WCDs
  2. checks on the stability and possible systematic variations in the time slewing corrections *vs* signal ToT
  3. automated, remote operation of the (final) calibration control software

# HAWC calibration *status/plans (II)* ...

- For HAWC30 we need additional parts:
  1. Overall *upgrade* from 1-tank to $30^{+}$-tank instrumentation
  2. Implement *minor* design changes based on CSU/MTU studies
  3. Address remaining issues ... *e.g. excess fiber storage*
- Complete upgrade of MTU hardware; then ship to Mexico
- Highest priority: ordering and shipping ...

# HAWC calibration *summary* ...


- The HAWC (laser) calibration system, and the analysis of the calibration data, are both well advanced.
- HAWC muon calibration (not presented): scintillator paddles are being procured and studies have begun of the response of the HAWC CSU WCD to muons.
- Current focus for HAWC30: ordering and shipping.
- Projected aggregate costs for the (laser) calibration (excluding shipping, customs and installation) are consistent with a $265K budget.

# Additional/backup slides


# Additional slides