HAWC Calibration Optimization:

Use Prototype WCD/Calibration/DAQ at CSU

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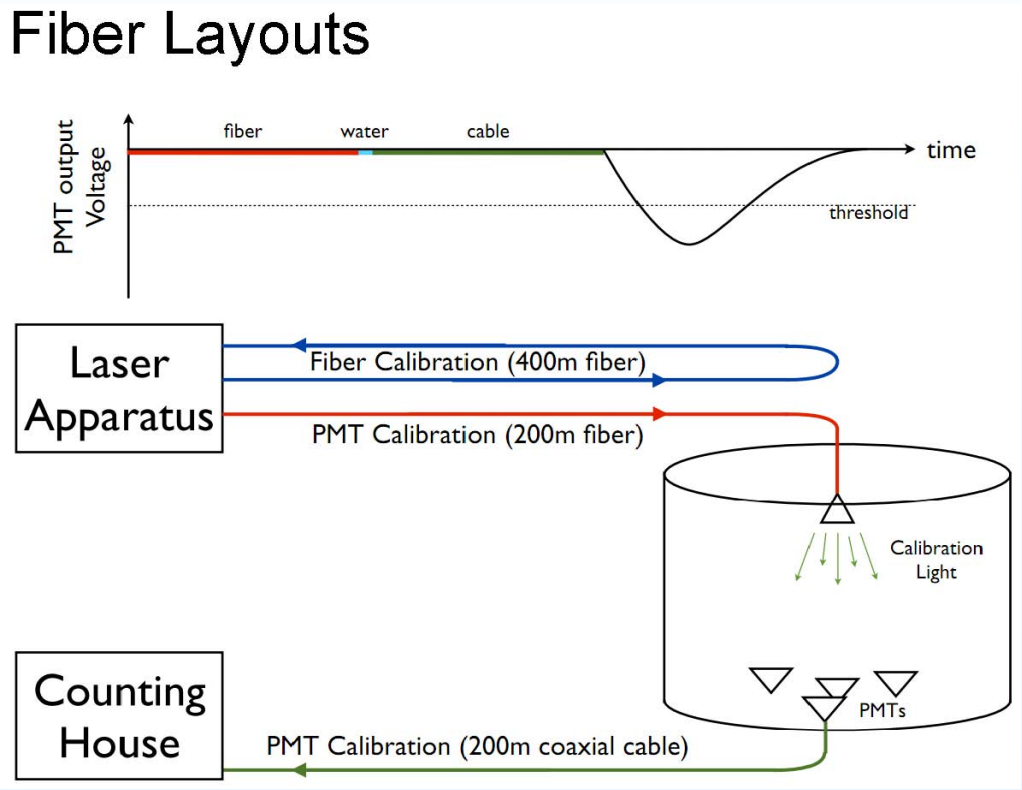
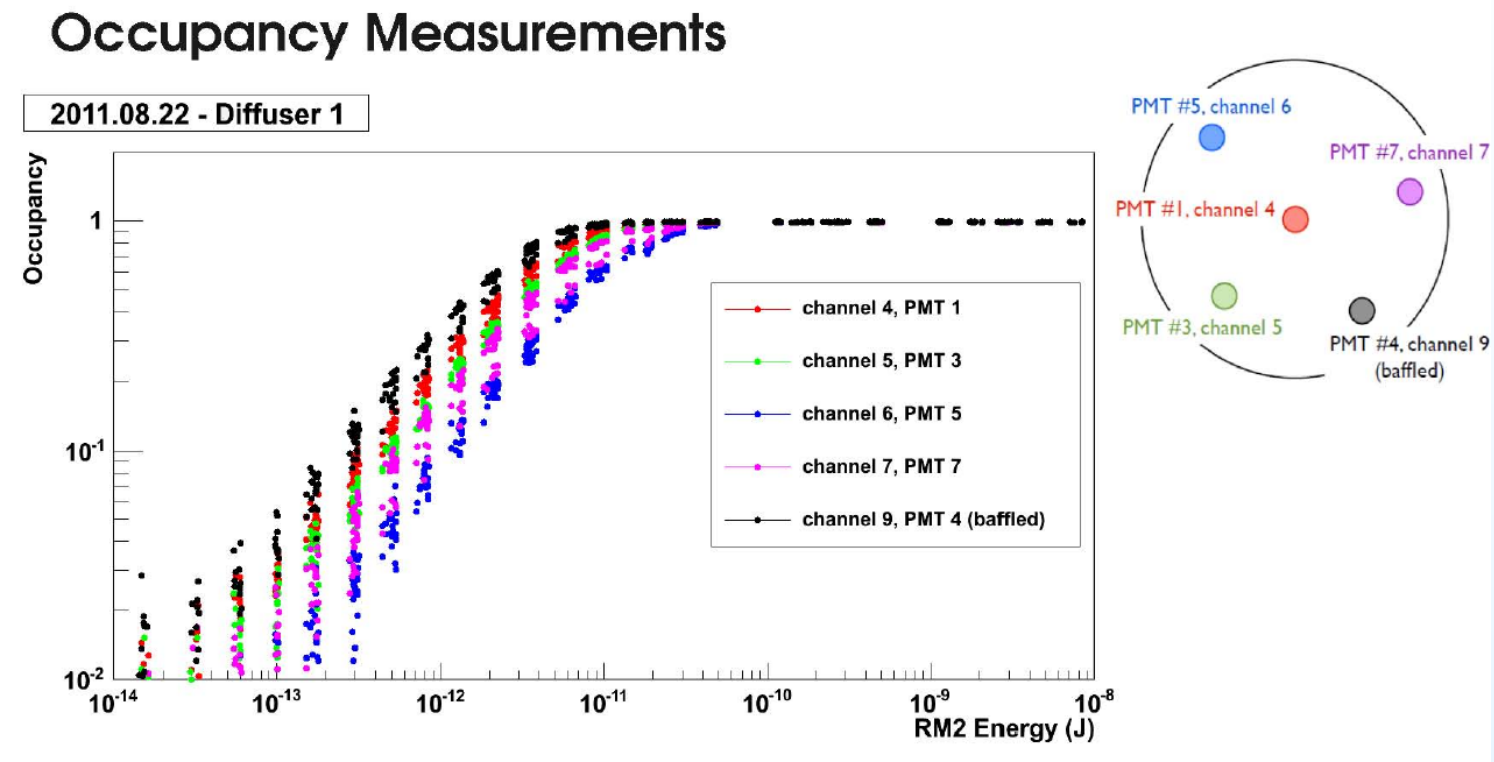
HAWC calibration: *conceptual design*



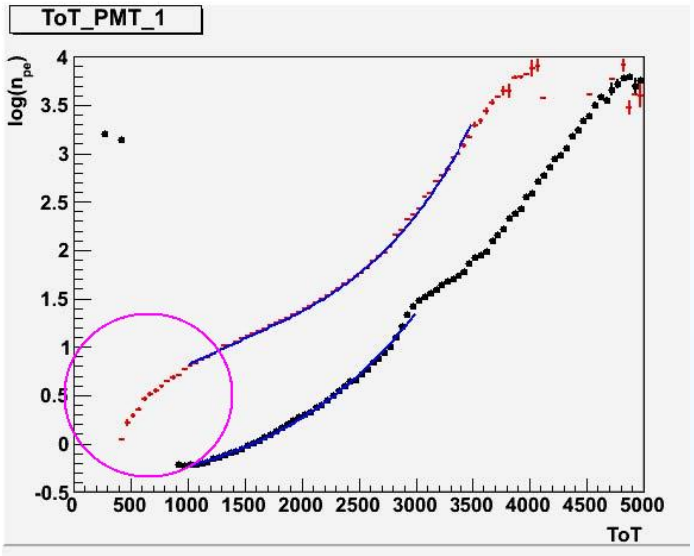
- Use a pulsed (300ps, 532nm laser) light source of known intensity and with known light transit time to the PMTs.
- Adjust the source intensity (using neutral density filters) over the (required) PMT dynamic range of ~ 0.1PE to $\sim 10^4$PEs.
- Optimize calibration details using the HAWC WCD prototype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

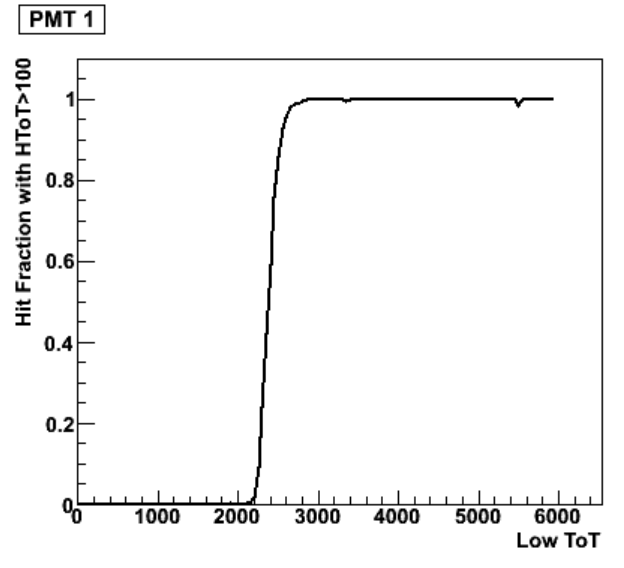
HAWC calibration: *current* $ToT \rightarrow n_{PE}$ *analysis*



- A calibration cycle involves ~ 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.

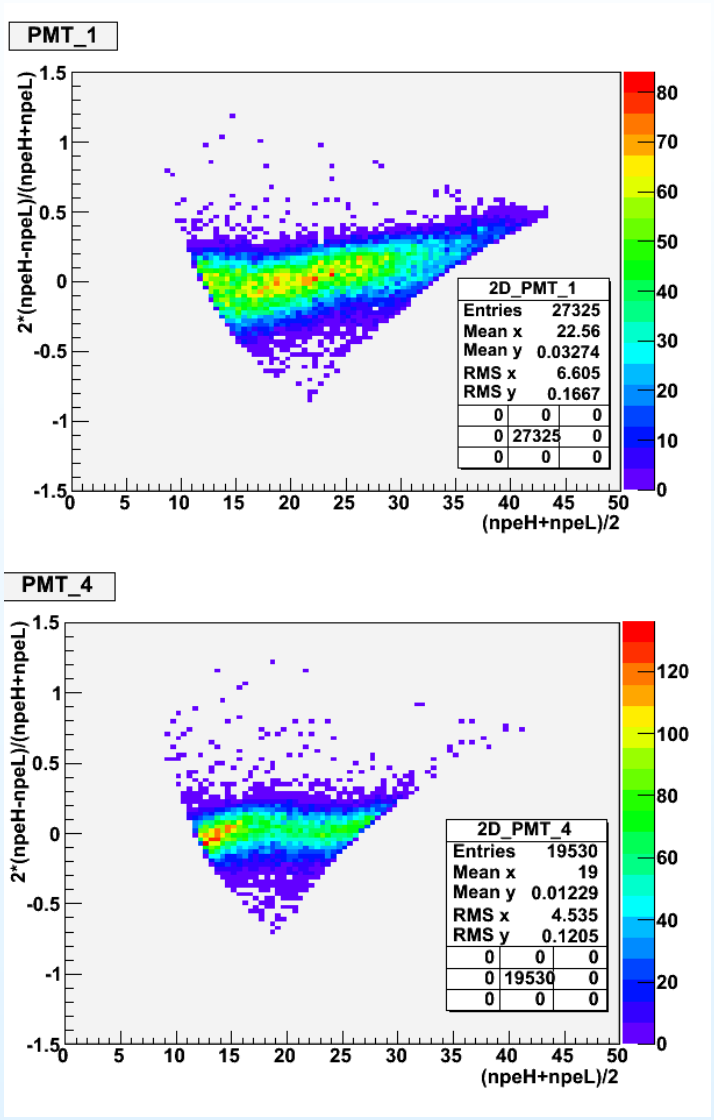
HAWC calibration: $ToT \rightarrow n_{PE}$ details





- As noted: from occupancy, the average PMT signals in photo-electrons, $< n_{PE} >$, are known for each calibration intensity.
- Use Poisson probability: $P(n_{PE}; < n_{PE} >)$, and known PMT (Gaussian) resolution: $\sigma = 0.35\sqrt{n_{PE}}$, to correlate the measured distribution of ToT and the simulated distribution of signals n_{PE}.
- As the simulated n_{PE} must include the High(Low) trigger threshold, for High ToT we should restrict calibration intensities to those with occupancies $\gtrsim 99\%$.

HAWC calibration: *best n_{PE} estimate*



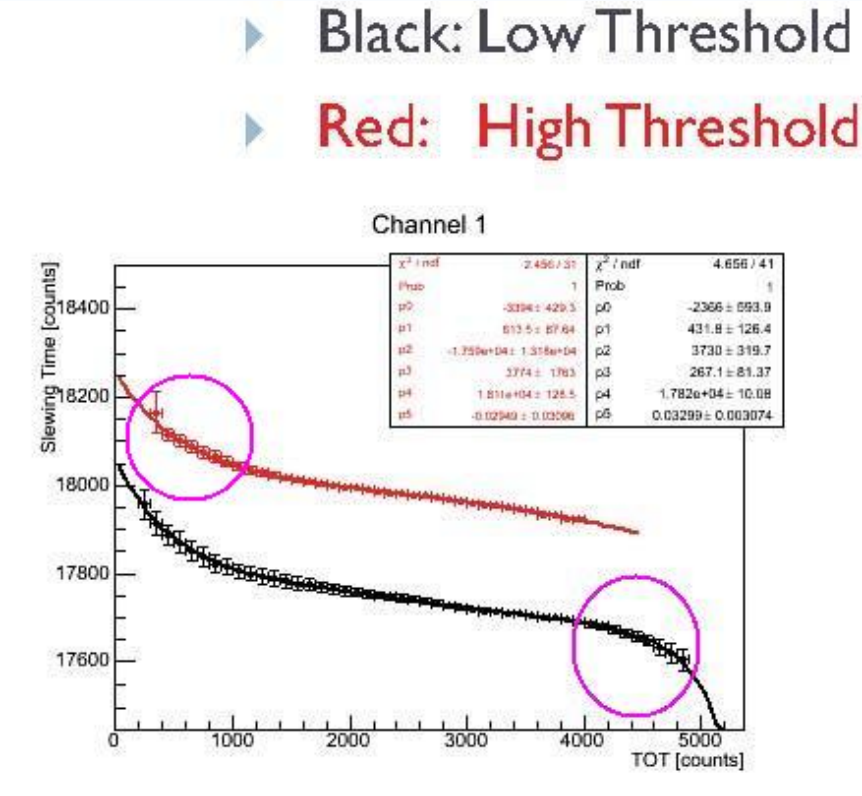
- With reliable conversions for $ToT \rightarrow n_{PE}$, how consistent are the determinations of n_{PE} from Low-ToT and High-ToT measurements?
- Plot shows:

$$\frac{(n_{PE}^{Hi} - n_{PE}^{Lo})}{\frac{(n_{PE}^{Hi} + n_{PE}^{Lo})}{2}}$$

1. Is there evidence for systematic differences *vs* n_{PE}?
2. What do the data tell us about the uncertainty in our evaluations of n_{PE}?

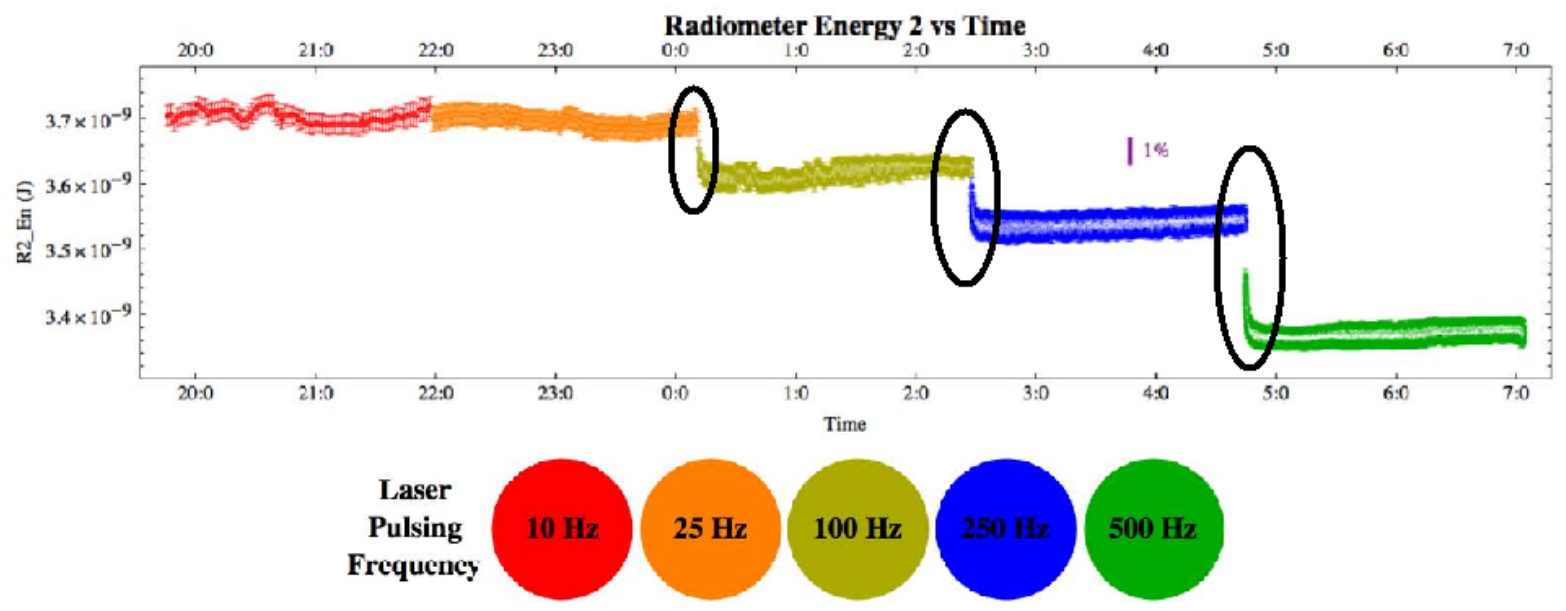
- Would look-up tables extend the $ToT \rightarrow n_{PE}$ calibration range?

HAWC calibration *best estimate for timing*



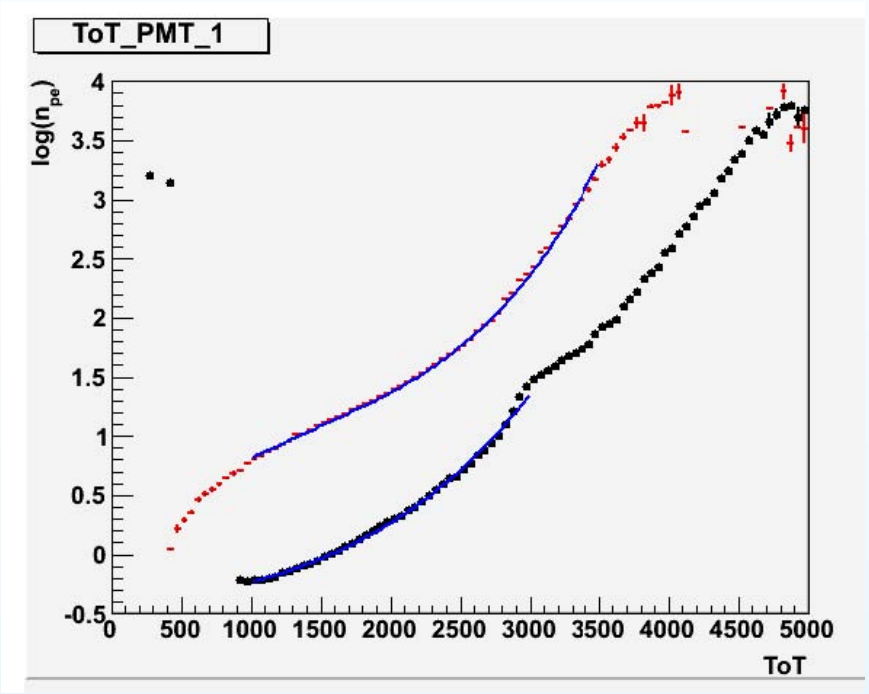
- The calibration system allows us to measure the time *slewing* for both Low and High threshold channels.
- For a given signal, in n_{PE}, is one of the measurements of higher precision?
  1. What are the (asymmetric Gaussian) widths for the Low and High threshold slewing measurements *vs* n_{PE}?
  2. Should we avoid using the High threshold slewing corrections near threshold (where the slewing correction varies rapidly with signal size)?
  3. Should we avoid using Low threshold slewing corrections in the region of possible PMT pre-pulsing?

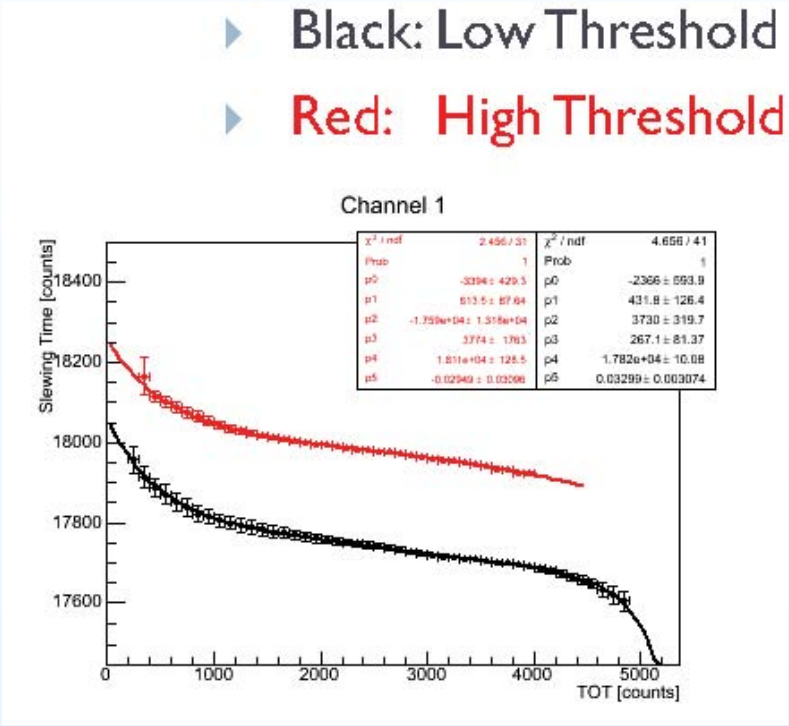
Calibration system: *can we use every laser pulse*



- Measurements of the laser intensity *vs* time have shown temporal variations.
- Can we find a calibration strategy:
  1. that minimizes laser warm-up or other non-calibration operation of the laser
  2. that is tolerant to temporal intensity variations (*e.g.* sub-divide a n-pulse calibration with 1-RAD2 intensity measurement into m blocks with m-RAD2 intensity measurements and n/m pulses per block)?

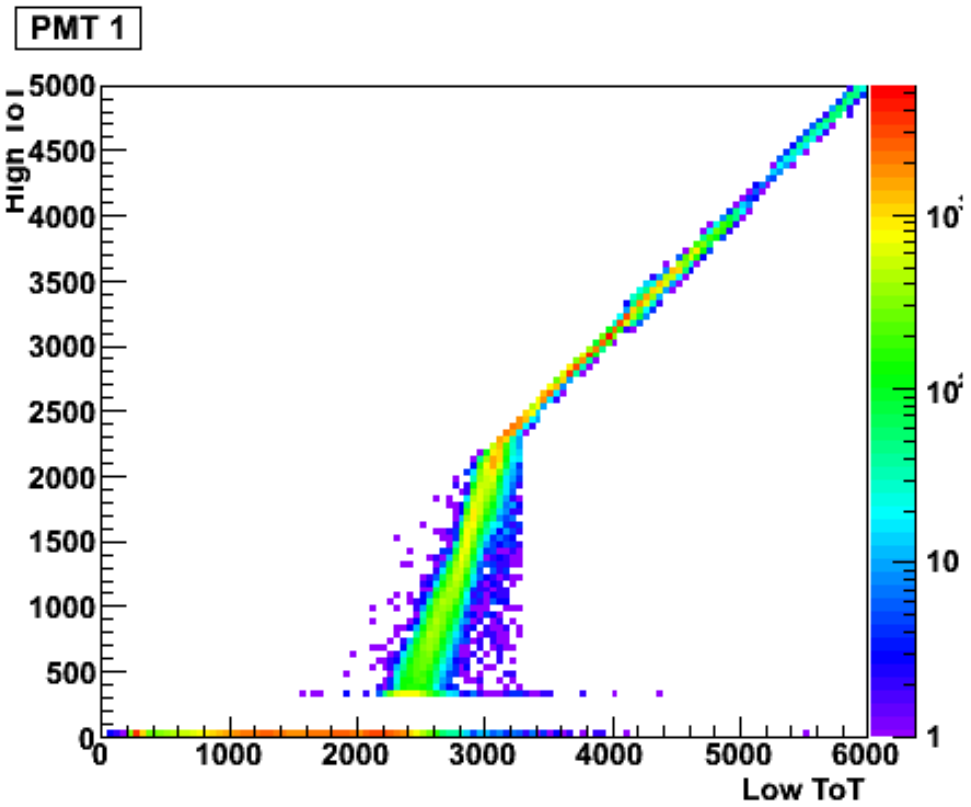
HAWC calibration: *how to maximize the efficiency*

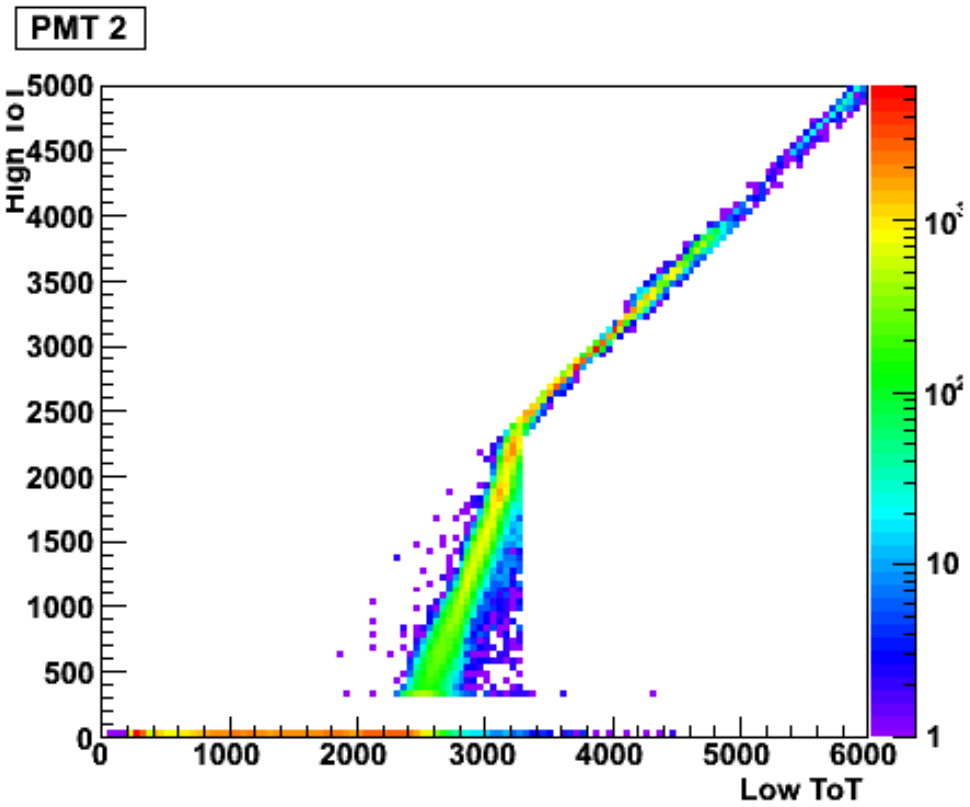




- The calibration deliverables are: $ToT \rightarrow n_{PE}$ and time slewing *vs* ToT.
  1. What are the minimum number of source light intensities needed?
  2. What are the optimal number of light pulses at each intensity?
- The goal is to minimize the calibration time and maximize laser lifetime.

HAWC calibration: *extra credit*





And the High *vs* Low ToT structure is explained by ...?