Characterization of the R5912-02 MOD Photomultiplier Tube at Cryogenic Temperatures

Thomas Caldwell
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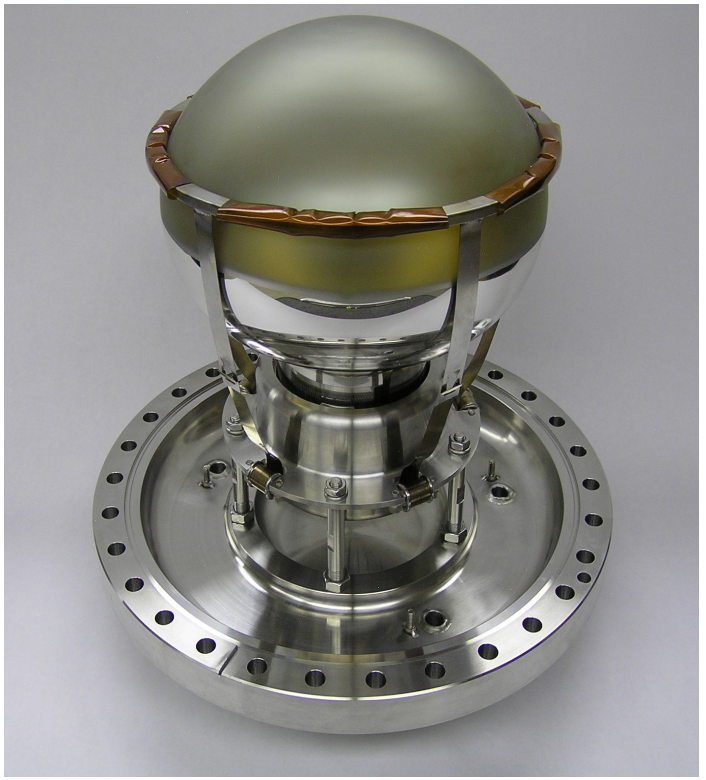
Outline

- R5912-02 MOD properties
- MiniCLEAN
- Cold test setup
- Modeling the response using pulse shape fits
- Timing and charge distributions
  - Prepulsing
  - Double pulsing
  - Late pulsing

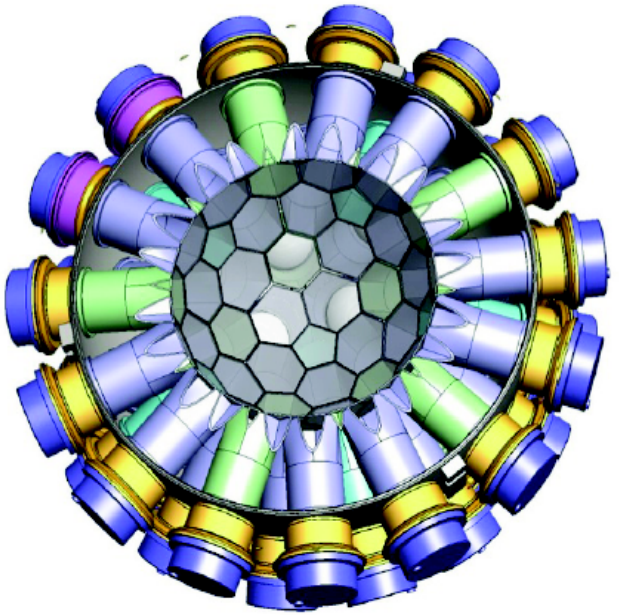
R5912-02 MOD

- 8” diameter cryogenic photomultiplier tube
- 14 stage dynode stack
- Photocathode with platinum underlay
- ~18% quantum efficiency at 430 nm, 87 K
- Performance demonstrated down to 29 K: http://arxiv.org/abs/astro-ph/0702202



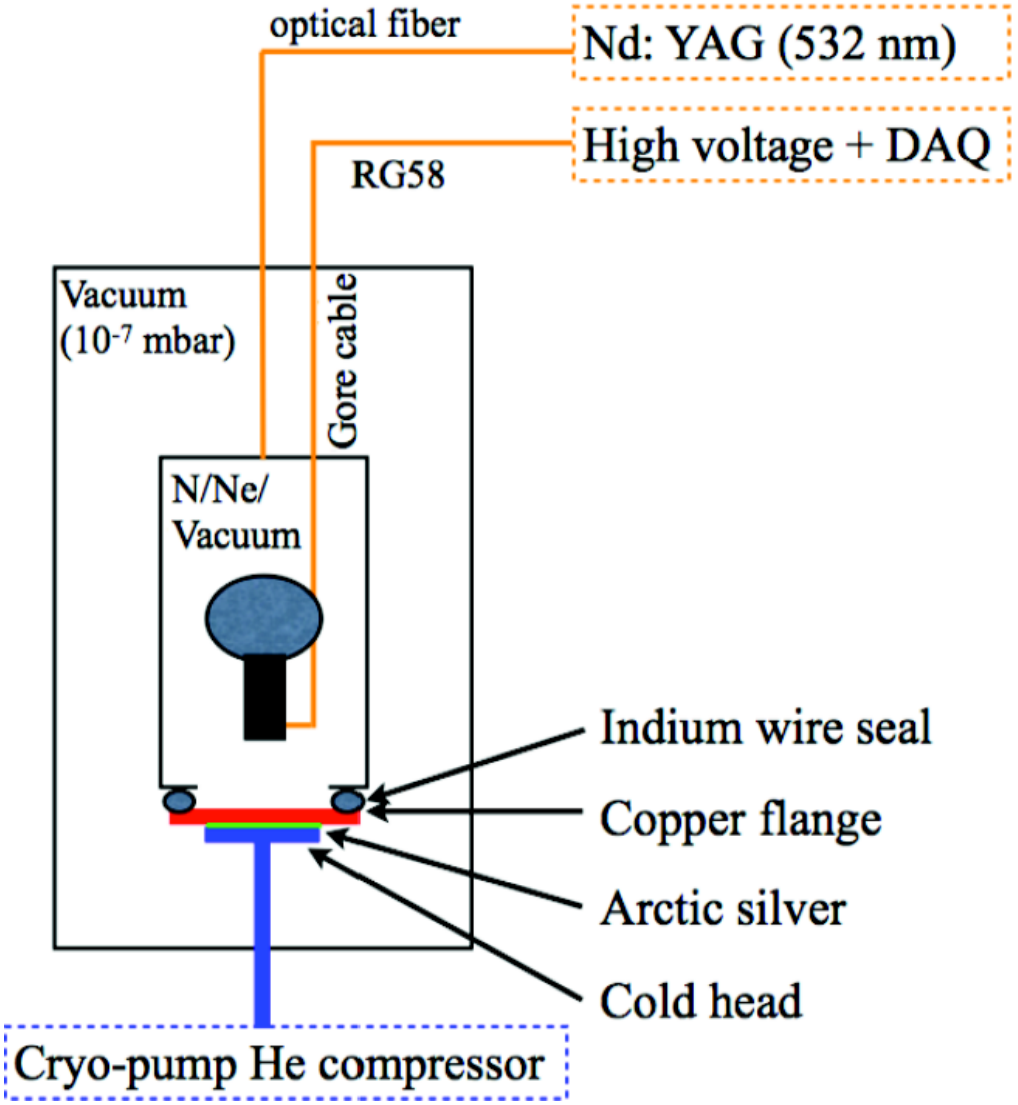
MiniCLEAN

- Single phase liquid argon (or neon) dark matter detector
- Under construction at SNOLAB (see S. Seibert Friday)
- Will use 92 R5912-02 MOD PMTs read out by CAEN V1720 250 MHz digitizers
- Operates close to the single photoelectron regime near threshold
- Need excellent timing based pulse shape discrimination to achieve 10^{10} background rejection from ^{39}Ar



Cold PMT Test Setup

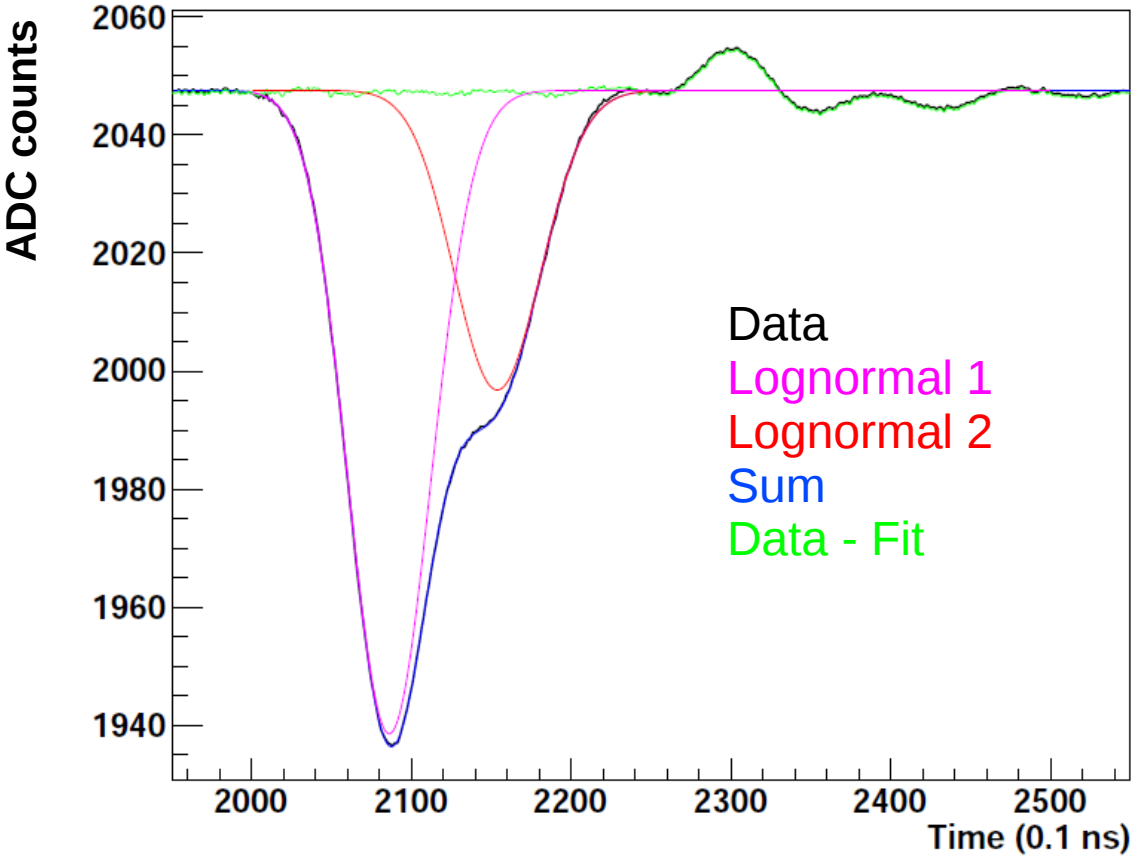
- Data taken at LANL by Steve Jaditz
- R5912-02 MOD cooled to 90 K in nitrogen gas
- 10 GHz Lecroy oscilloscope
- Fast readout over ethernet using lecrunch (T. Latorre)
- Trigger on laser output
- 4.5% coincidence rate from collimated laser
- Study detailed single photoelectron response for input to simulation



Averaged Pulse Shape

- Pulses have interesting timing features
- Excellent fit to sum of 2 lognormal distributions

$$I(t) = \sum_{i=1}^{n} \frac{Q_i}{(t+t_0)\sqrt{2\pi\sigma_i^2}} e^{-\ln^2\left(\frac{t+t_0}{\tau_i}\right)/2\sigma_i^2}$$



Q_i: charge of component i

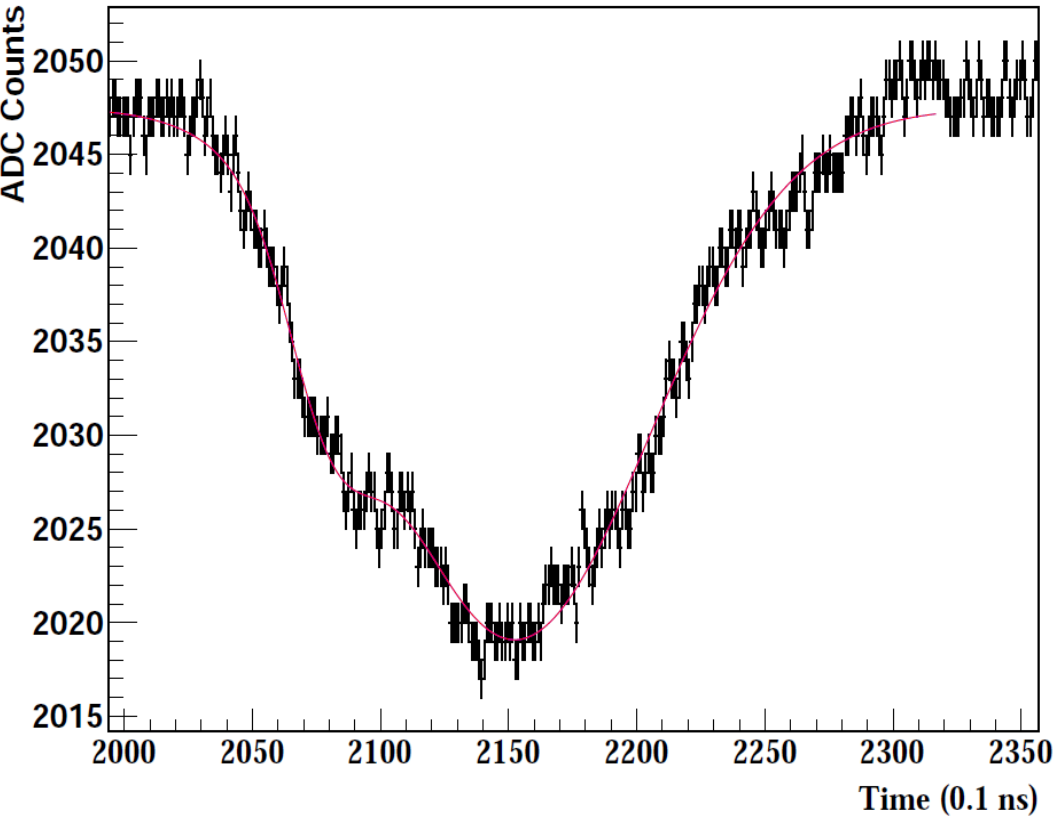
t_0: arbitrary time offset

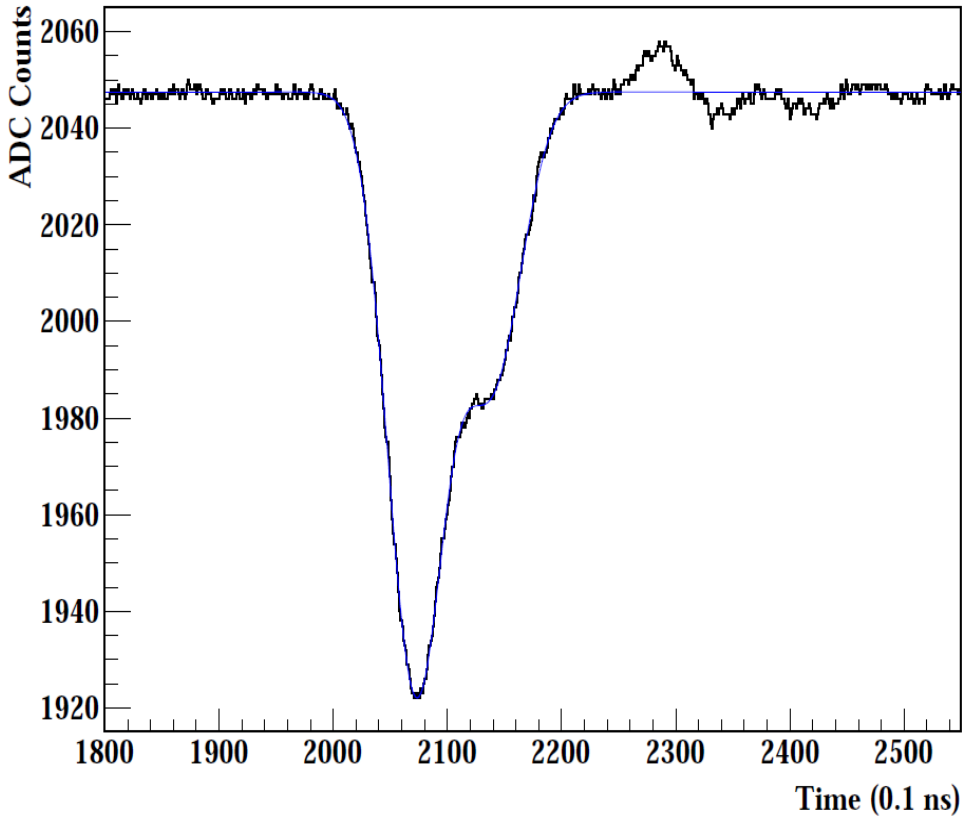
τ_i: geometric mean

σ_i: width

Individual Pulse Fits

- Simple pulse finding with noise filter, fit to 2-component lognormal sum
- Typical pulse (right)
- ~4% of pulses have larger 2nd component (left)
- Rules out most scenarios where 2nd component is a feature of the base





Individual Pulse Fits

- Simple pulse finding with noise filter, fit to 2-component lognormal sum
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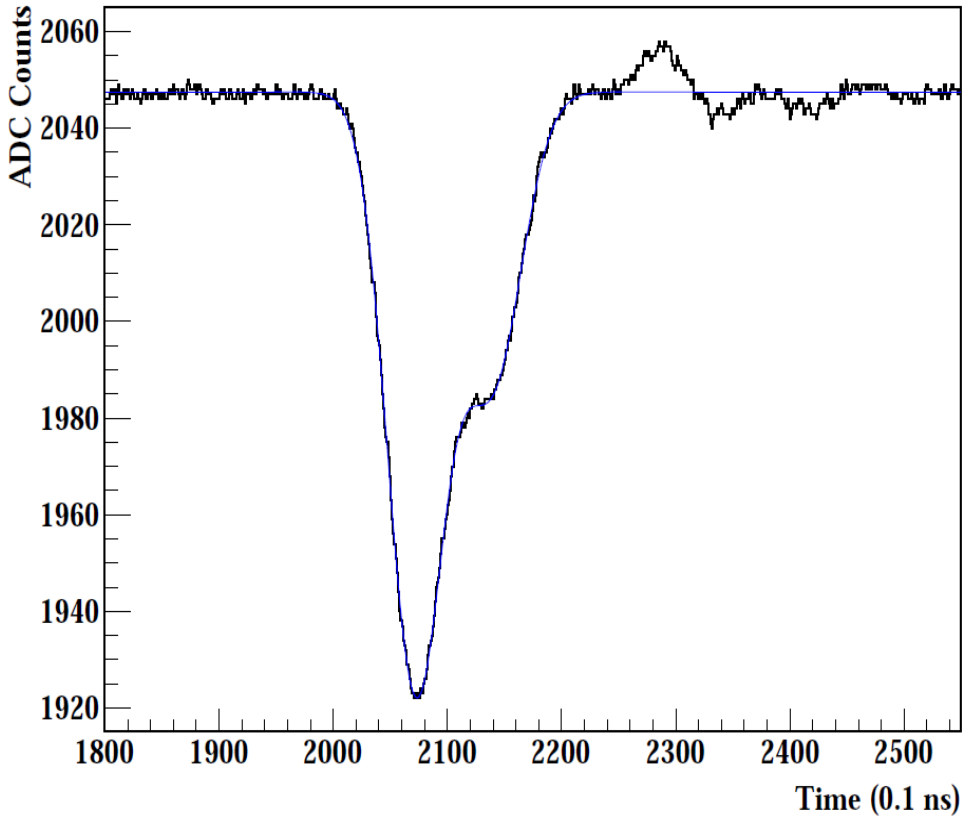
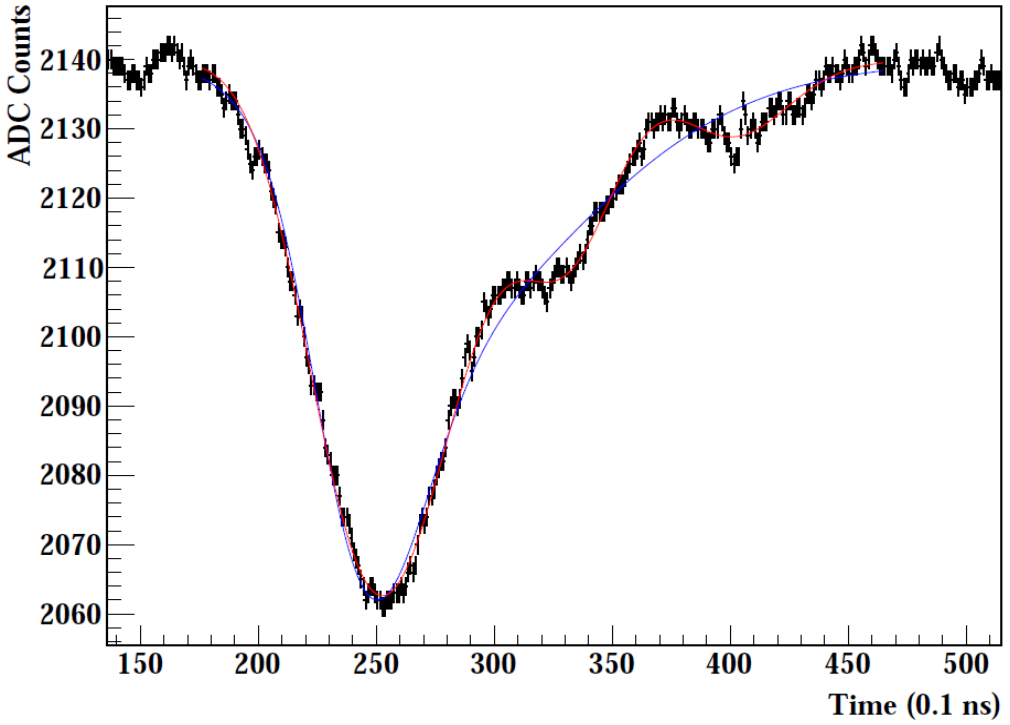
- ~4% of pulses have larger 2nd component
- Rules out most scenarios where 2nd component is a feature of the base

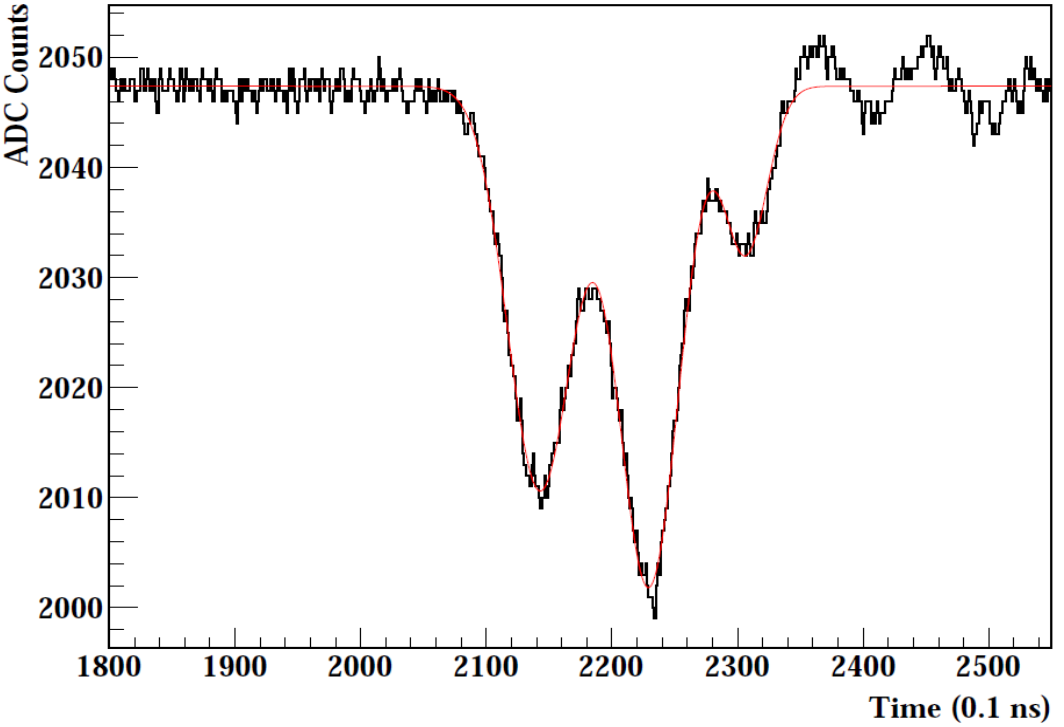
- Every pulse shows this multi-component feature
- Structure still seen after modifying base to reduce ringing
- Very similar features warm
- Similar features in R5912-HQE PMT with different base design



More Pulse Shape Features

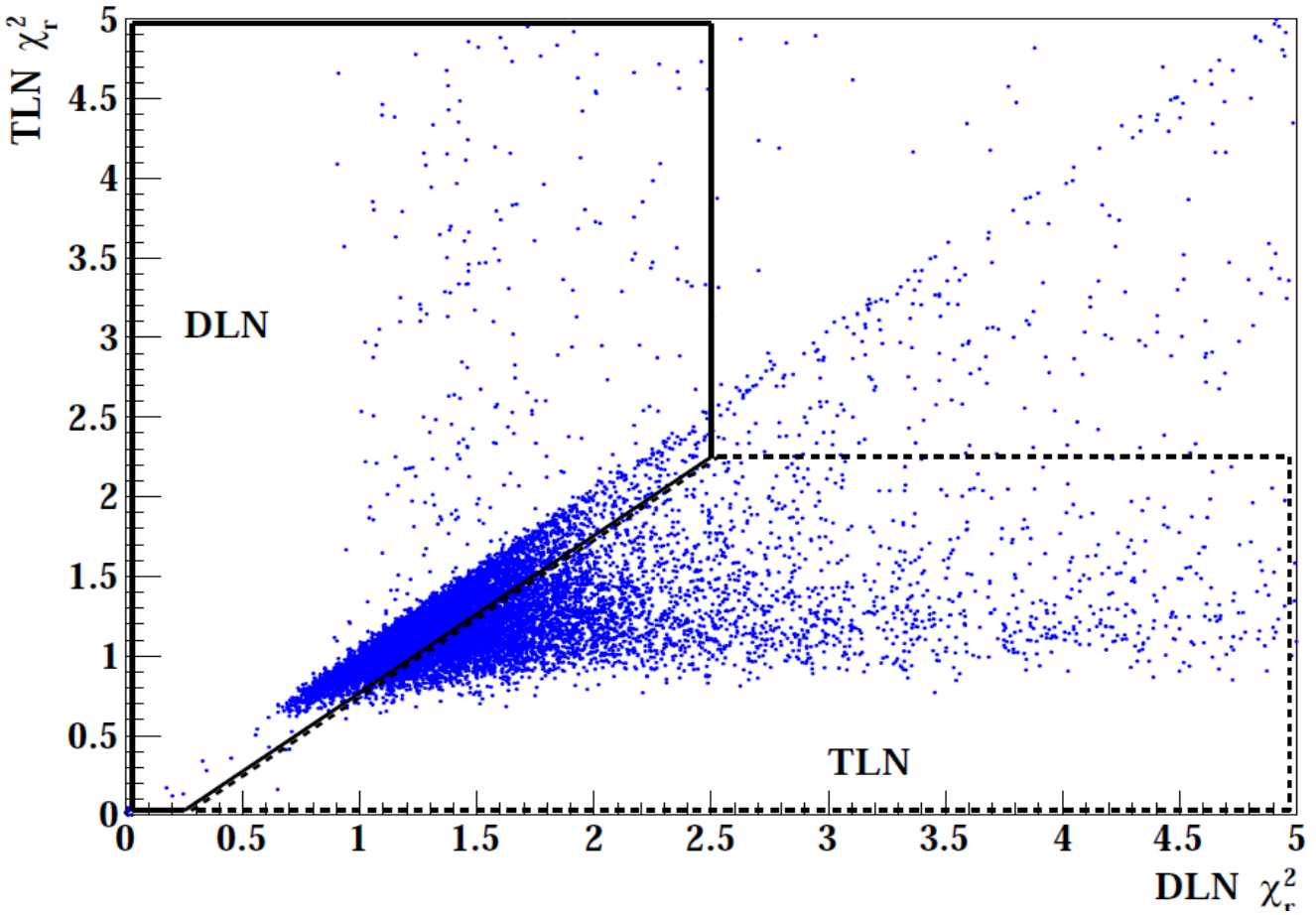
- 5% of pulses had poor chi-square using 2-component lognormal sum
- These pulses fit well to a 3-component sum
- Typical 3-component pulse (left)
- Few percent of pulses with larger 2nd component (right)





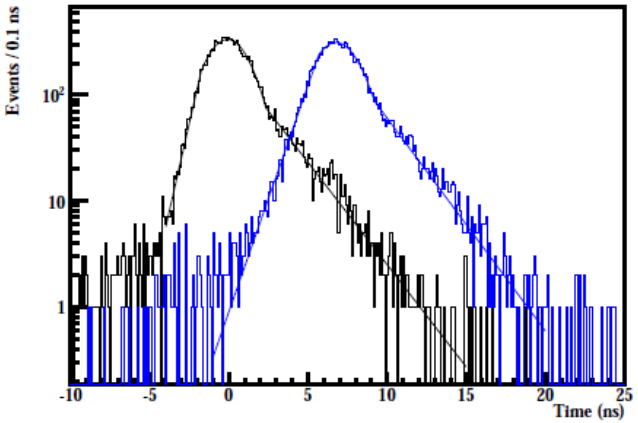
Pulse Selection

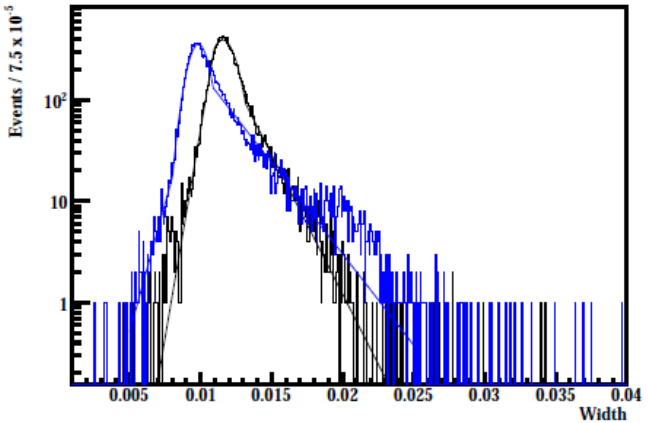
- Use fit chi-square to classify pulses as either 2-component (DLN) or 3-component (TLN)
- Reject pulses with poor chi-square for both fits
- Rejects 0.202% of pulses, expect 0.199% pileup

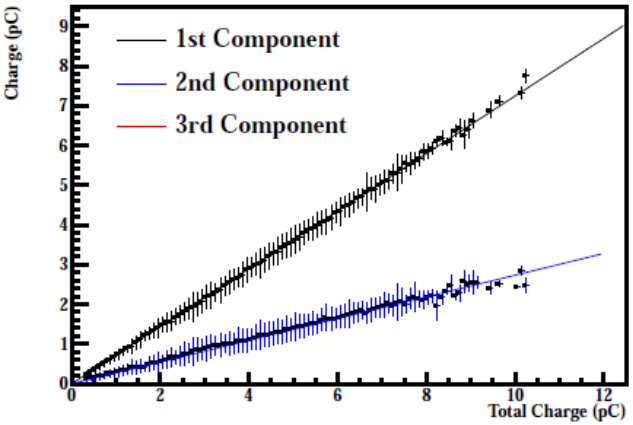


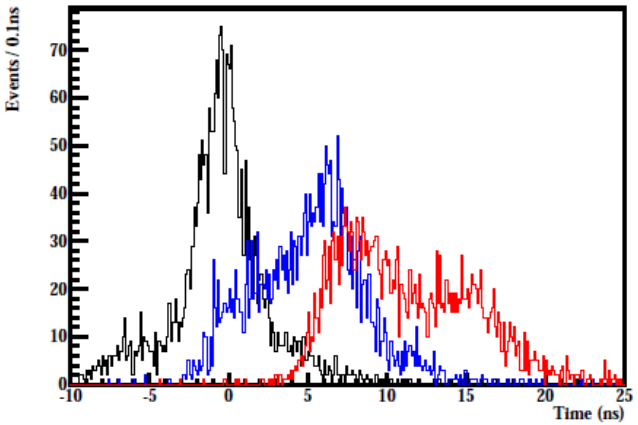
Fit Parameter Distributions

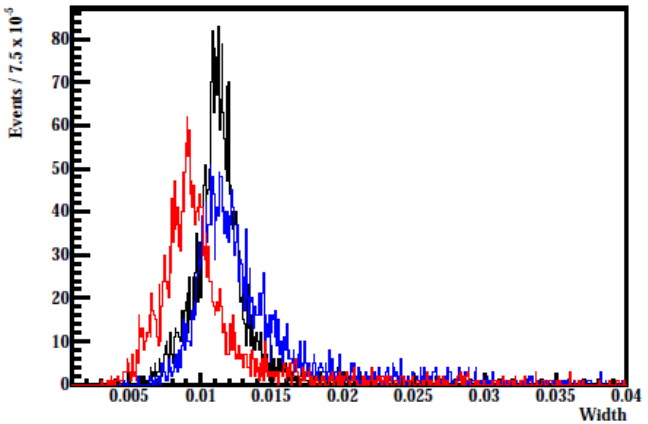
- Uncertainties on the fit parameters much smaller than the width of their distributions
- Distributions below used to simulate variations in pulse shape
- Use fit parameters to get time and charge of each pulse

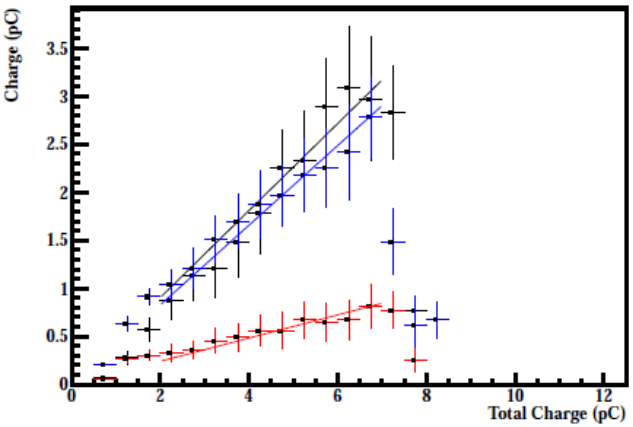






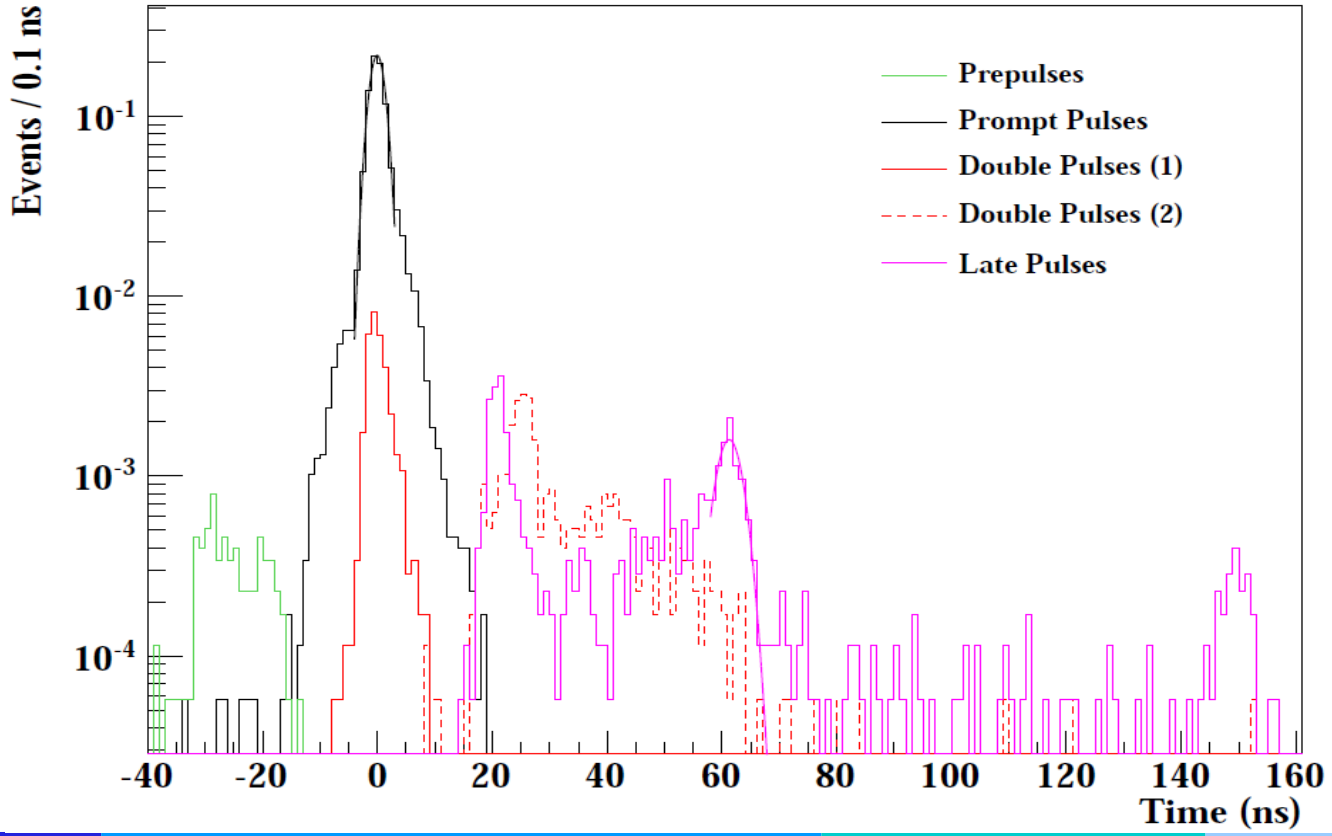






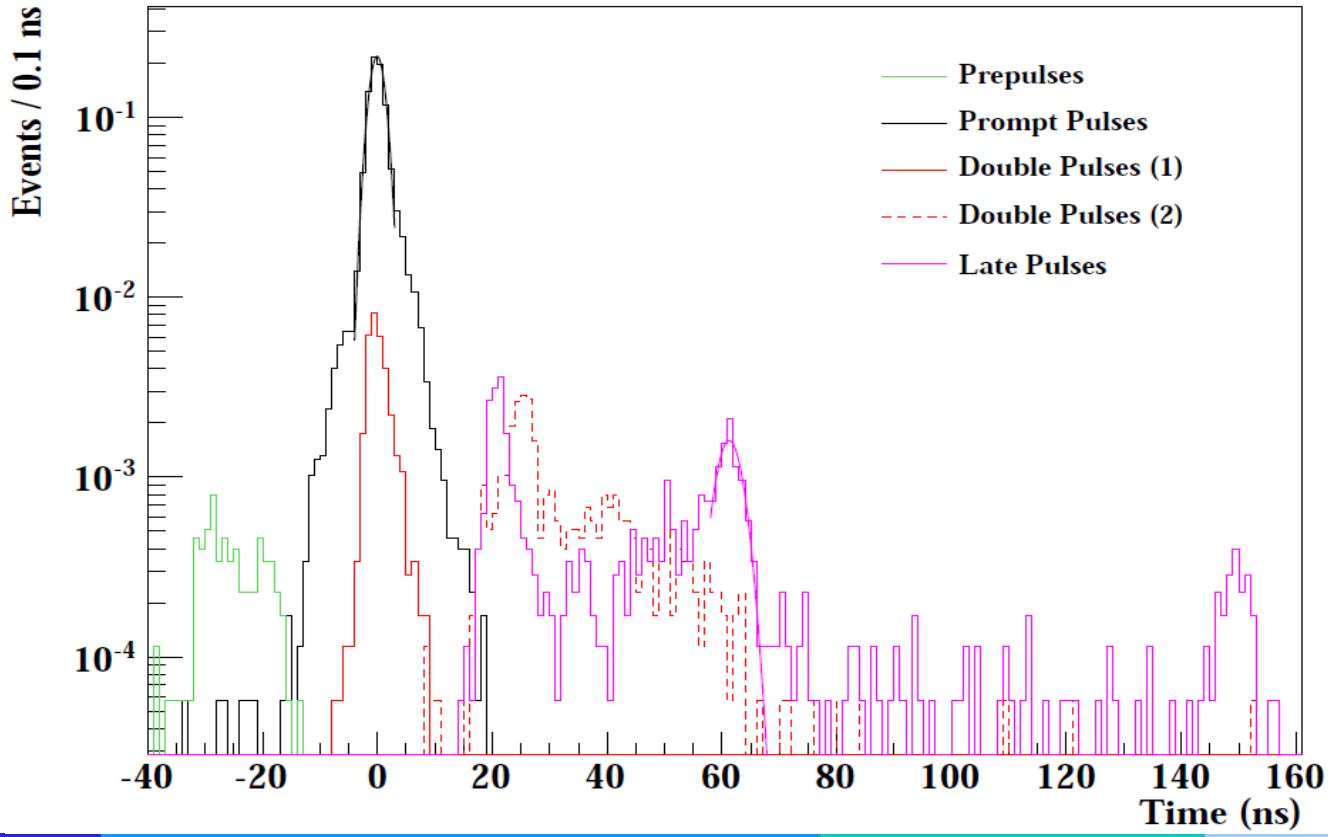
Timing

- Timing distribution from cold test below
- Prepulsing: transmission through photocathode, photoelectron created at 1st dynode
- Double pulsing: inelastic scattering off 1st dynode
- Late pulsing: elastic scattering off 1st dynode
- After pulsing: ion drift to 1st dynode



Timing

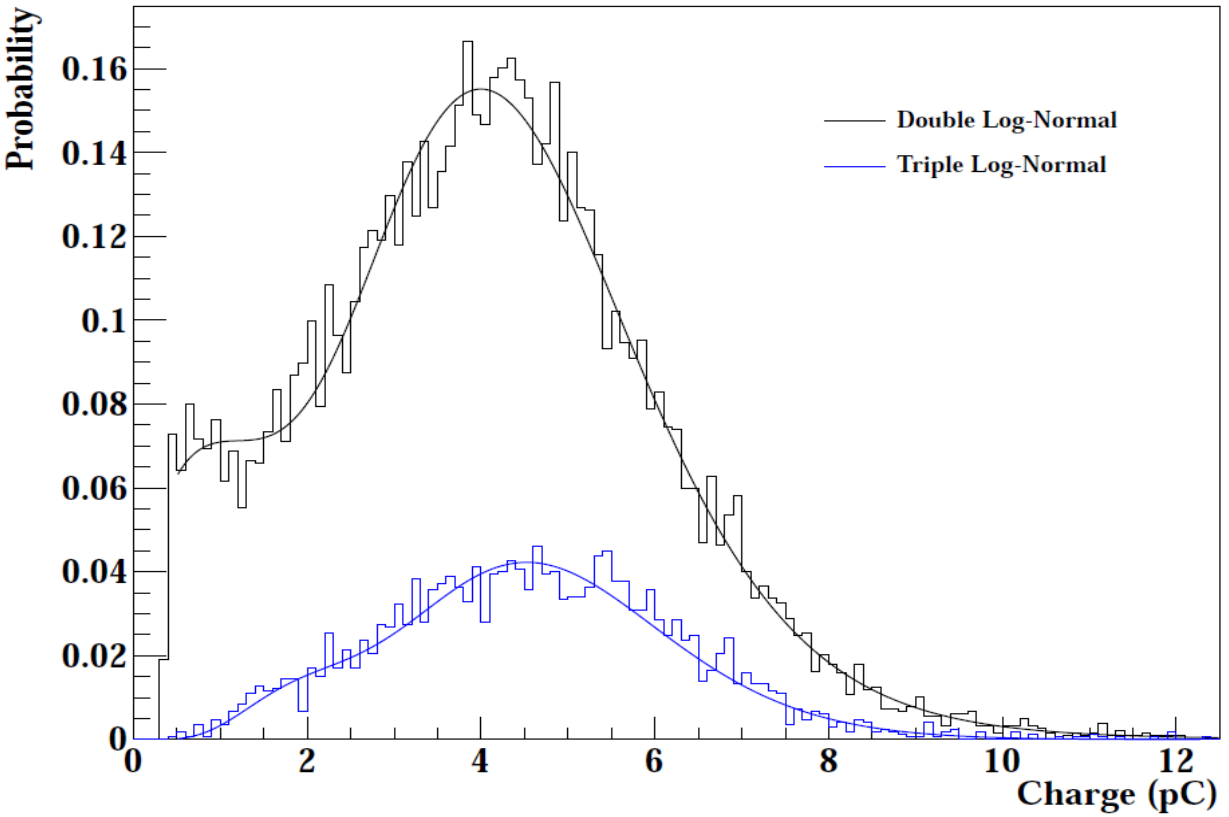
- Pulse time defined as geometric mean of 1st fit component
- Observe 0.7% prepulsing (at normal incidence), 4.5% double, 4.7% late, 1480 Hz noise rate
- No significant after pulsing when cold (statistically limited)
- Transit time spread of 1.5 ns
- 30.6 ns transit time using late and early pulsing peaks



Charge Distribution

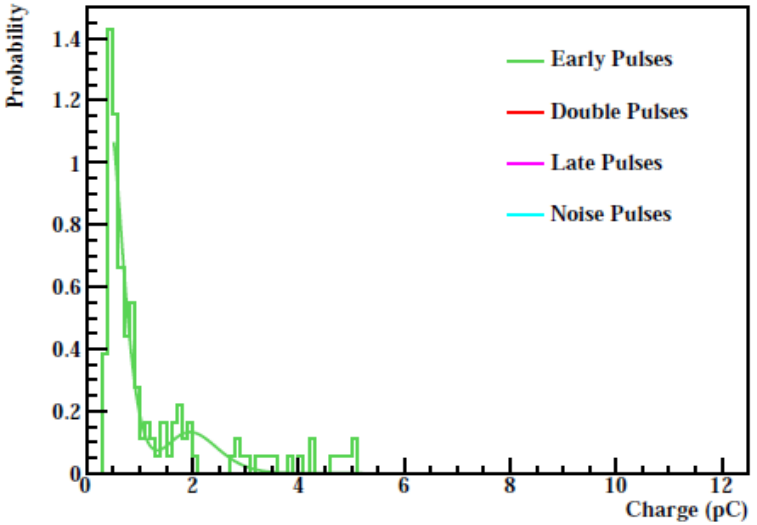
- Charge from integral of lognormal sum fit, reducing smearing from electronics noise
- Fit to the sum of 2 gamma distributions for the peak and the low charge shoulder

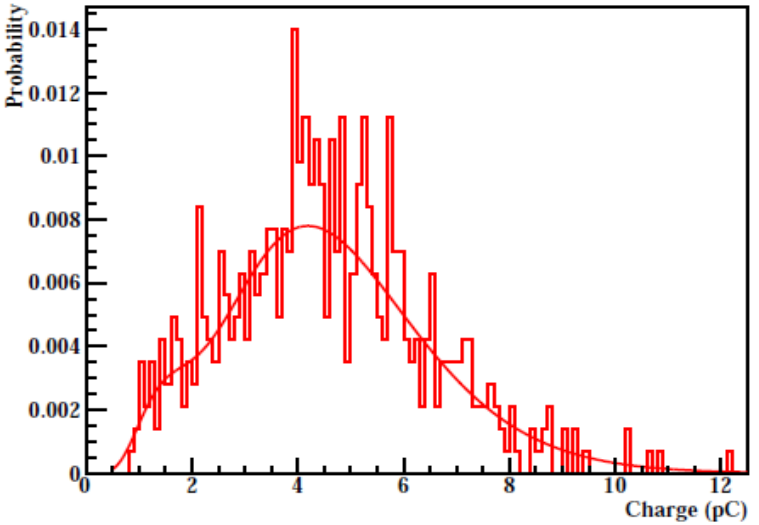
$$p(q) = \frac{p_1}{\Gamma(k_1) q_1^{k_1}} q^{k_1 - 1} e^{-q/q_1} + \frac{1 - p_1}{\Gamma(k_2) q_2^{k_2}} q^{k_2 - 1} e^{-q/q_2}$$

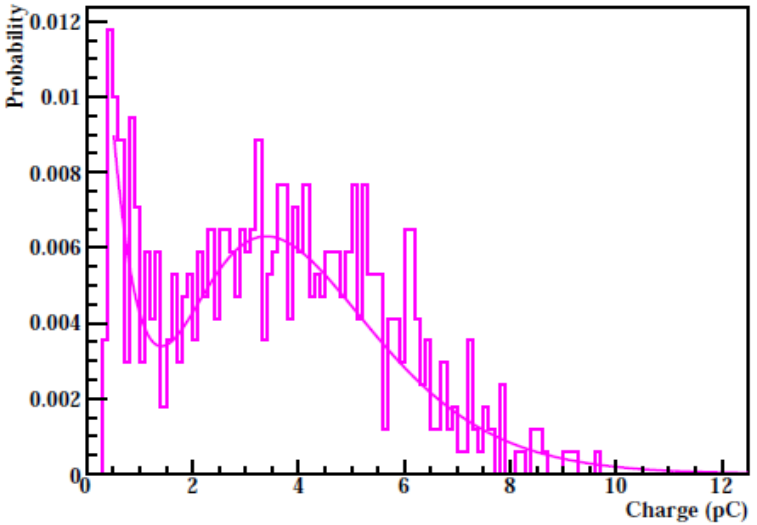


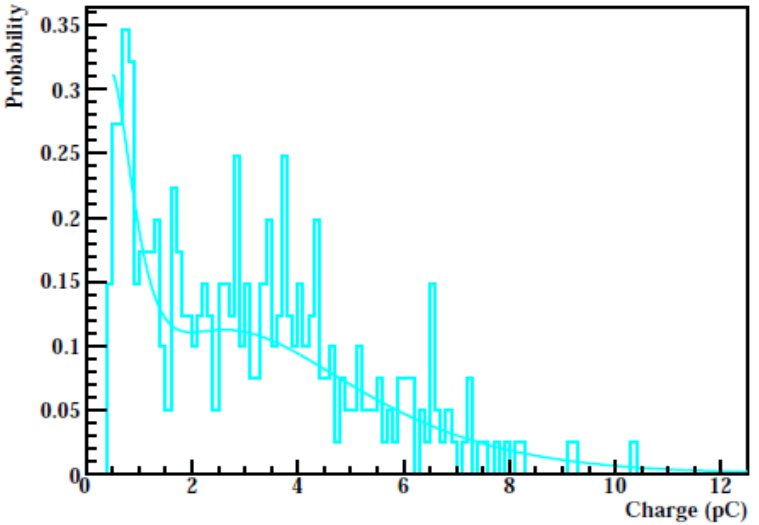
Charge Distribution

- Lower charge for prepulsing due to missing gain stage
- Lower mean charge for noise hits



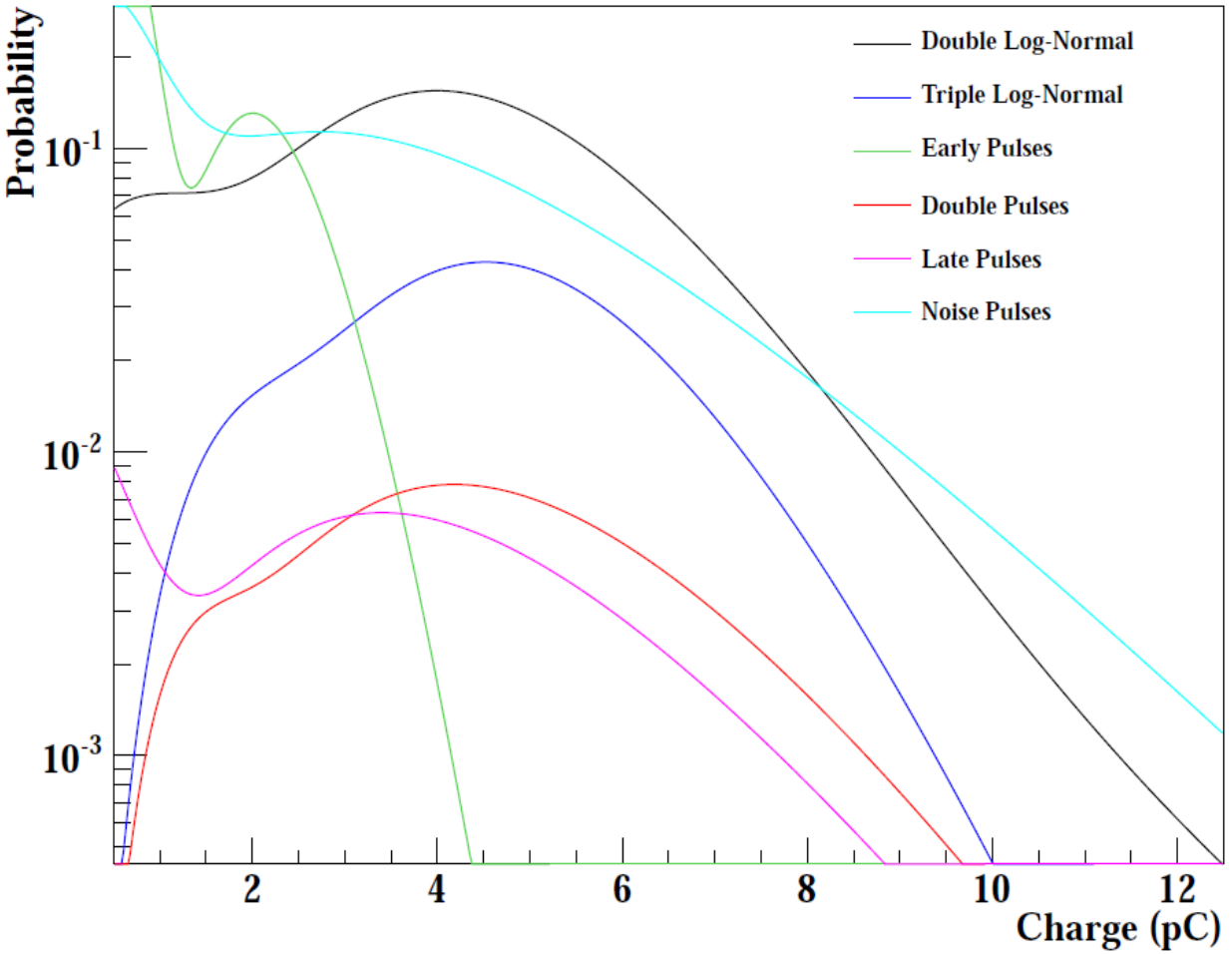






Charge Distribution

- Charge distributions weighted by relative probability below (unit normalization for noise and prepulsing)
- Would get the sum of these without triggered source



Summary

- R5912-02 MOD tested at 90 K with 10 GHz digitization
- A lognormal sum gives excellent fits to individual pulses
- This was used to extract the pulse shape, timing, and charge characteristics
- Implemented all of these features in MiniCLEAN MC
  - Lognormal sum pulse shape
  - Variations in pulse shape
  - Timing and charge distributions for each pulse type
  - Prepulsing
- Including timing and charge distribution features in PDFs improves likelihood based particle identification, especially at low energies
- Similar model works well for the R5912-HQE PMT
- 92 R5912-02 MODs on their way to SNOLAB for MiniCLEAN construction (see Stan Seibert's talk Friday)