Carleton UNIVERSITY

DEAP 3600

DEAP-3600 Data Analysis

Implementing an Intermediate Lifetime for Liquid Argon Scintillation Timing

By: Adam Smith-Orlik

Thursday, August 15, 2019

Overview

- Background
- Motivations
- How – Implementing Intermediate Lifetime
- Results
- Next Steps
- Questions

Carleton UNIVERSITY

DEAP 3600

Background—What is DEAP-3600?

- DEAP is a Dark Matter Experiment using Argon Pulse-shape Discrimination
- Searching for direct detection of WIMPs (Weakly Interacting Massive Particles) as a dark matter candidate
- Using 3600kg of Liquid Argon (LAr) cooled to 90K in a 170cm diameter spherical acrylic vessel surrounded by 255 PMTs situated 2km underground at SNOLAB in Sudbury

Background—What is DEAP-3600?

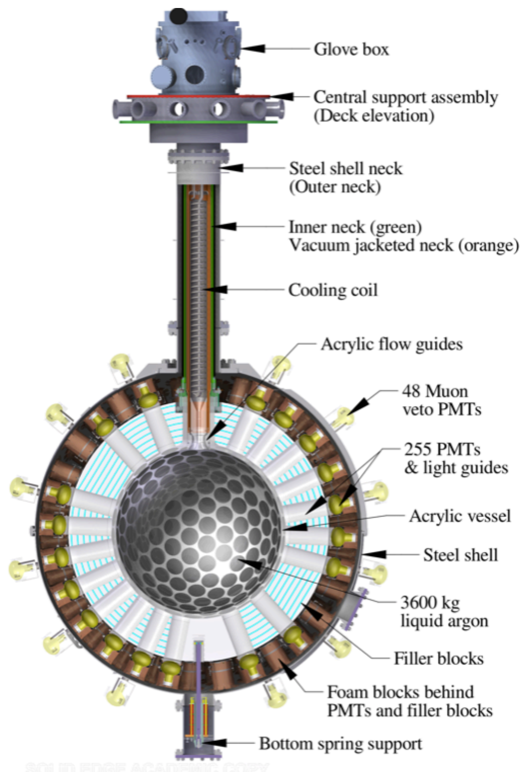


Fig 1: Cross-section of the DEAP-3600 detector.

Background—Pulse-shape Discrimination (PSD)

- Pulse shape discrimination in LAr allows for the separation of electron (ER) and nuclear (NR) recoil scintillation events

- The timing of scintillation (singlet and triplet lifetimes) in LAr is unique for different events and can be grouped into ER and NR

- Ar39 beta decays make up the largest background and can be identified by their singlet-triplet ratio in the ER band

- The WIMP-nucleon signature occurs in the NR band

Background—Pulse-shape Discrimination

AmBe Hit-map with ER, NR, and ROI

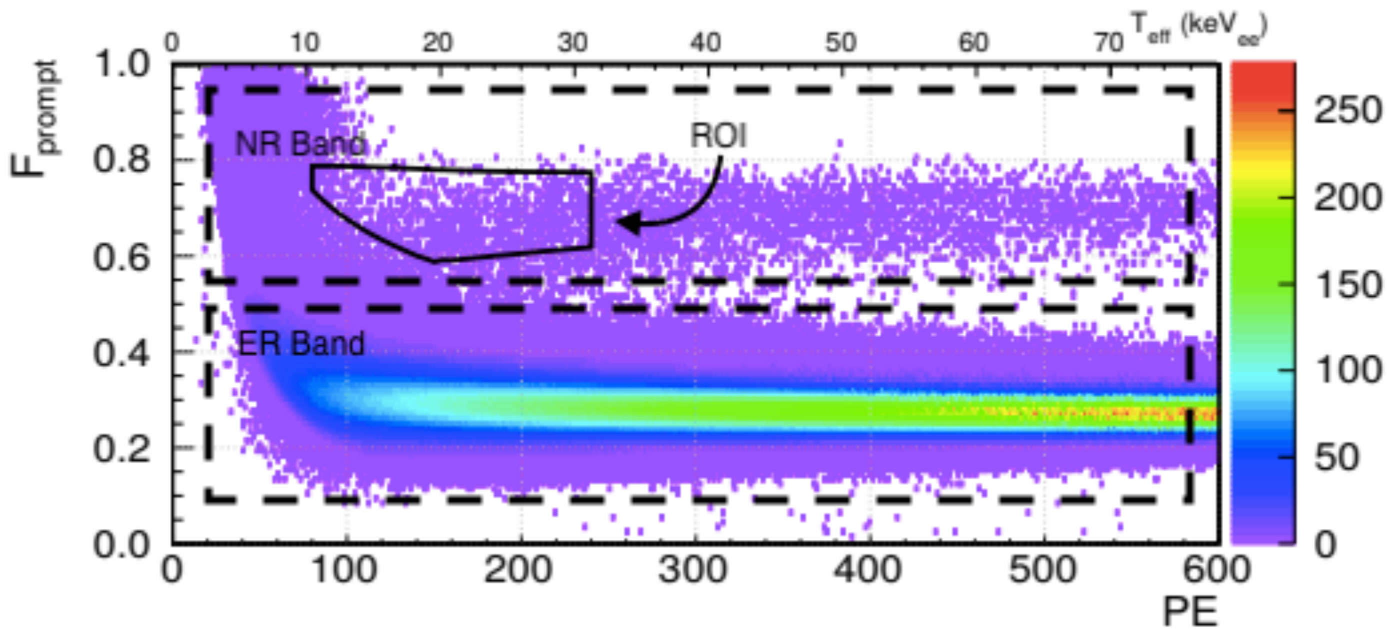


Fig 2: Hit-map example of ER, NR, and ROI with AmBE source deployed for calibration.

Background—Pulse-shapes and fprompt

- The Pulse-shape is the resulting plot of the sum of the photon intensity detected by all 255 PMTs in the event window (10μs)
- fprompt is the fraction of the light detected in the prompt window (-28 to 60ns) over the entire event window
- ER and NR bands are plotted on an fpromt vs energy (qPE) plot as seen in Figure 2

Background—Pulse-shapes and fprompt

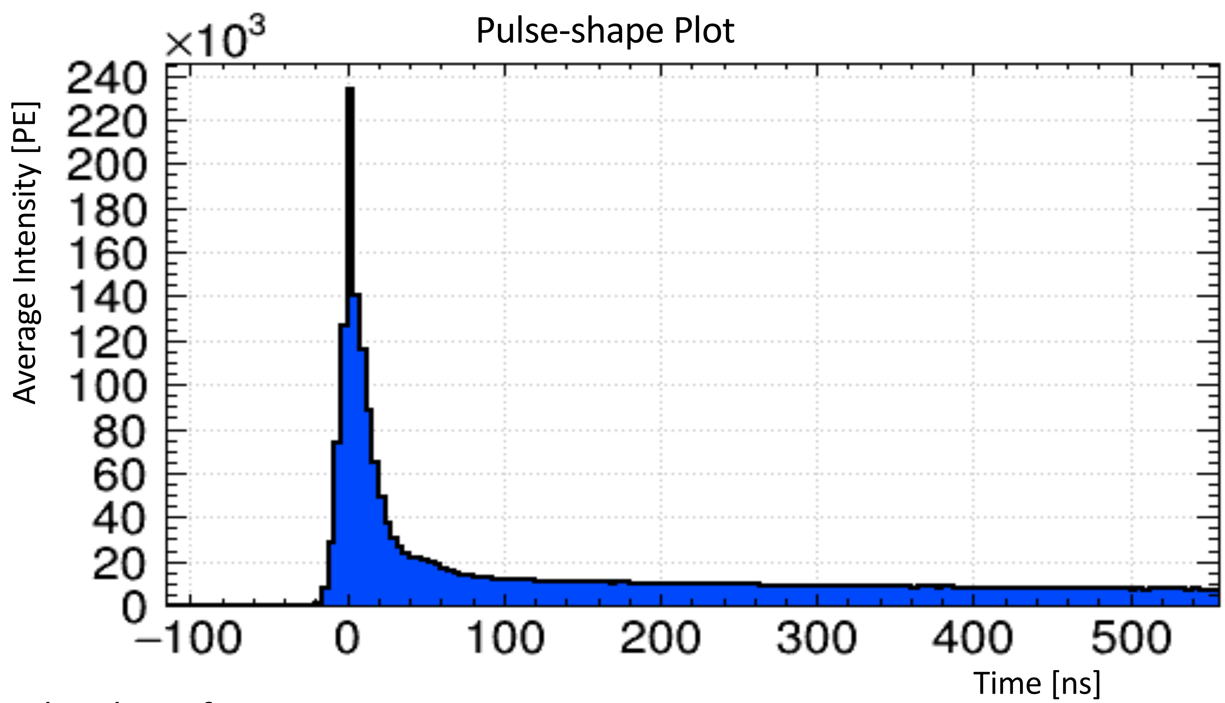


Fig 3: Example of pulse-shape from -100 to 500.

Motivation

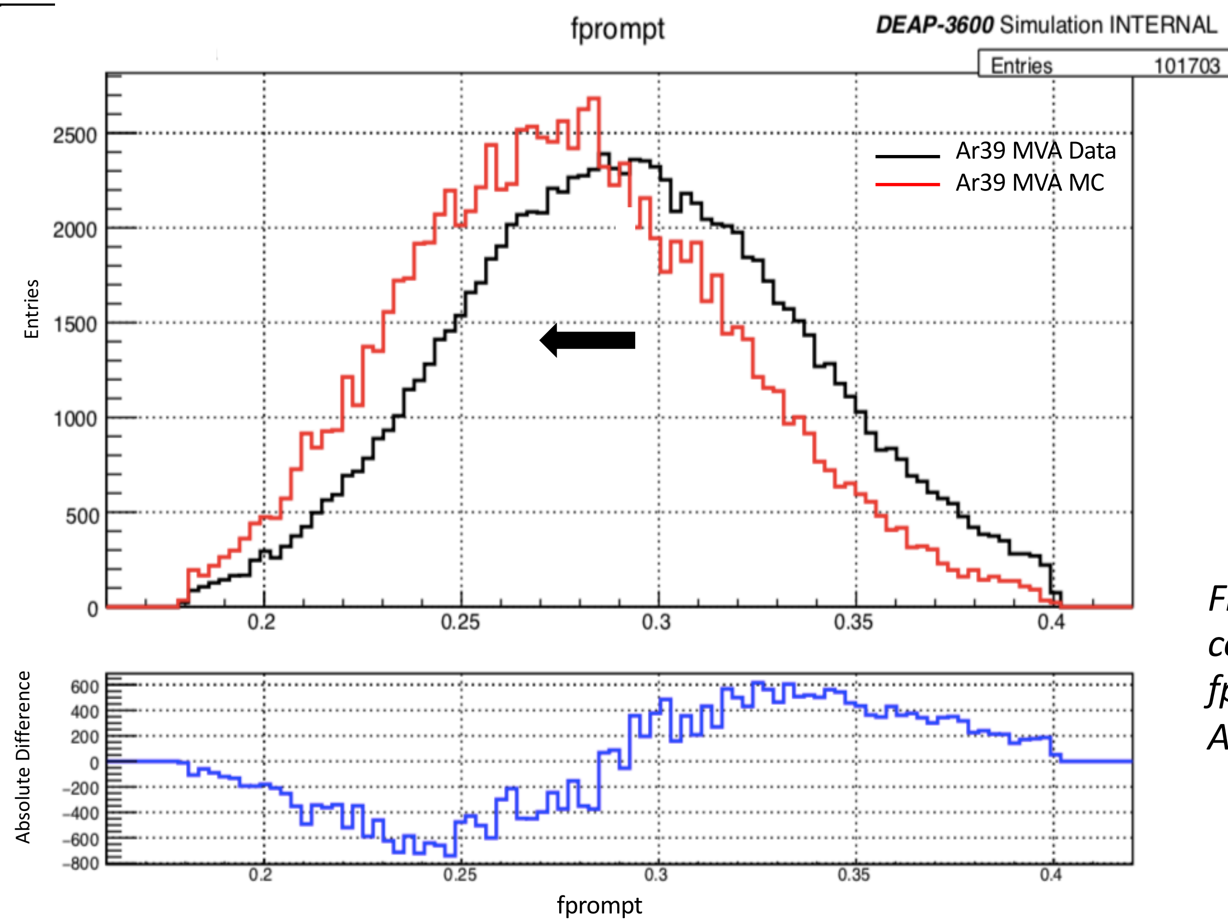


Fig 4: Data MC comparison for fprompt of Ar39.

Motivation

- Differences in fprompt and other prompt-type variables, between Data and MC for Ar39

↓ ↑

- Root of these differences are the pulse-shape Data and MC comparisons

↓ ↑

- If agreement between Data and MC at the pulse-shape level is made better so will the agreement at the prompt level

Motivation

- Evidence for the existence of an intermediate lifetime between the singlet and triple lifetime can be found in the pulse shape data:

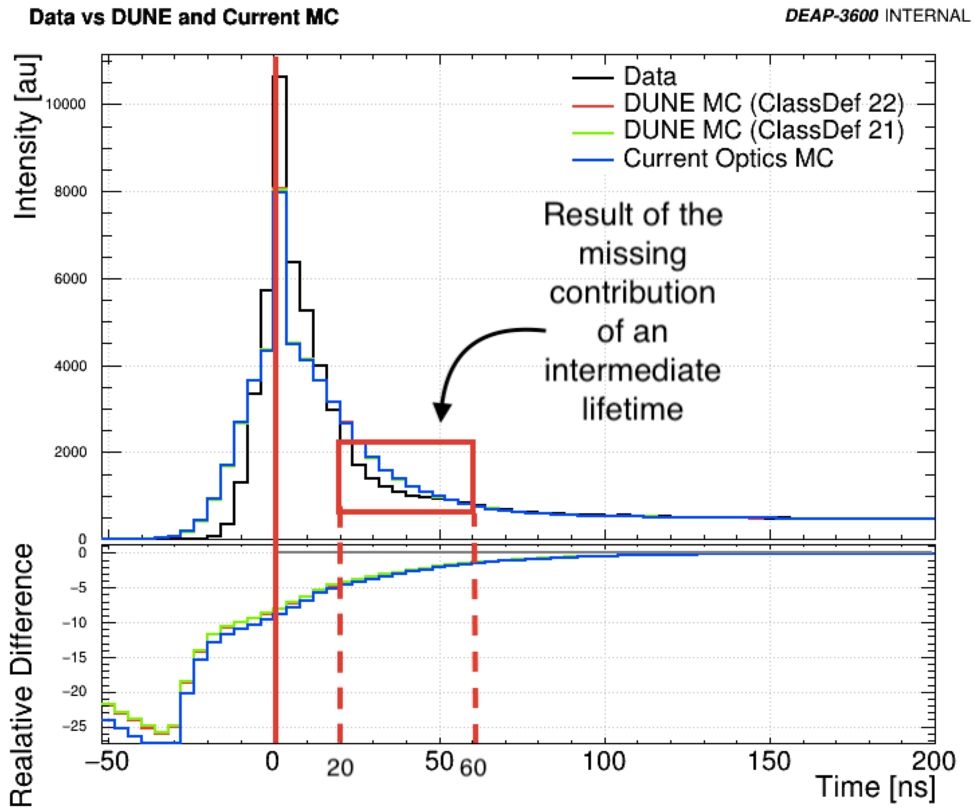


Fig 5: Pulse shape comparison without intermediate lifetime.

Motivation

- Evidence for the existence of an intermediate lifetime between the singlet and triple lifetime can be found in the pulse shape data:

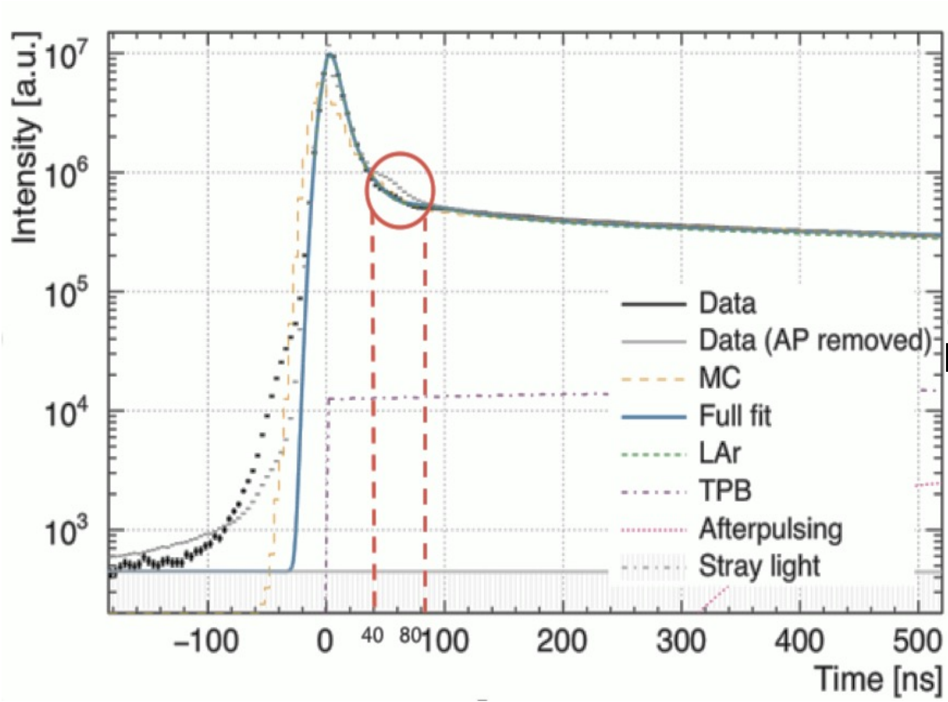


Fig 6a: Pulse shape comparison without intermediate lifetime.

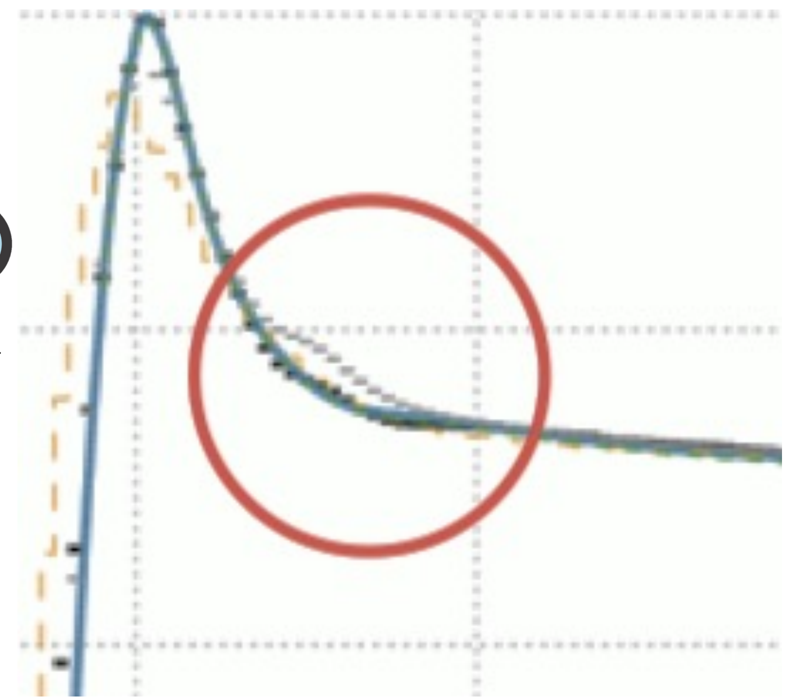


Fig 6b: Zoomed pulse shape without intermediate lifetime

How – Implementing Intermediate Lifetime

- Current form of the model of the time structure constant for liquid argon scintillation:

$$I_{Ar}(t) = I_0[\underbrace{\frac{R_s}{\tau_s} e^{-\left(\frac{t}{\tau_s}\right)}}_{\text{Singlet Lifetime}} + \underbrace{\frac{R_t}{\tau_t} e^{-\left(\frac{t}{\tau_t}\right)}}_{\text{Triplet Lifetime}}]$$

Eqn 1: Current time structure of pure Liquid Argon Scintillation. [1]

How– Implementing Intermediate Lifetime

- From Tina's work-in-progress pulse-shape paper the following function has been suggested for the liquid argon scintillation time profile:

$$I_{Ar}(t) = I_0[\underbrace{\frac{R_s}{\tau_s} e^{-\left(\frac{t}{\tau_s}\right)}}_{\text{Singlet Lifetime}} + \underbrace{\frac{R_{rec}}{\tau_{rec}} \frac{1}{(1+\frac{t}{\tau_{rec}})^2}}_{\text{Intermediate Lifetime}} + \underbrace{\frac{R_t}{\tau_t} e^{-\left(\frac{t}{\tau_t}\right)}}_{\text{Triplet Lifetime}}]$$

Eqn 2: Tina's time structure of pure Liquid Argon Scintillation. [1]

How – Implementing Intermediate Lifetime

- To implement this into RAT's GLG4Scint.cc physics processor we need to model the intermediate term as a third exponential:

$$I_{Ar}(t) = I_0[\frac{R_s}{\tau_s}e^{-\left(\frac{t}{\tau_s}\right)} + \underbrace{\frac{R_I}{\tau_I}e^{-\left(\frac{t}{\tau_I}\right)}}_{\text{Exponential model of the Intermediate Lifetime}} + \frac{R_t}{\tau_t}e^{-\left(\frac{t}{\tau_t}\right)}]$$

Eqn 3: Three Exponential Model of the Time structure of pure Liquid Argon Scintillation.

How – Implementing Intermediate Lifetime

- The task is to find the parameters R_I and τ_I for which the exponential model fits Tina's model

Current Model	Lifetime [ns]	Weight
Singlet	6.0	0.23
Intermediate	N/A	N/A
Triplet	1590	0.73

→

Tina's Model	Lifetime [ns]	Weight
Singlet	8.7	0.2
Intermediate	88	0.05
Triplet	1408	0.62

How – Implementing Intermediate Lifetime

- The task is to find the parameters R_I and τ_I for which the exponential model fits Tina's model

Tina's Model	Lifetime [ns]	Weight
Singlet	8.7	0.2
Intermediate	88	0.05
Triplet	1408	0.62

→

3 Exponential Model	Lifetime [ns]	Weight
Singlet	8.7	0.2
Intermediate	??	??
Triplet	1408	0.62

How – Implementing Intermediate Lifetime

- The task is to find the parameters R_I and τ_I for which the exponential model fits Tina's model

3 Exponential Model	Lifetime [ns]	Weight
Singlet	8.7	0.2
Intermediate	78	0.04
Triplet	1408	0.62

How – Implementing Intermediate Lifetime

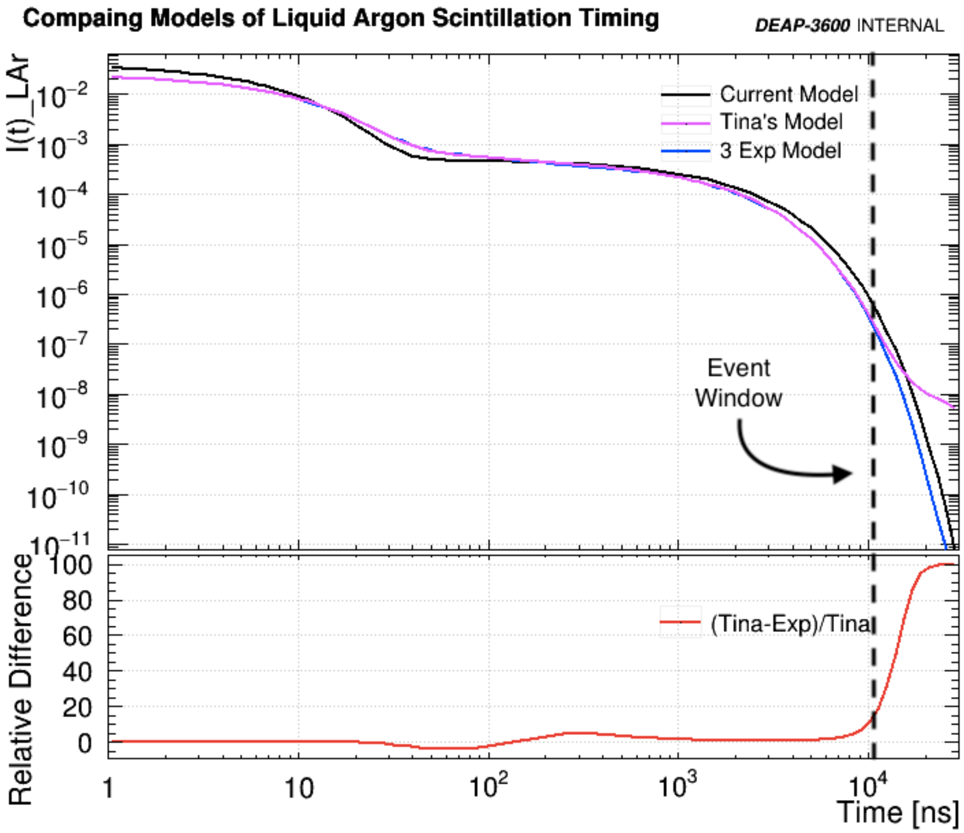


Fig 7: Comparison between different models for the time structure of liquid argon scintillation.

Carleton UNIVERSITY

How – Implementing Intermediate Lifetime

- Why are they so similar? Expanding as a Taylor series about $t = 0$:

1

$$\frac{R_{rec}}{\tau_{rec}} \frac{1}{(1 + \frac{t}{\tau_{rec}})^2}$$

2

$$\frac{R_I}{\tau_I} e^{-(\frac{t}{\tau_I})}$$

Taylor Expand →

$$\frac{R_{rec}}{\tau_{rec}} (1 - \frac{2}{\tau_{rec}} t + \frac{3}{\tau_{rec}^2} t^2 + \cdots)$$

$$\frac{R_I}{\tau_I} (1 - \frac{1}{\tau_I} t + \frac{1}{2\tau_I^2} t^2 + \cdots)$$

How – Implementing Intermediate Lifetime

- Why are they so similar? Expanding as a Taylor series about $t = 0$:

1. $$\frac{R_{rec}}{\tau_{rec}} \frac{1}{(1 + \frac{t}{\tau_{rec}})^2}$$

2. $$\frac{R_I}{\tau_I} e^{-(\frac{t}{\tau_I})}$$

Taylor Expand →

$$\frac{R_{rec}}{\tau_{rec}} \left(1 - \frac{2}{\tau_{rec}} \boldsymbol{t} + \frac{3}{\tau_{rec}^2} \boldsymbol{t^2} + \cdots \right)$$

$$\frac{R_I}{\tau_I} \left(1 - \frac{1}{\tau_I} \boldsymbol{t} + \frac{1}{2\tau_I^2} \boldsymbol{t^2} + \cdots \right)$$

For $\frac{t}{\tau} \ll 1$ the approximations are very similar!

Results

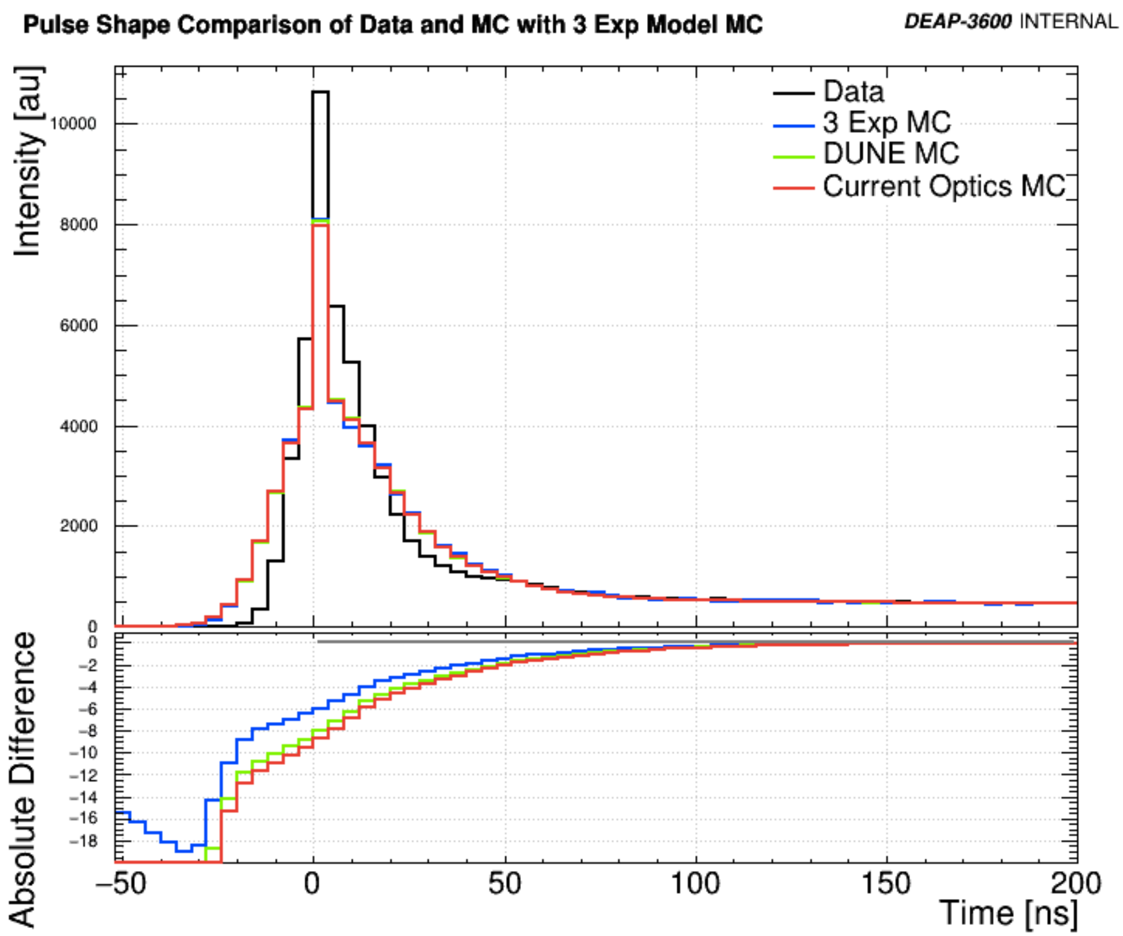


Fig 8: Comparison of fprompt distribution for 3 Exp MC with data.

Results

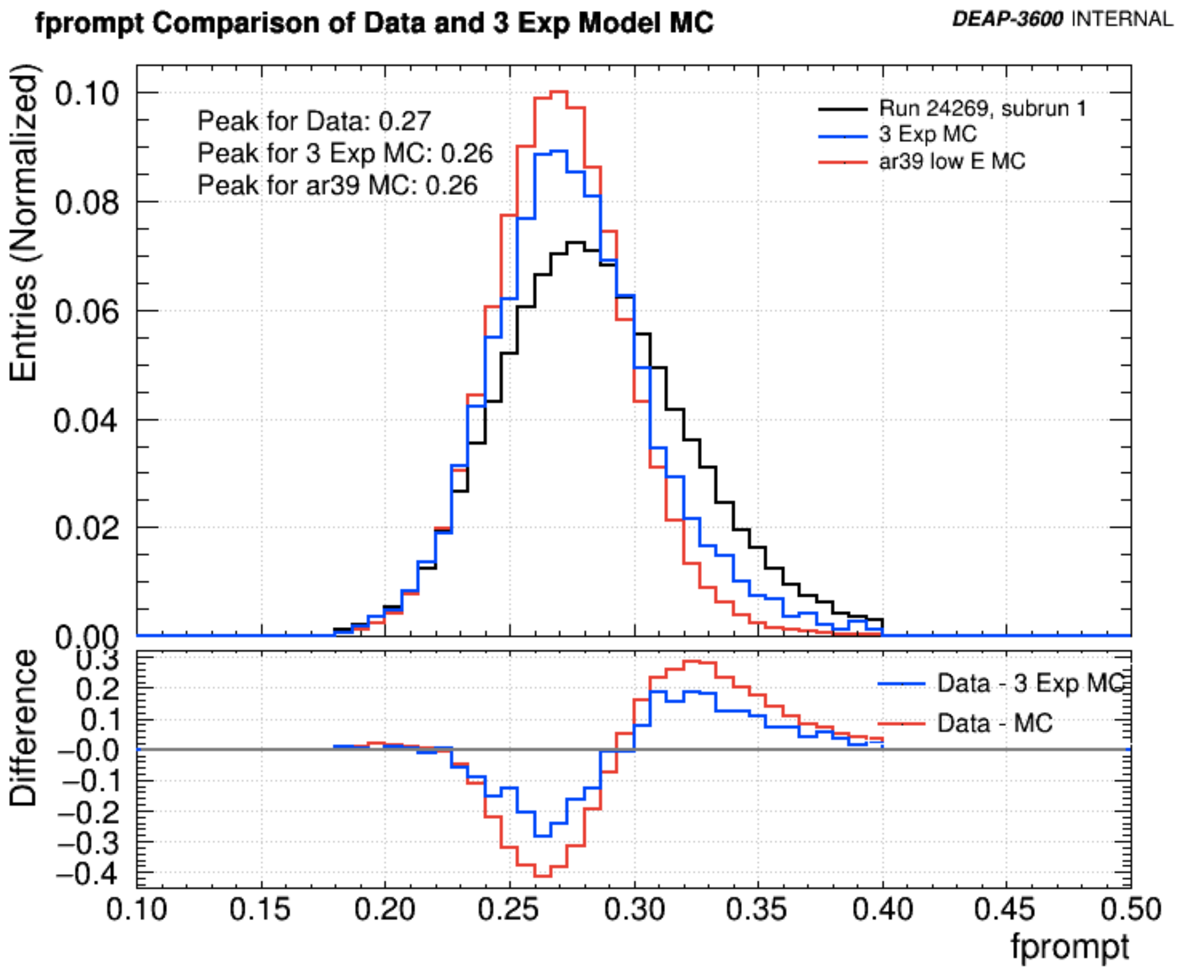


Fig 8: Comparison of fprompt distribution for 3 Exp MC with data.

Results

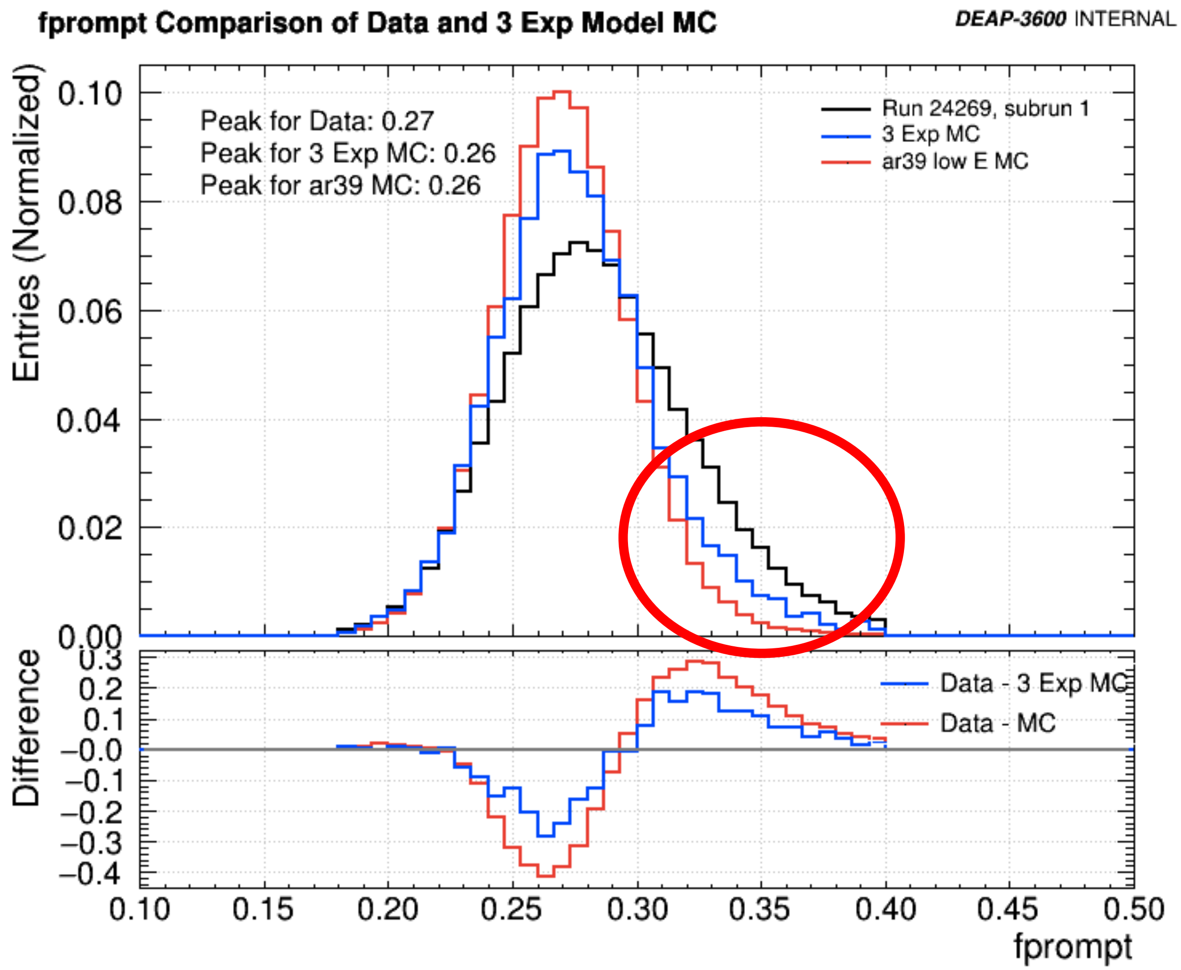


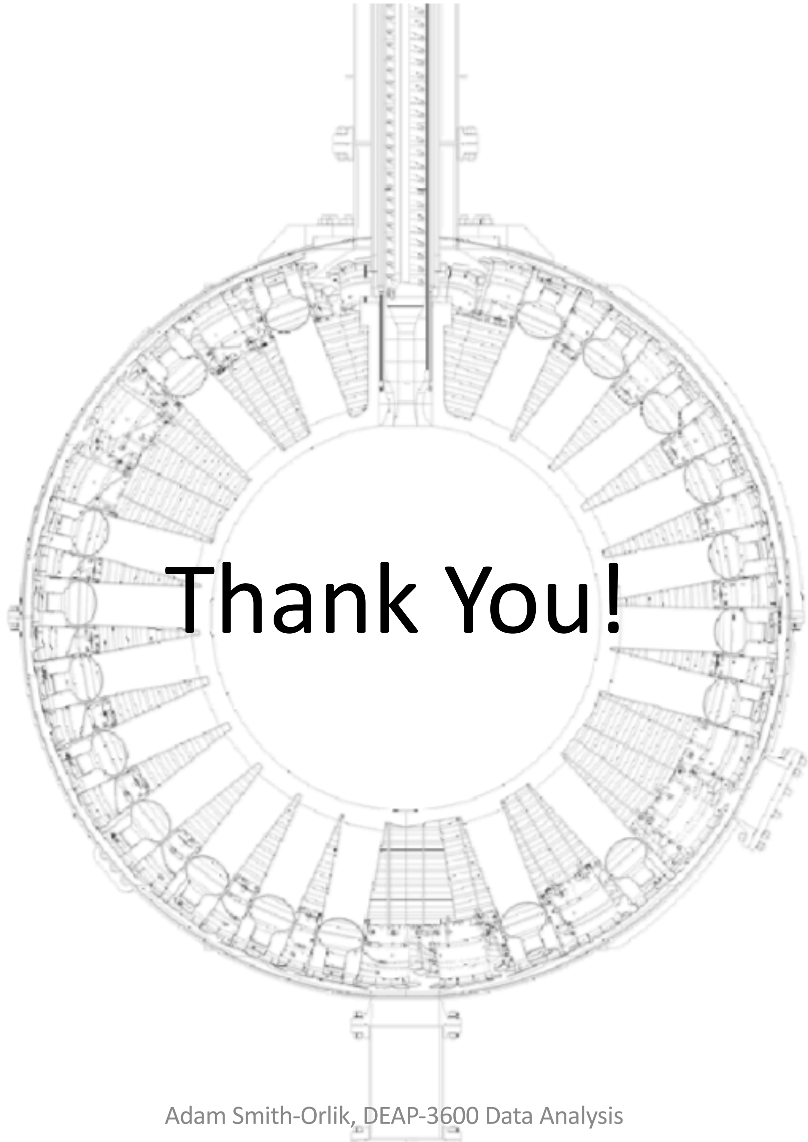
Fig 8: Comparison of fprompt distribution for 3 Exp MC with data.

Next Steps

- The addition of the intermediate component has an effect on the pulse-shape but does not resolve the shift in the MC with respect to the data

- Validate the effect on fprompt by running larger simulations and comparing with reprocessed data with same cuts applied

Questions



Thank You!

BACKUP SLIDES

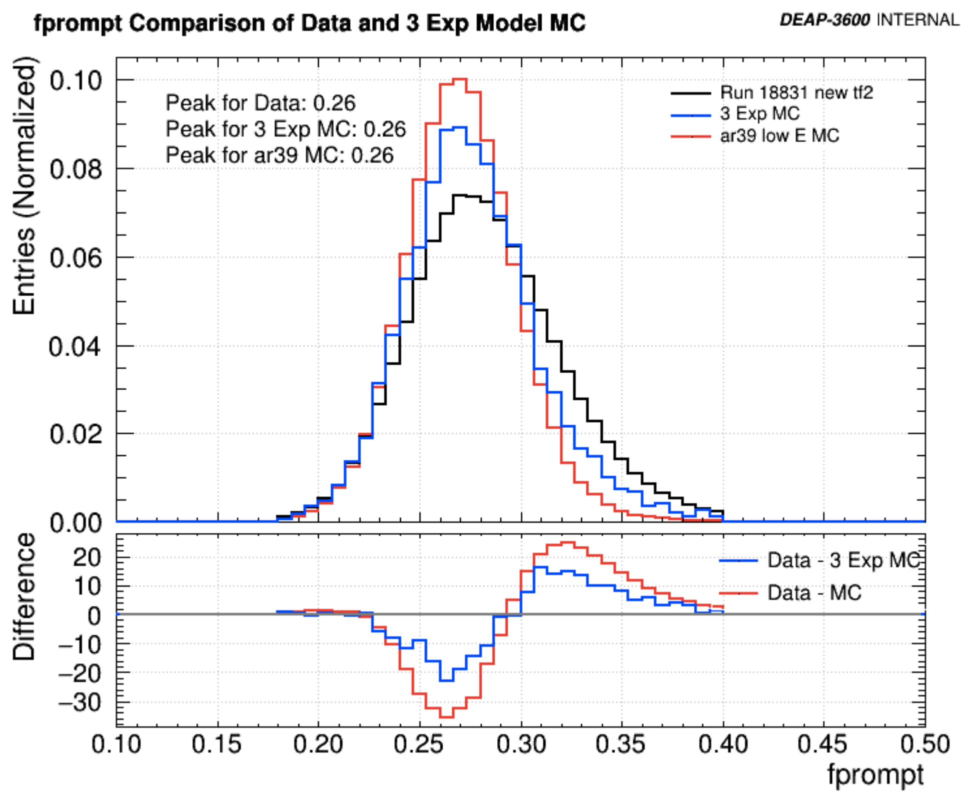


Fig 9: Comparison of fprompt for golden run and 3 Exp model.

BACKUP SLIDES

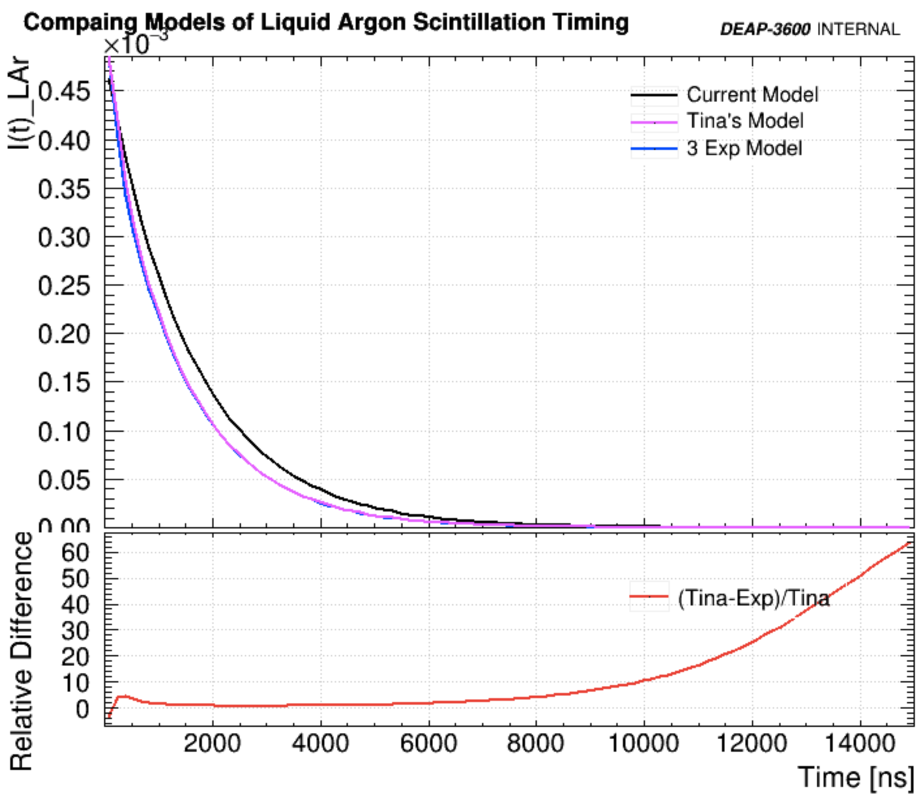


Fig 10: Comparison between different models for the time structure of liquid argon scintillation with linear axes.

BACKUP SLIDES

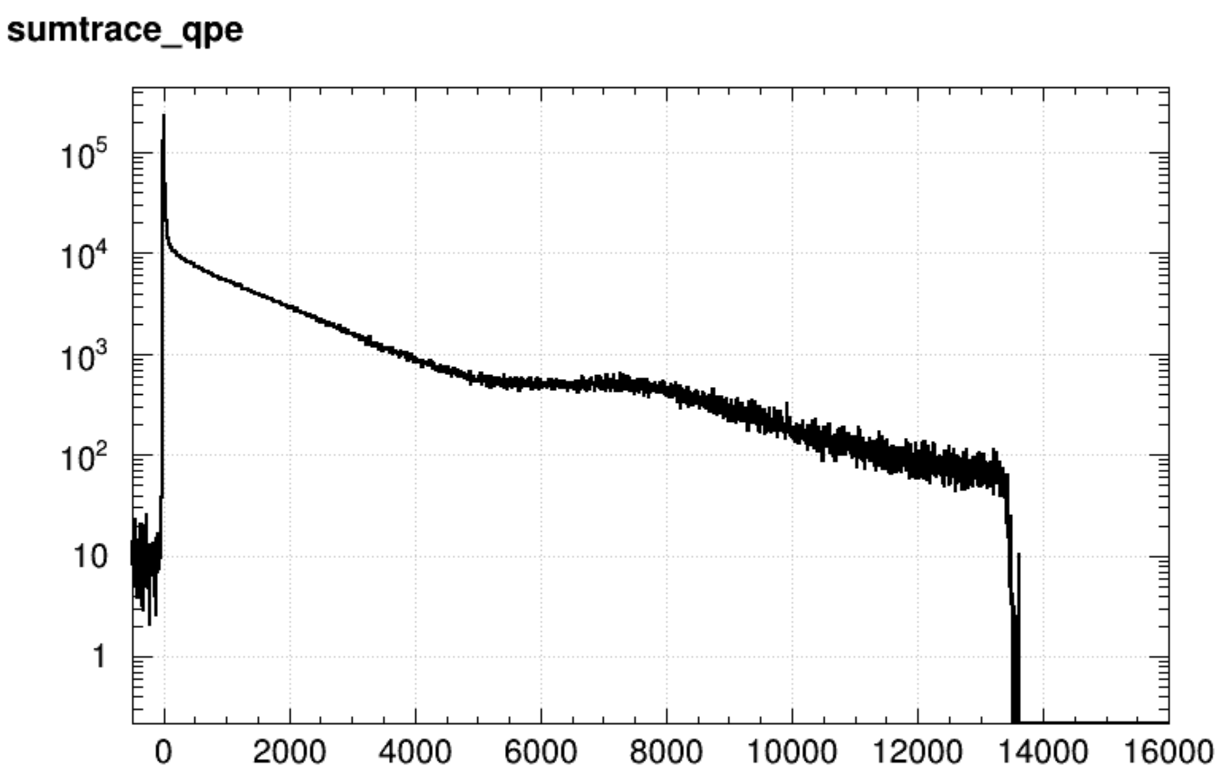


Fig 11: Pulse-shape plot with log Y axis.