

Pulse Shape Simulation in 2-Phase Xenon Detectors

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S1 Pulse Shape

- In a liquid noble, the S1 pulse shape is generated via one of 2 processes
 - Direct Excitation
 - Recombination following ionization
 - Ionized electrons can escape or recombine
 - Presence of electric field quenches the recombination contribution (for example in a dual phase detector)
- The medium-determined aspects of the pulse shape are determined by:
 - Singlet and triplet decay time constants
 - Example: In xenon: 3.1 and 24 ns respectively
argon: 6 and 1600 ns respectively
 - Singlet to triplet ratio differs depending on type of energy deposition
 - Nuclear recoils vs. electron recoils
 - Recombination Time

S1 Scintillation

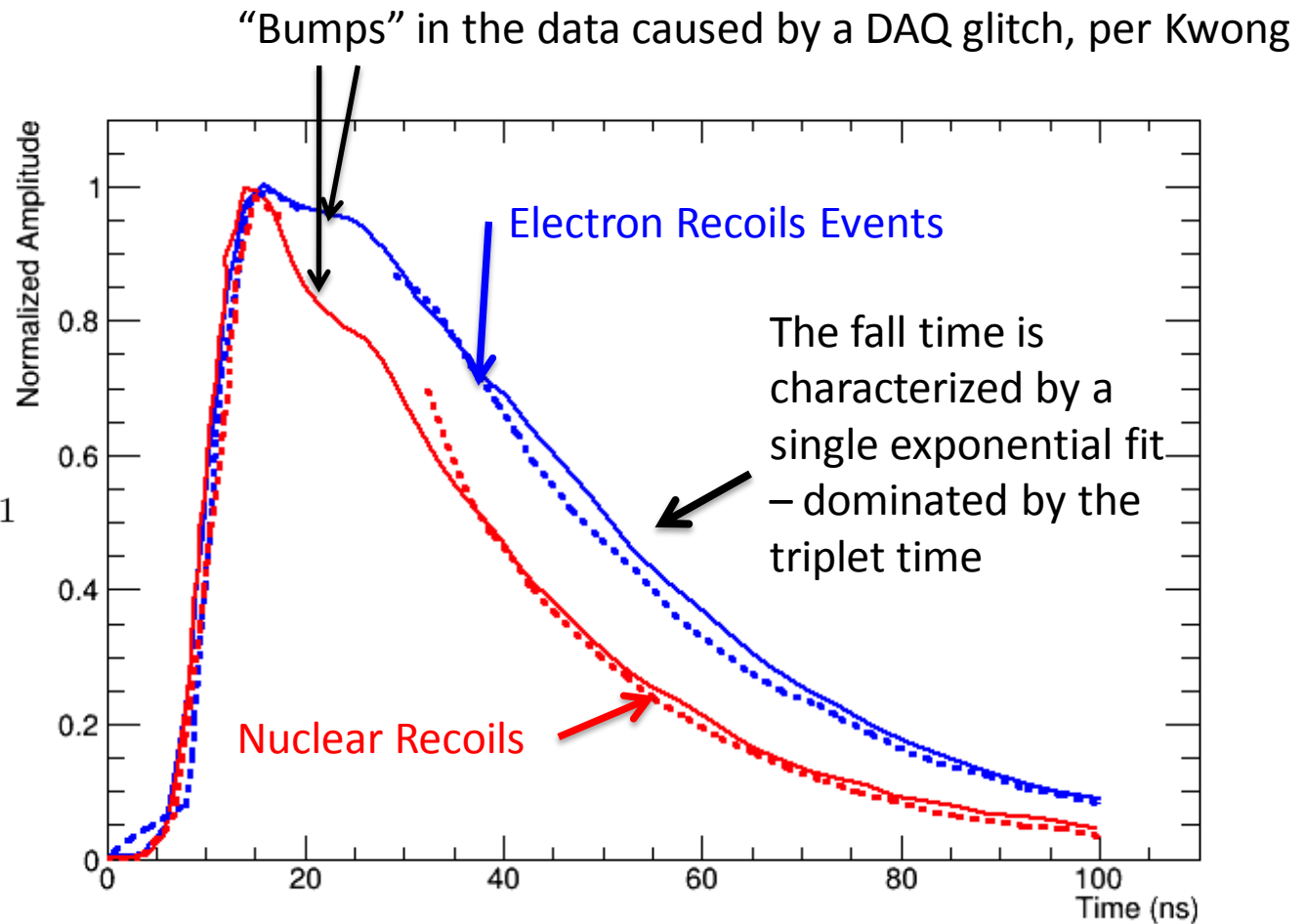
There is a recombination time associated with electron recoils but it is negligible in nuclear recoil events

NEST models recombination time constant as the inverse of recombination probability

$$\tau = \Phi\left(\frac{a \times LET}{1 + b \times LET}\right)^{-1}$$

a and b are constants in the recombination model

But the recombination time constant does not plug into an exponential, but at high times the pulse looks exponential, and that is a good fit

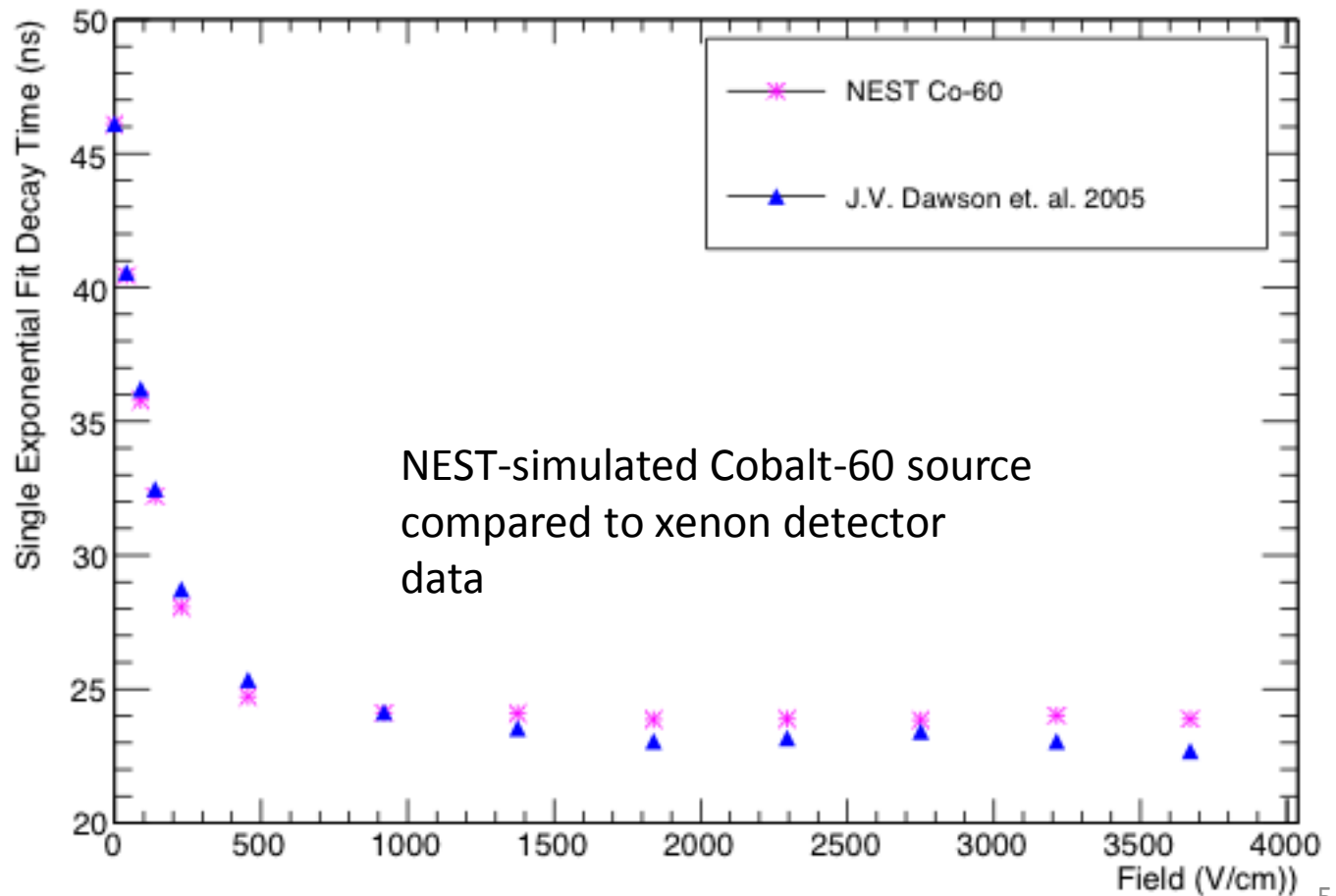


Solid Lines – 78 keV recoils in xenon with 60 V/cm from Kwong et al 2009₃
Dotted lines – NEST simulation with same physical parameters

Prompt Scintillation – Non-Zero Field

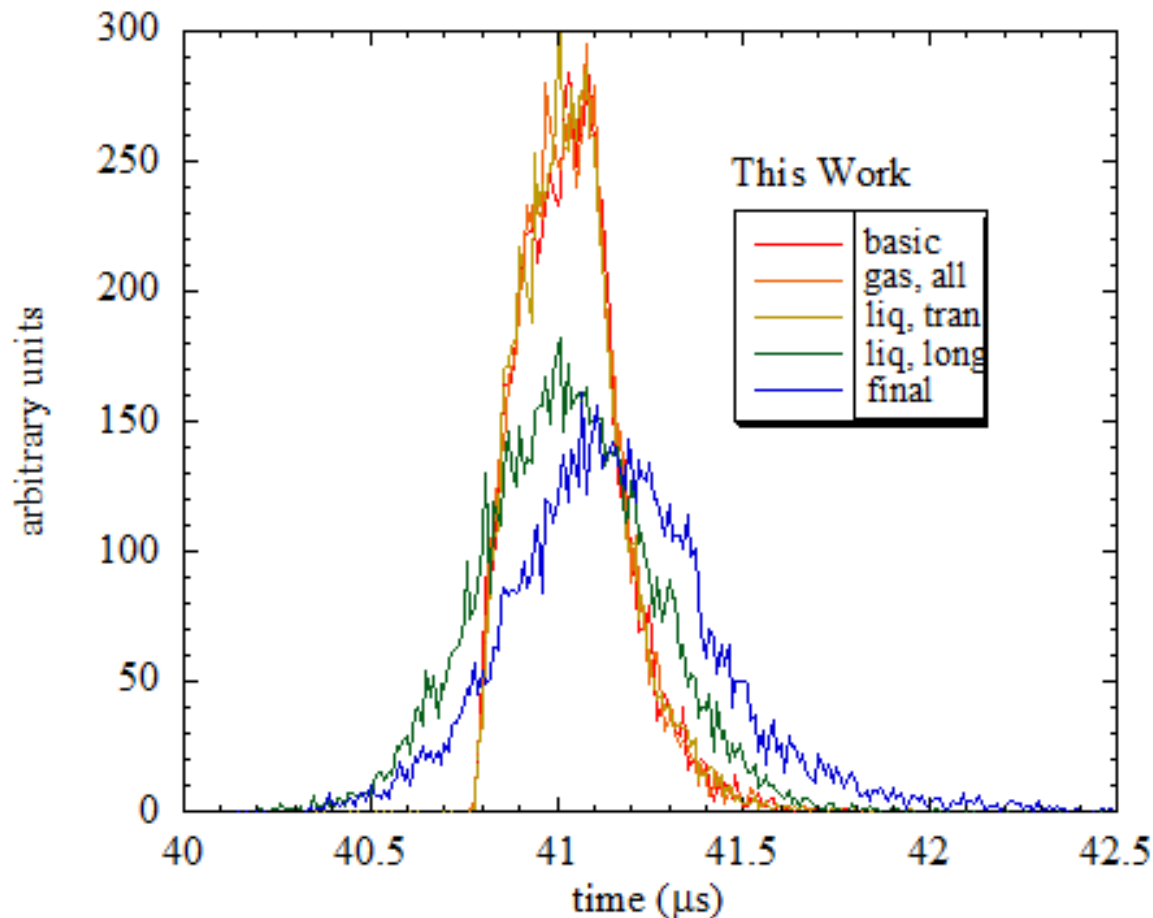
As field increases, recombination time is suppressed – differences between ER and NR disappear

NEST models field dependence by adding an exponential decay component to recombination time



Electroluminescence (S2)

- Pulses that result from drifting ionized electrons and extracting them into and accelerating through gas
- Effects modeled by NEST to create S2:
 - Drift Speed
 - Creates square shaped pulse
 - Constant velocity depending on the field
 - Triplet and singlet lifetimes
 - Distorts square into “shark fin” (dominated by triplet time)
 - Diffusion constants
 - All gas diffusion
 - Yellow – liquid transverse diffusion
 - Liquid longitudinal diffusion – dominant effect
 - Electron Trapping time
 - Provides additional peak “delay” leading to final shape

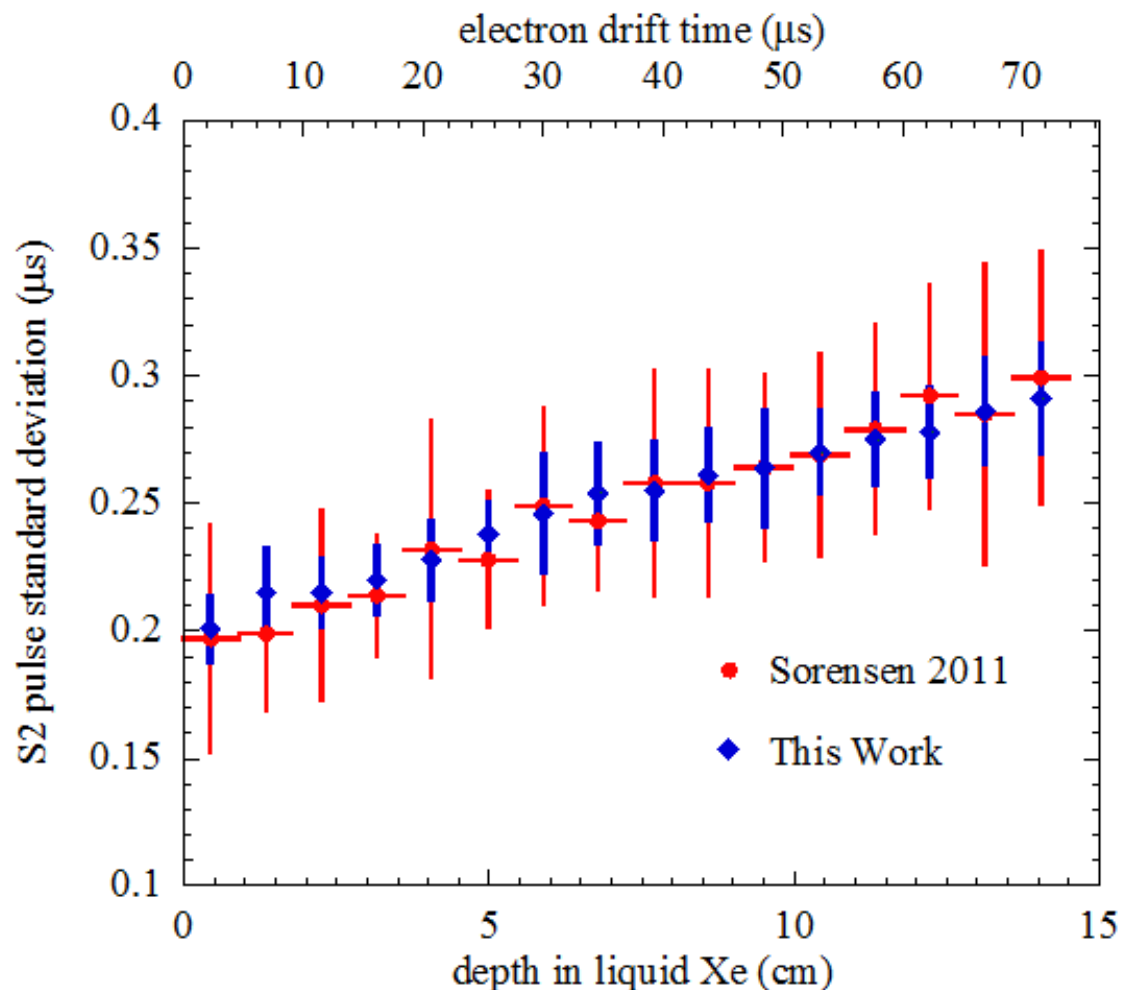


Electroluminescence (S2)

The width of the pulse vs. depth is accurately reproduced by NEST given the simulation parameters

The longitudinal diffusion in liquid is the dominant effect to the width of the pulse – the deeper the event the greater the width

The NEST prediction was ~ 1 sigma too low until the electron trapping effect was incorporated into the model



Summary

- NEST accurately models and can reproduce the pulse shapes seen in liquid and gas noble gas detectors used in rare event searches
- Achieved computationally via a Geant4 add-on that does not add any time to the simulation