Slow Fluors for Effective Separation of Cherenkov Light in Liquid Scintillators

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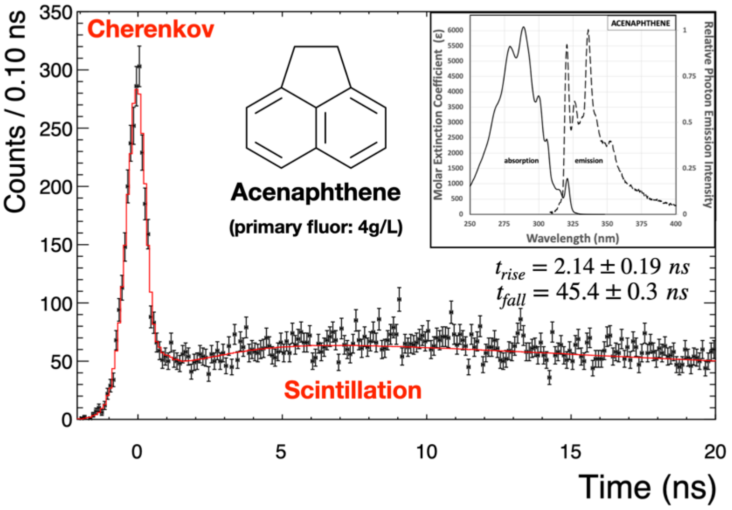
The properties of four slow fluors have been studied in the context of LAB-based liquid scintillator mixtures to provide a means to effectively separate Cherenkov light in time from the scintillation signal with high efficiency. This allows for directional and particle ID information while also maintaining good energy resolution. Such an approach is highly economical (*i.e.* small compared to other experimental costs) and can be readily applied to existing and planned large-scale liquid scintillator instruments without the need of additional hardware development and installation. Using this technique, we have explicitly demonstrated Cherenkov separation on a bench-top scale, showing clear directionality, for electron energies extending below 1 MeV.

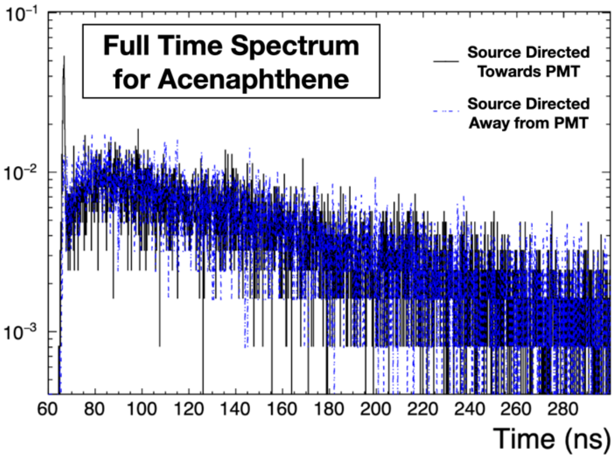
Timing measurements were made using a ^{90}Sr source directed through the sample vial and either towards or away from a measurement PMT. Electrons from supported beta decay of ^{90}Y (Q=2.28 MeV) first pass through a 2mm diameter scintillating fibre coupled to a trigger PMT. Typical electron energies that make it through the fibre and vial wall are less than 1 MeV.

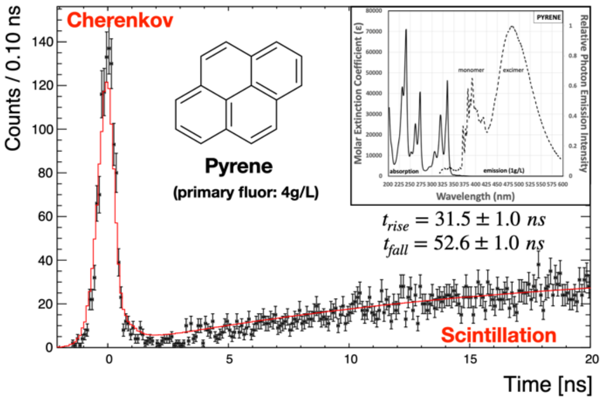


$t_{rise} = 2.14 \pm 0.19\ ns$
$t_{fall} = 45.4 \pm 0.3\ ns$

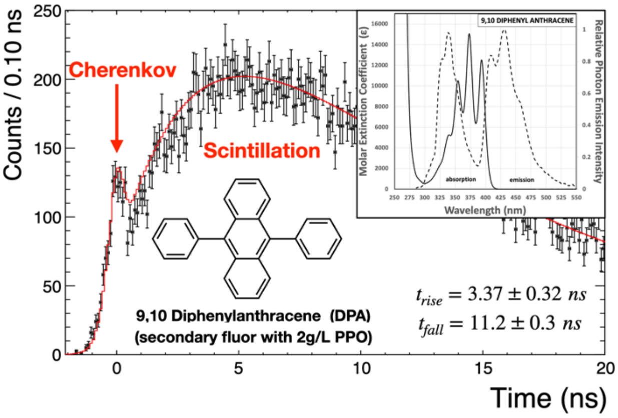
The plot on the left shows the measured time spectrum for acenaphthene for the case where electrons are directed through the scintillator sample and towards the measurement PMT. It is used here as a primary fluor, with a concentration of 4g/L in LAB. Absorption and emission spectra were separately measured and are shown in the inset of the figure.

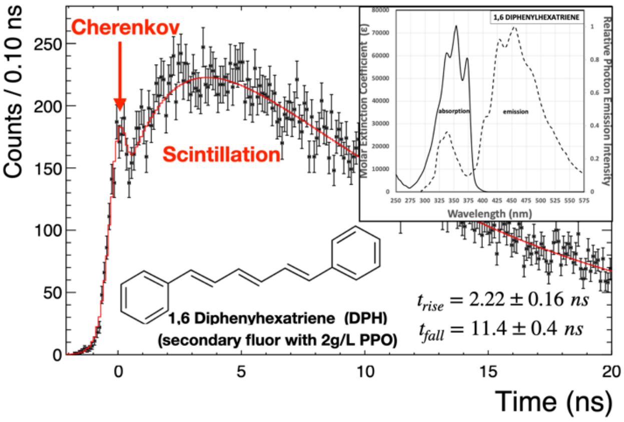
The plot on the right shows the full time spectrum for acenaphthene in LAB, comparing configurations when the source is directed towards and away from the measurement PMT. A well-separated, directional Cherenkov signal is clearly observed for the forward configuration. The Cherenkov signal and scintillator time constants are extracted using a combined fit of data from both configurations. The primary scintillator time constant values are given in each figure.





Similar spectra a shown for pyrene (left), used as a primary fluor with a concentration of 4g/L in LAB; 9,10-diphenylanthracene (DPA) (lower left) used as a secondary fluor at 30mg/L together with 2g/L of PPO in LAB; and 1,6-diphenylhexatriene (DPH) (lower right) as a secondary fluor at 10mg/L together with 2 g/L of PPO in LAB.





The table on the right lists some of the fluor combinations studied along with the measured intrinsic light yield, which were deconvolved from the PMT response and normalised relative to the previously determined yield of PPO in LAB from studies by SNO+.

Fluor	Conc. (g/l)	Peak em (nm)	Intrinsic LY in LAB (photons/MeV)
PPO	2	360	11900
Acenaphthene	4	335	7686 ± 315
Pyrene	1	390(m),480(e)	9430 ± 509
	10	480(e)	11833 ± 766
DPA	5	430	13584 ± 582
DPA+PPO	0.3, 2	430	11610 ± 498
DPH+PPO	0.1, 2	450	12356 ± 926

Different fluor combinations may prove suitable for different applications. This study has potentially important consequences for a variety of future instruments, including measurements of low energy solar neutrinos and searches for neutrinoless double beta decay in loaded scintillator detectors. This also opens the possibility of obtaining good directional information for elastic scattering events from supernovae neutrinos and reactor anti-neutrinos in large scale liquid scintillation detectors. While the use of slow fluors means that the vertex resolution may be worse than typical large-scale liquid scintillator detectors (but better than typical large-scale Cherenkov detectors), the balance between position resolution, Cherenkov separation purity and energy resolution can be tuned for a particular physics objective by modifying the fluor mixture. This balance is also affected by the presence of fluorescence quenchers, which may be naturally present in the case of loaded scintillator mixtures or could be purposely introduced to change the balance.