SAND2012-3817C

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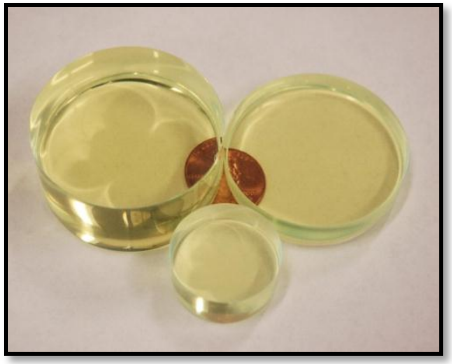
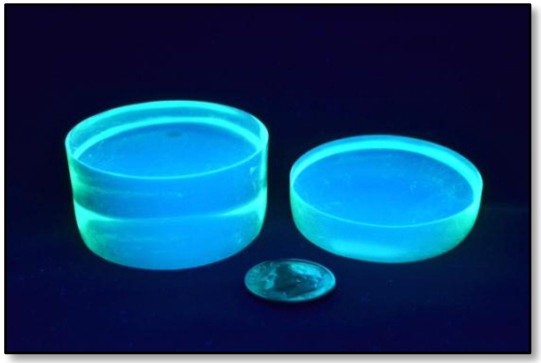
Advanced Plastic Scintillators





Sandia National Laboratories

Patrick Feng

F. Patrick Doty, Stan Mrowka, Bryan Wong, Mitch Anstey

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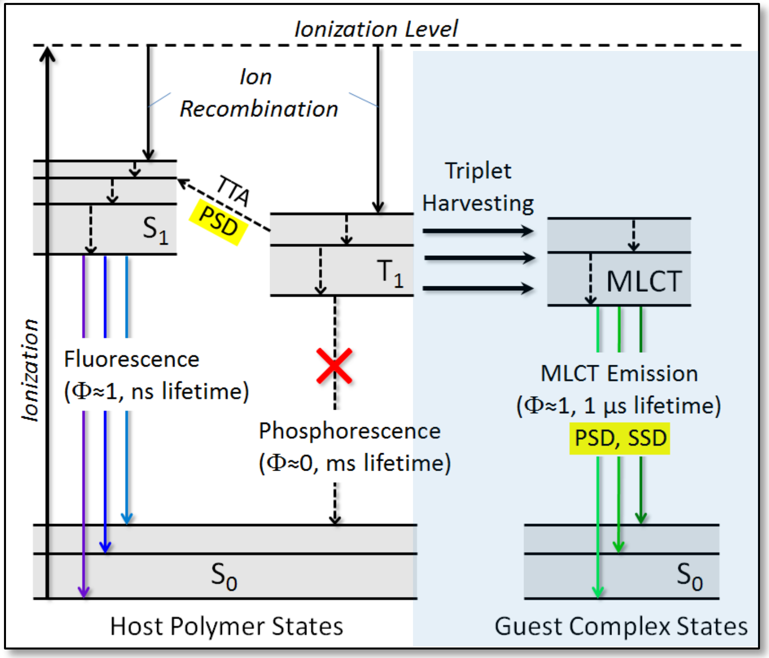
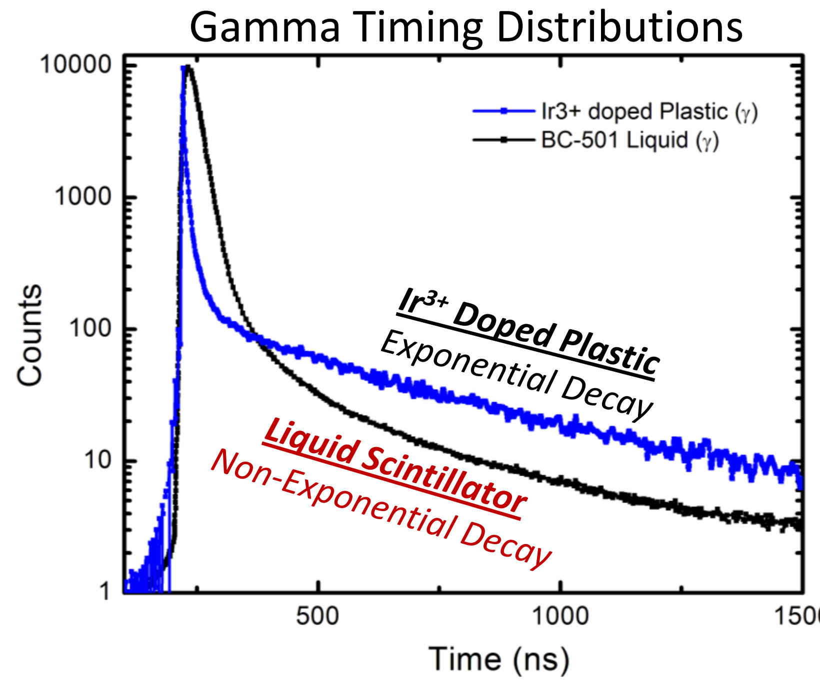
Background: *How are our materials different?*





Traditional Organic Scintillators:

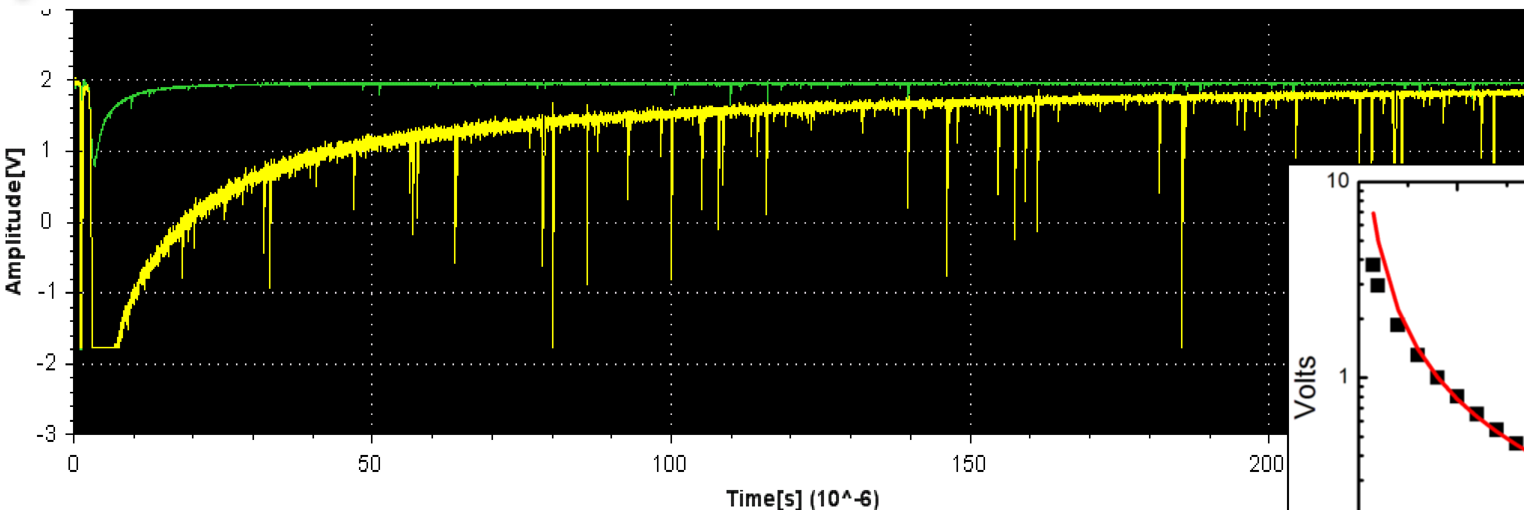
- Prompt and delayed components
- Single-wavelength emission
- Triplet emission is bimolecular (*indirect*)
  - Non-exponential decay

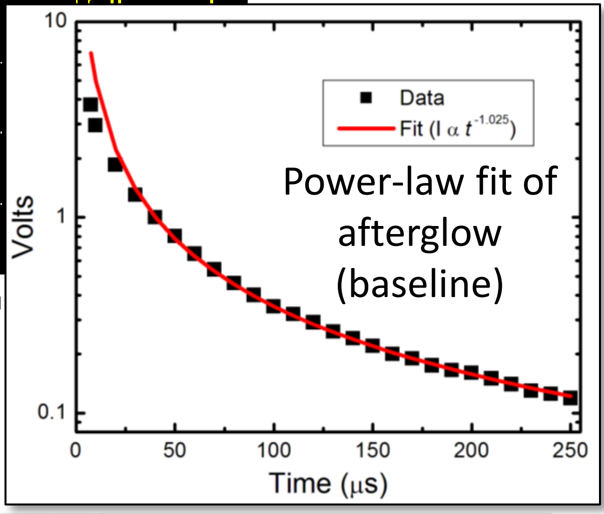
Ir^{3+} Doped Organic Scintillators:

- Prompt and delayed components
- Single *or* multi-wavelength emission
- Triplet emission is unimolecular (*direct*)
  - Exponential decay

Afterglow in Organic Scintillators: Active Interrogation

(Why are new materials needed?)

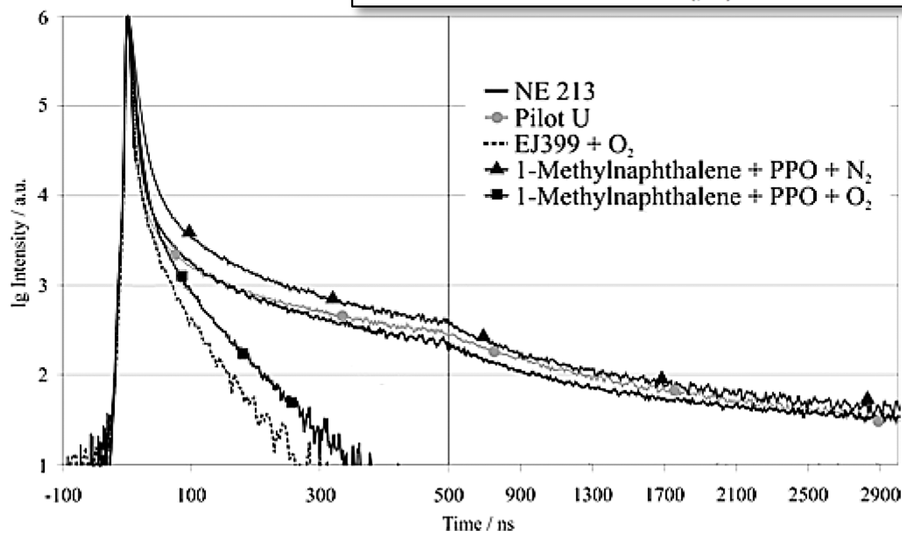




- Pulse pile-up and afterglow is a consequence of power-law decay
  - No characteristic decay time for delayed light

- Limitations for high-field applications:
  - Active interrogation
  - Reactor monitoring
  - High-power laser research

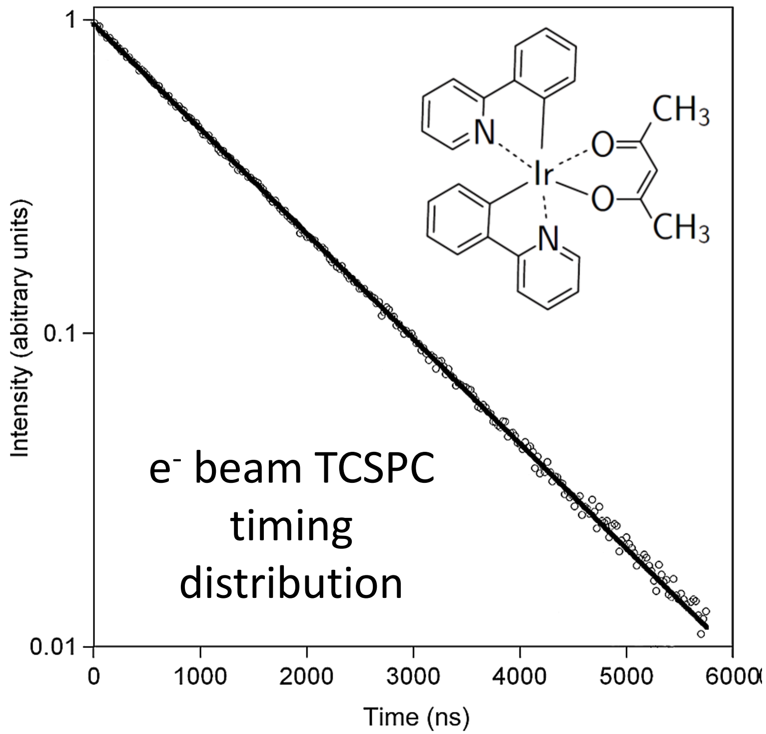
- Triplet emission may be quenched for faster scintillation response: (Loss of PSD capabilities)
  - Benzophenone
  - Molecular oxygen



R. Lauck et al. *IEEE Trans. Nucl. Sci.* **2009**, 56, 989.

A Proposed Solution: Direct Triplet Emission

(How do our materials address the limitations of traditional scintillators?)

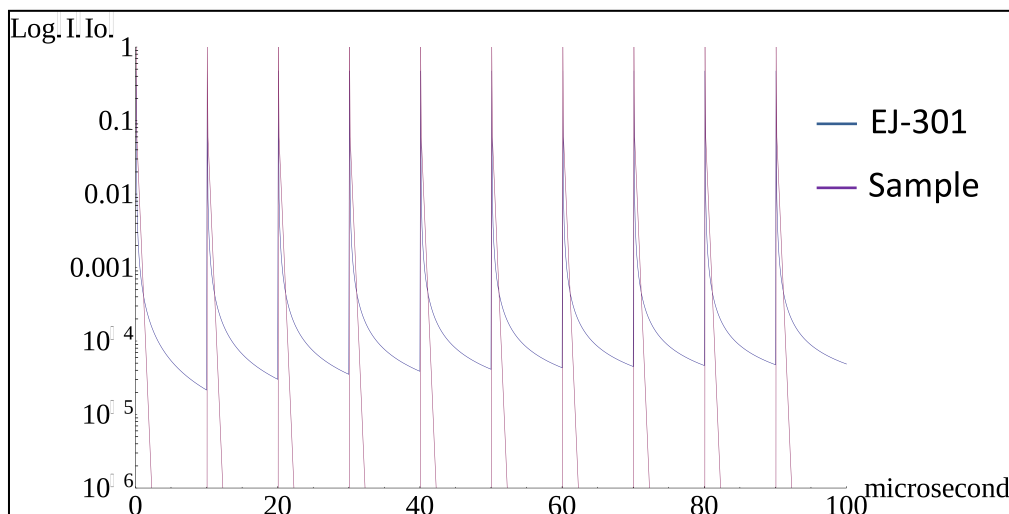


Decay Characteristics:

- Phosphorescence from a triplet molecular state
- $Ir(ppy)_2(acac)$: Mixing of heavy-ion character into ^3LC orbitals
- Single exponential, τ = 1.3µs
- Lifetime is synthetically tunable from ~100ns to ~10µs

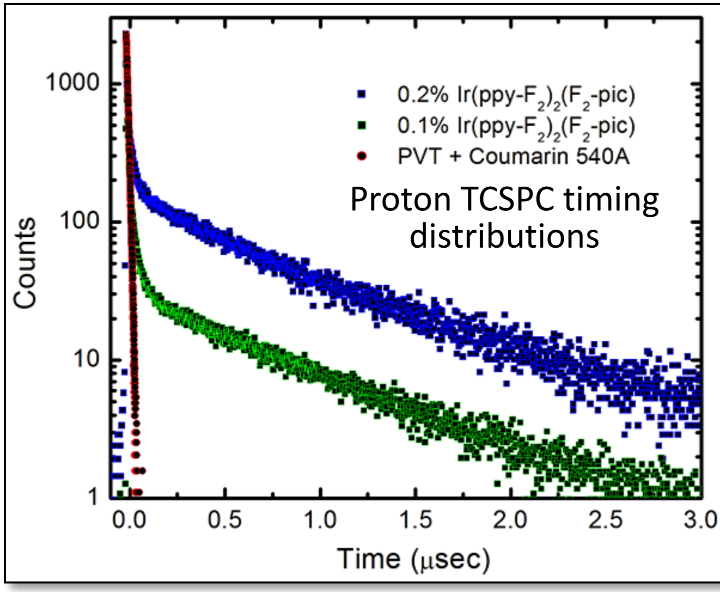
Reduced Dark Current for Exp. Decay:

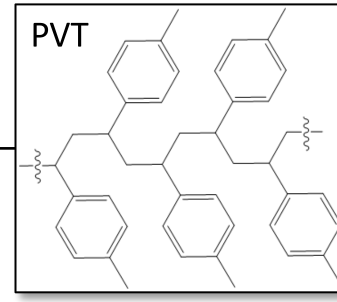
- Prompt, delayed (25ns, 250ns)
- Count rate of 100 kHz
- Simulation based on experimental decay curves

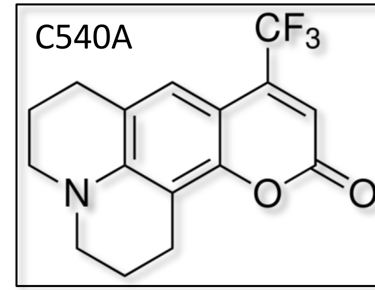


K-C. Tang et al. *Chem. Phys. Lett.* **2004**, 386, 347.

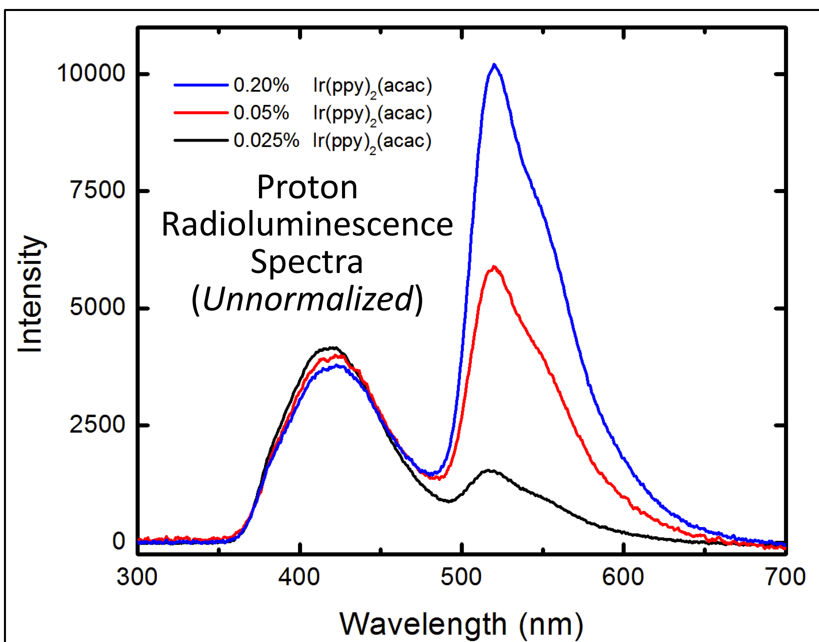
Conc. Dependence of Pulse-Shapes and Spectra





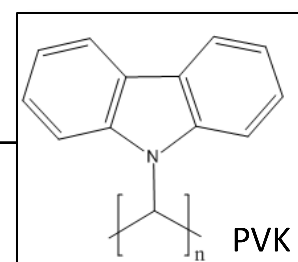


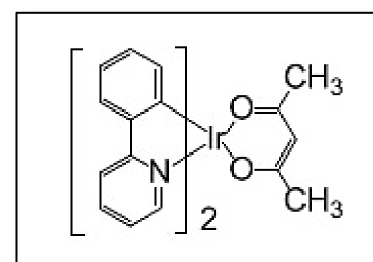
- Extrinsic state affords control over relative fraction of delayed luminosity
  - Spectral intensities
  - Timing characteristics



- Additive effect of triplet luminescence at modest doping levels

- Low Ir^{3+} concentrations required: (0.05% ≈ 150 ppm Ir^{3+})





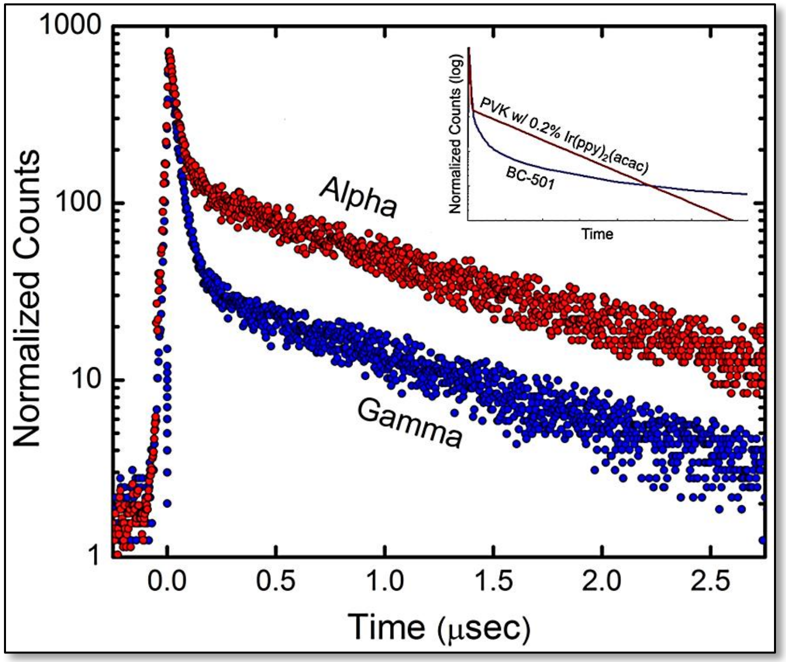
$Ir(ppy)_2(acac)$

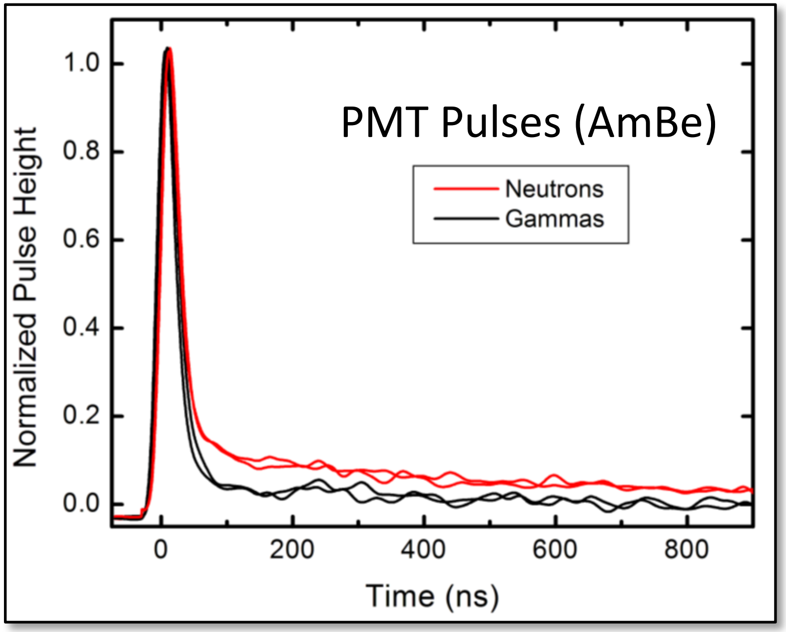
Timing Distributions and Scintillation Decay: PSD

Fast component described by Birks' equation:

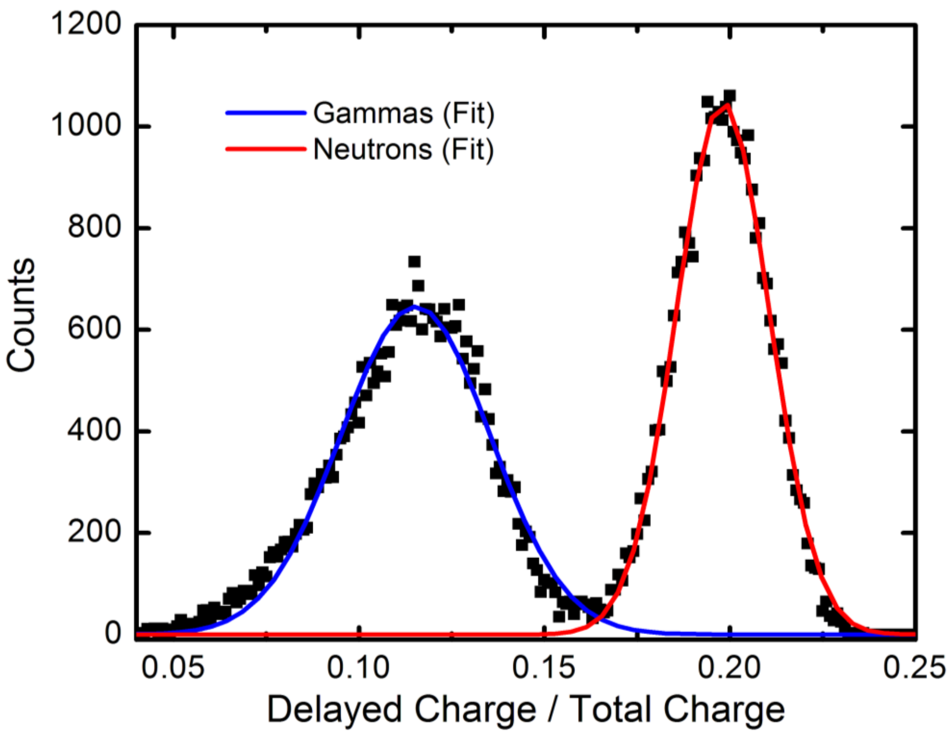
$$\frac{dL}{dx} = S\,\frac{dE/dx}{1 + kB(dE/dx)}$$

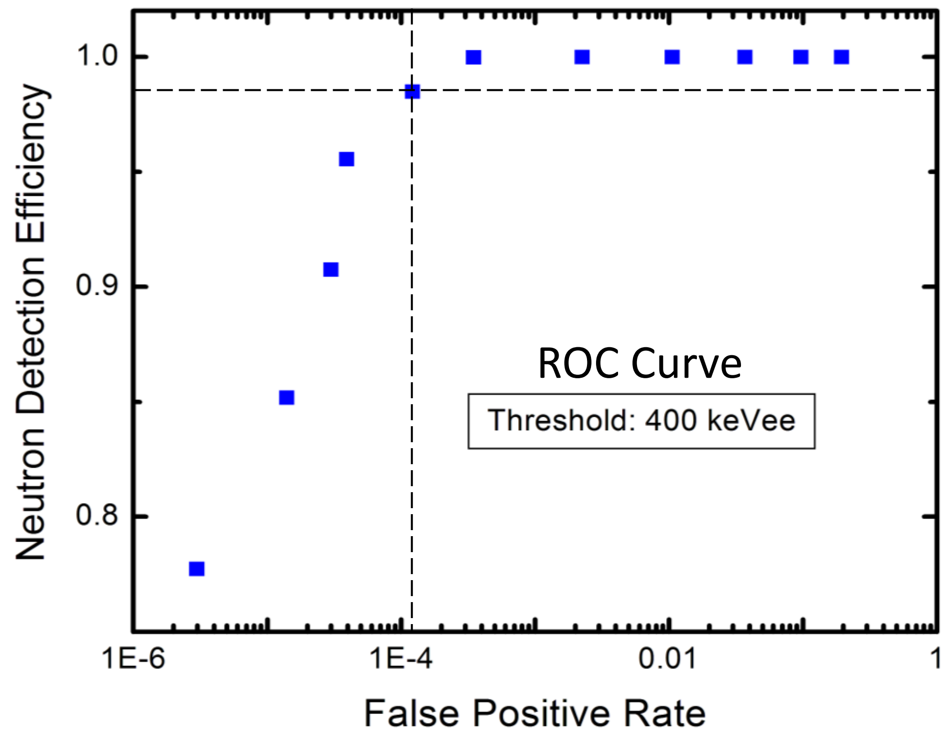
- S = Scintillation efficiency
  kB = Birks' parameter
- Luminescence per unit length decreases in high dE/dx region
- Larger quenching effect for singlet vs. triplet states
- Ionization quenching evident in radioluminescence timing distributions and scintillation measurements
- Exponential decay distinct from behavior of traditional organic scintillators





Gamma Rejection and PSD-FOM: PVT Scintillator





- 5.68 g PVT
  16.4 mg 4,4'-bis(diphenylvinylenyl)anthracene
  18.9 mg Ir(ppy-F_2)$_2$(F_2-pic)

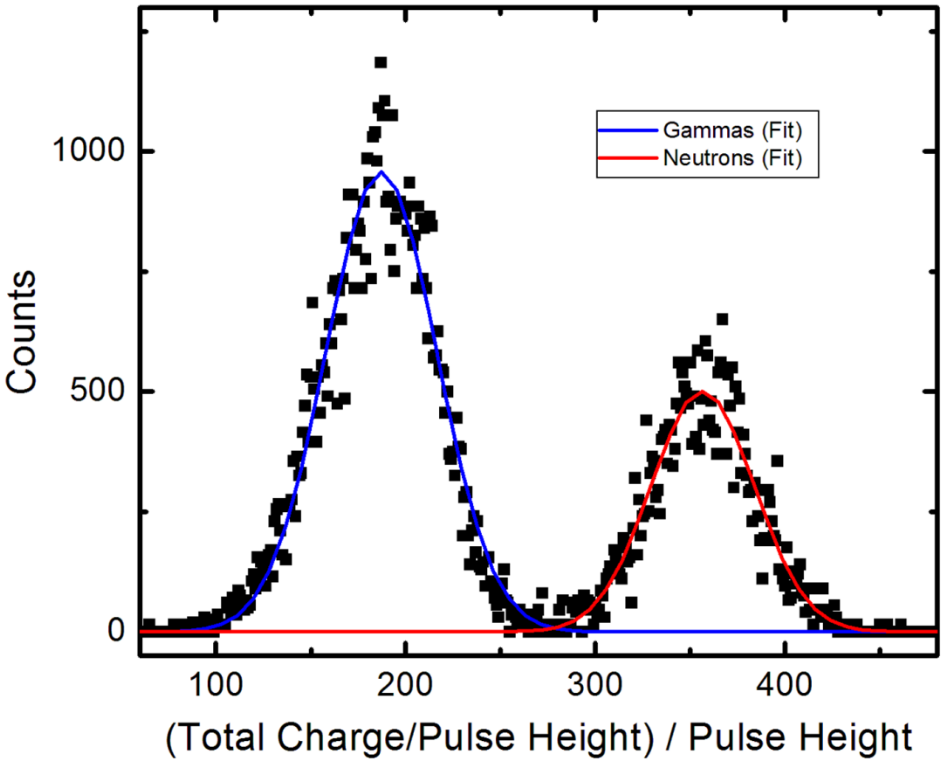
GRR ≈ $1{\cdot}10^{-4}$ at 400 keVee and 98% neutron detection threshold

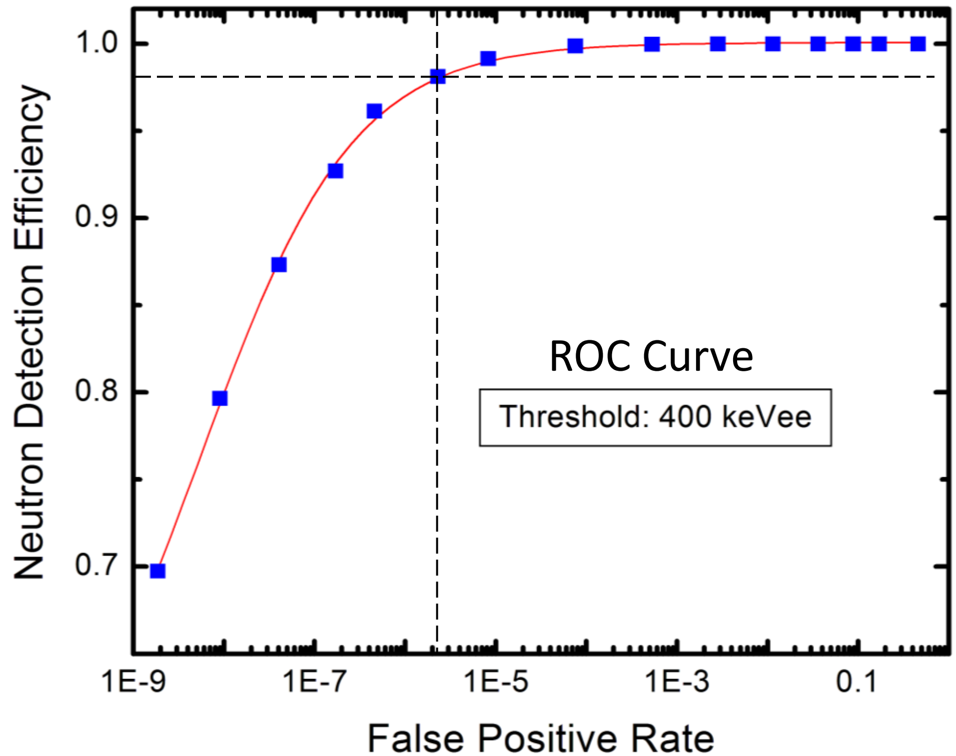
Average Total Count Rate: 50.1 cps
n:γ ratio: 1.01
Neutron Count Rate: 50.5 cps

- Gamma rejection ratios (GRR) calculated from fitting of PSD-FOM histogram

R.A. Winyard et al. *Nucl. Instr. Meth.* **1971** 95, 141.

Gamma Rejection and PSD-FOM: PVK Scintillator



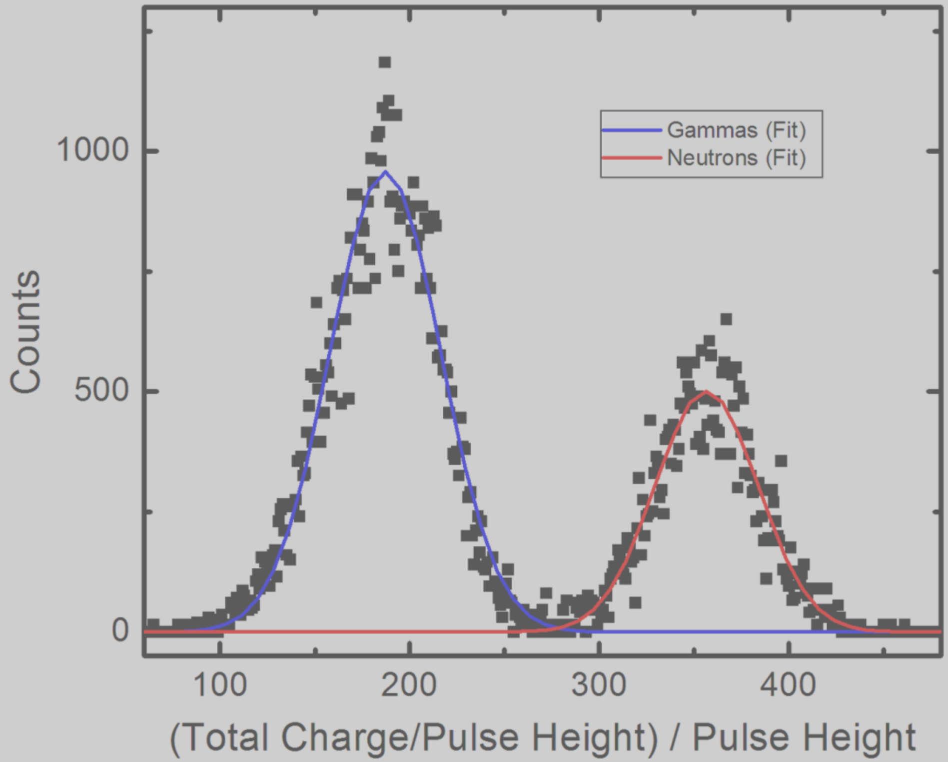


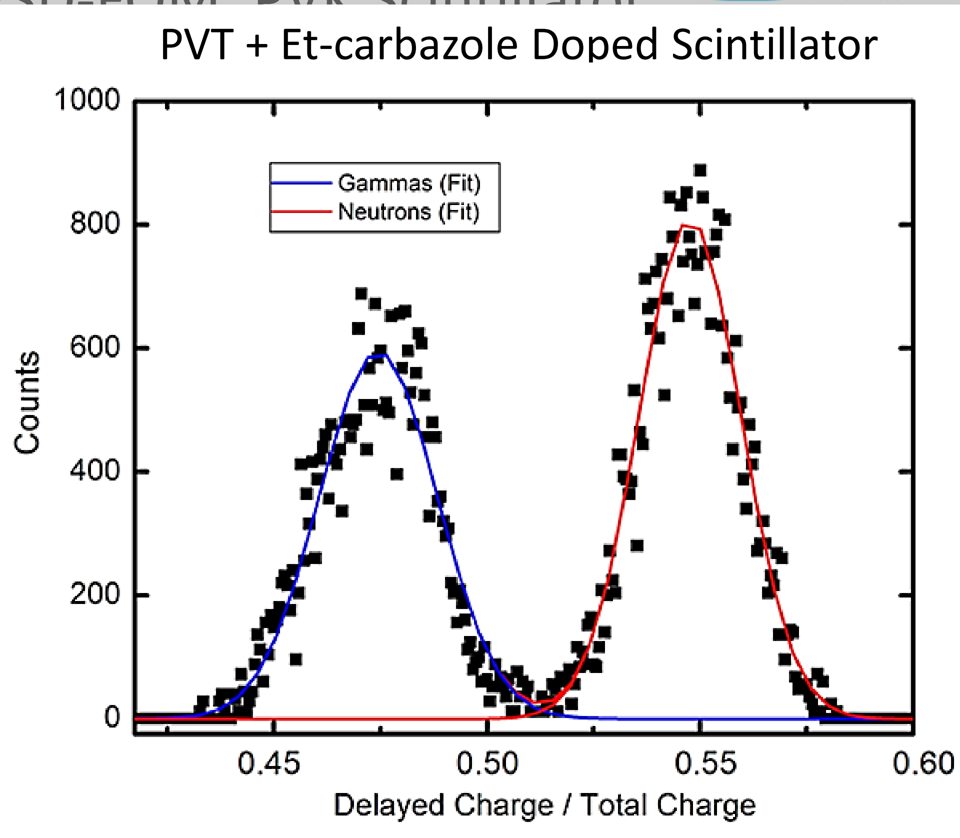
- 4.8 g PVK
  15.4 mg 7-(diethylamino)-4-(trifluoromethyl)-1-benzopyran-2-one
  17.6 mg Ir(ppy-F_2)$_2$(F_2-pic)
- Improved gamma rejection but lower neutron detection efficiency than PVT-based scintillator
  - Lower H:C ratio (PVK: **0.7** vs. PVT: **1.1**)

GRR ≈ $2\cdot10^{-6}$ at 400 keVee and 98% neutron detection threshold

Average Total Count Rate: 49.4 cps
n:γ ratio: 0.65
Neutron Count Rate: 32.2 cps

Gamma Rejection and PSD-FOM: PVK Scintillator





- 4.8 g PVK
  15.4 mg 7-(diethylamino)-4-(trifluoromethyl)-1-benzopyran-2-one
  17.6 mg $Ir(ppy\text{-}F_2)_2(F_2\text{-}pic)$

- Improved gamma rejection but lower neutron detection efficiency than PVT-based scintillator
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GRR ≈ $2 \cdot 10^{-6}$ at 400 keVee and 98% neutron detection threshold

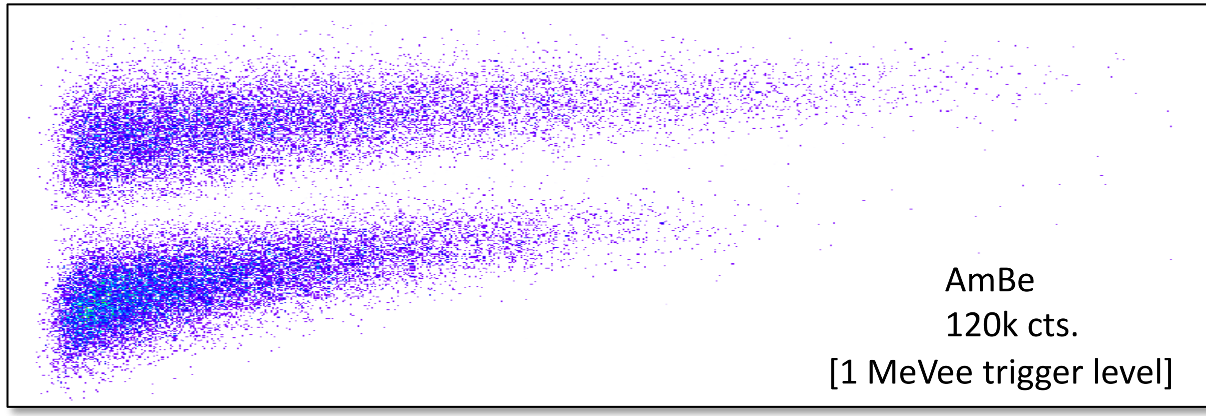
Average Total Count Rate: 49.4 cps
n:γ ratio: 0.65
Neutron Count Rate: 32.2 cps

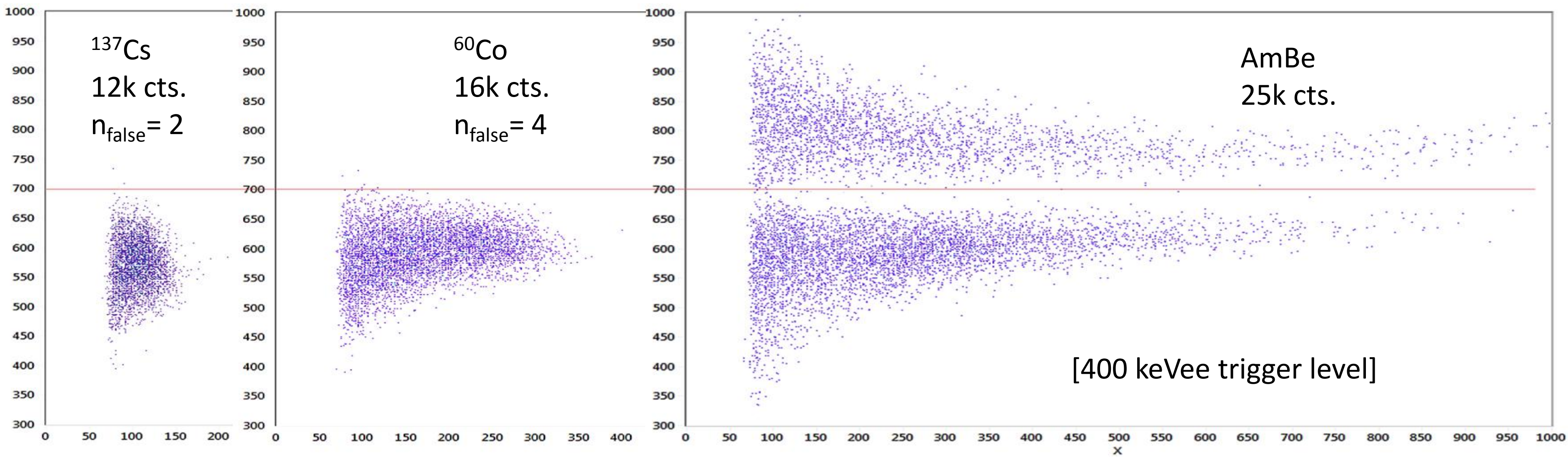
Gamma Rejection in the Absence of Neutrons

4.8 g PVK

15.4 mg 7-(diethylamino)-4-(trifluoromethyl)-1-benzopyran-2-one

17.6 mg $Ir(ppy\text{-}F_2)_2(F_2\text{-}pic)$



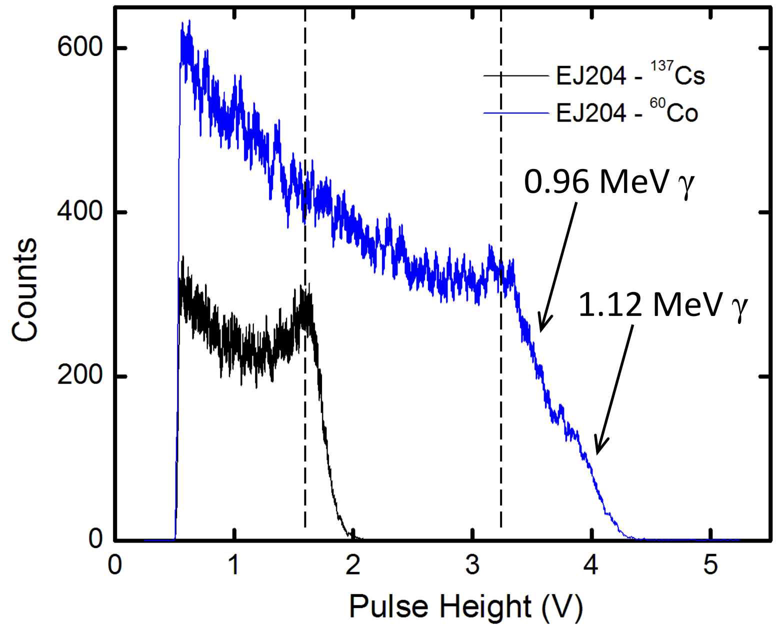


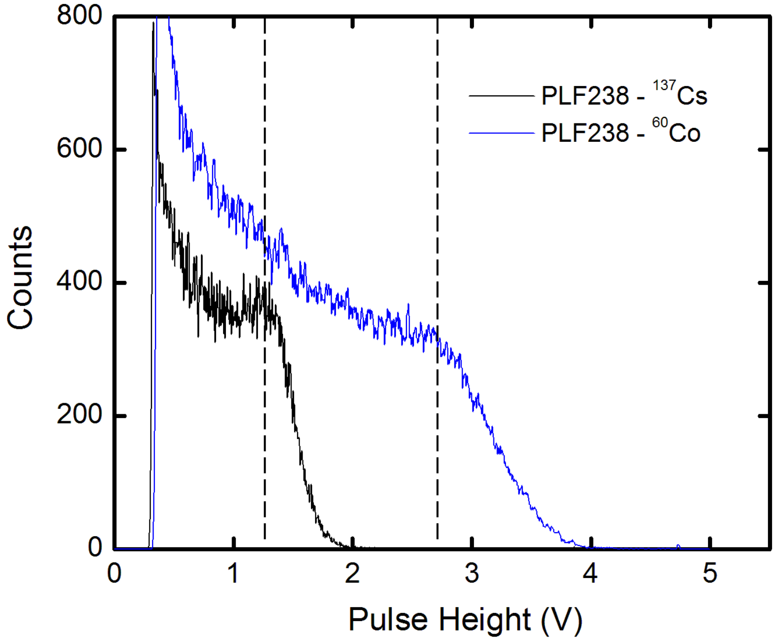
Fraction of false gamma events at 400 keVee threshold:

($1.7 \cdot 10^{-4}$ for ^{137}Cs)

($2.5 \cdot 10^{-4}$ for ^{60}Co)

Pulse-Height Spectra





EJ-204 Plastic Scintillator:

Polymer Base:……………………………Polyvinyltoluene
Scintillation Efficiency, photons/ 1MeVee……10,400

Light Output, % Anthracene	68
Max Emission Wavelength	408
Rise Time, ns	0.7
Decay Time, ns	1.8
Pulse Width, FWHM, ns	2.2

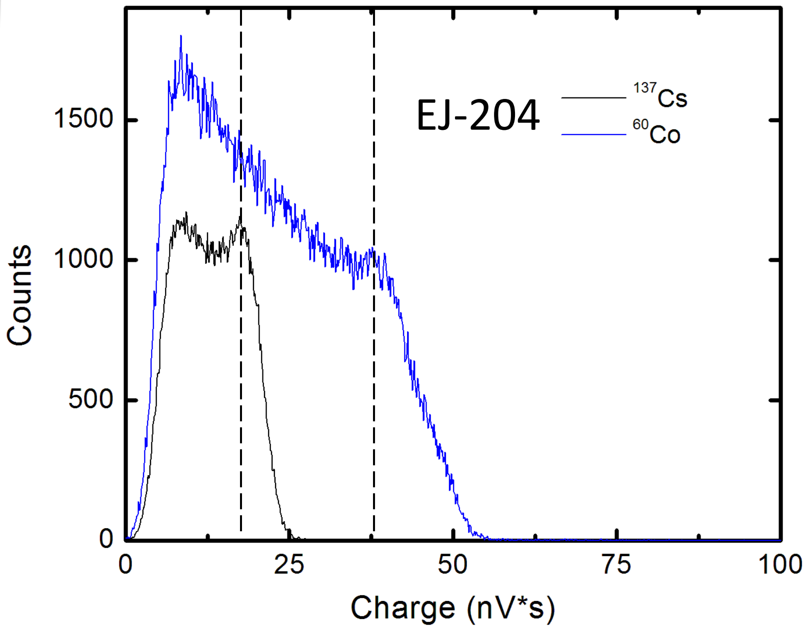
PLF238 Doped Plastic Scintillator:

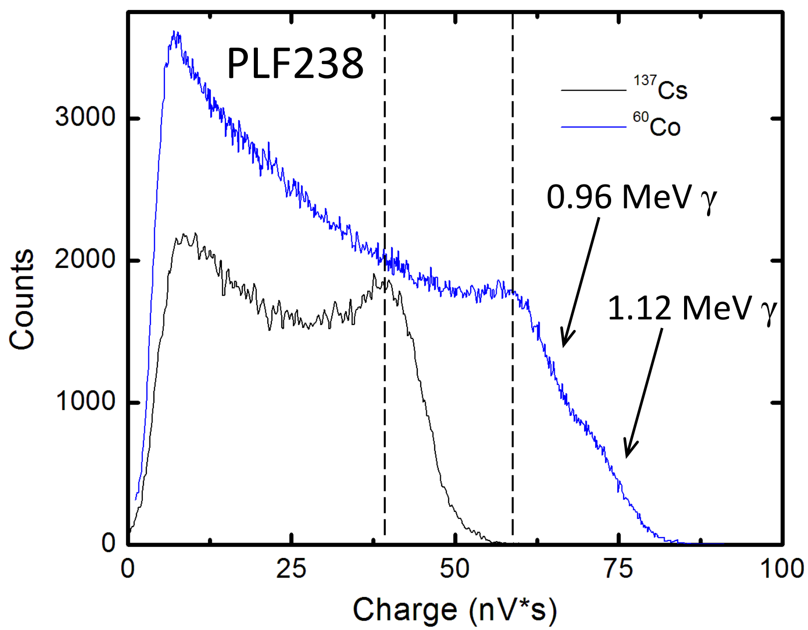
Polymer Base:……………………………Polyvinylcarbazole

Light Output, % Anthracene	~60%
Max Emission Wavelength	468
Rise Time, ns	0.9
Decay Time, ns	5.4 (prompt)
Pulse Width, FWHM, ns	6.8 (prompt)

- Larger *pulse-heights* in commercial EJ-204 plastic scintillator associated with:
  1. Better match to PMT spectral response
  2. Faster prompt decay time

Pulse-Area Spectra





EJ-204 Plastic Scintillator:

Polymer Base:....................................Polyvinyltoluene
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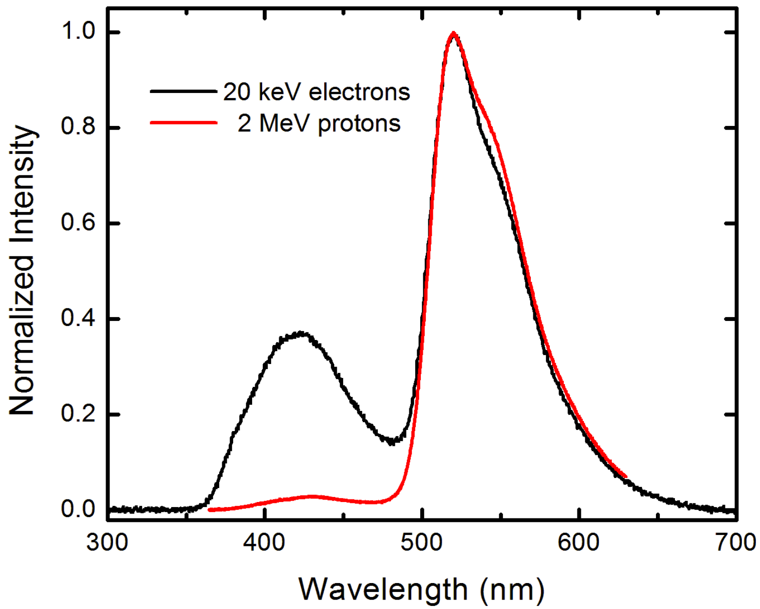
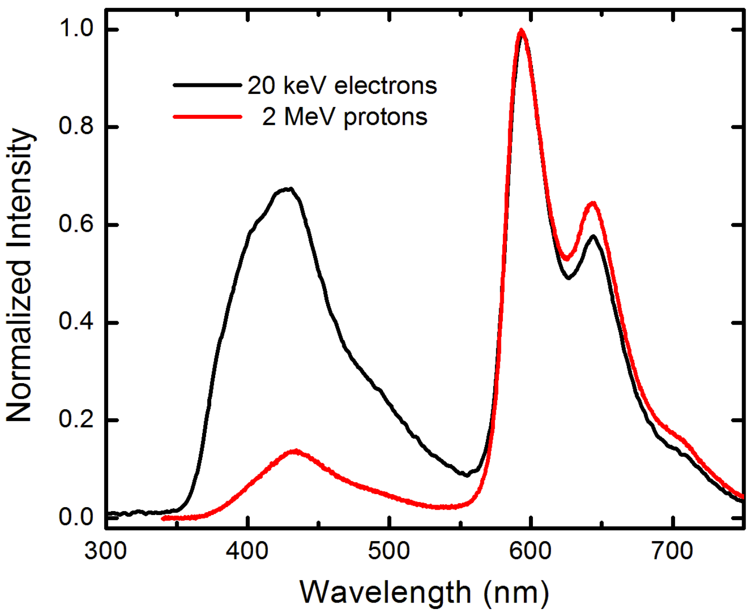
Light Output, % Anthracene	68
Max Emission Wavelength	408
Rise Time, ns	0.7
Decay Time, ns	1.8
Pulse Width, FWHM, ns	2.2

Notable Observations for doped polymer sample:

- Larger absolute photon yield than EJ-204 (***150%***)
  - Confirmed in steady-state radioluminescence measurements
- Evidence for both ^{60}Co gammas in pulse-area spectrum for PLF238
- Similar gamma sensitivity/count rate as EJ-204

SSD in Radioluminescence Measurements

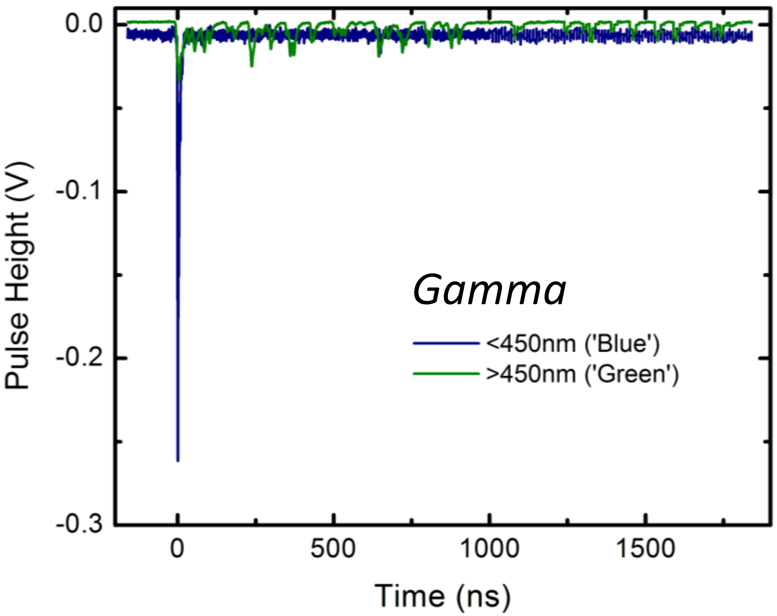


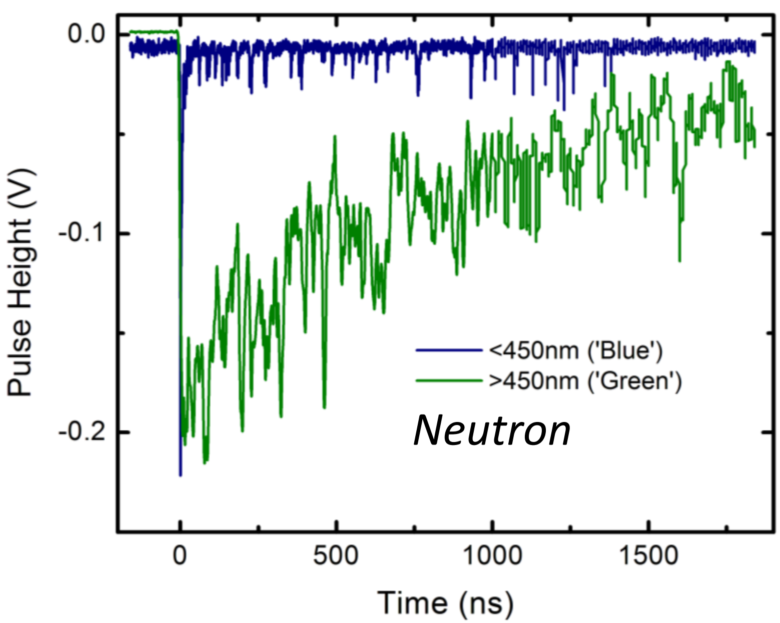


Dopant	Dopant Conc.	Singlet Emission (nm)	Triplet Emission (nm)	Electron-to-Proton Singlet Ratio
$Ir(ppy\text{-}F_2)_2(Me\text{-}pic)$	0.025%	421	468	1.8
$Ir(ppy\text{-}F_2)_2(Me\text{-}pic)$	0.1%	421	471	4.8
$Ir(ppy)_2(Me\text{-}pic)$	0.1%	424	509	5.3
$Ir(ppy)_2(acac)$	0.2%	422	520	13.5
$Ir(thio)_3$	0.05%	426	594	4.9

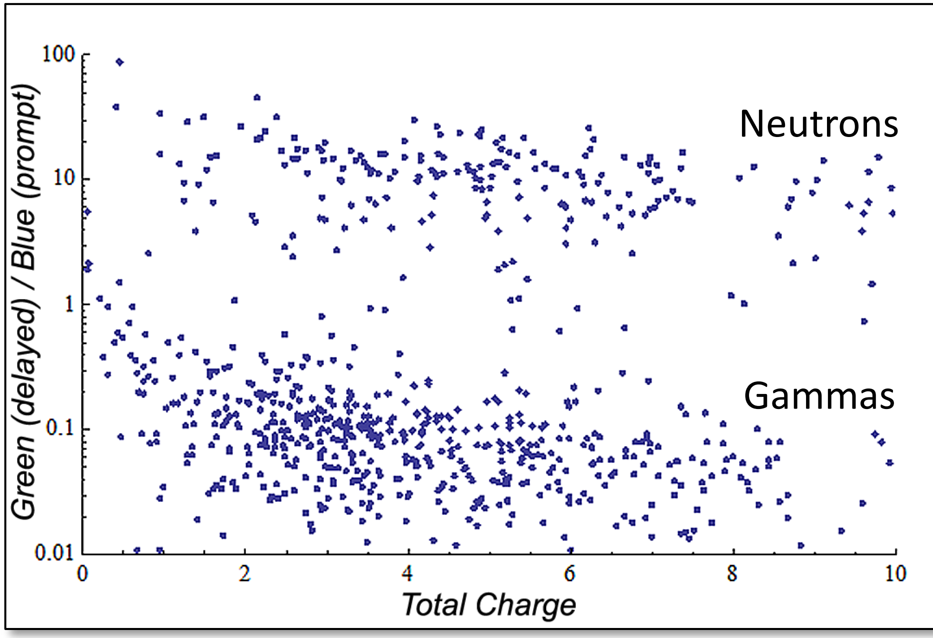
- Measurements performed on thick films (1.5 mm)
- Relative extent of dE/dx quenching dependent upon dopant identity and concentration

Pulse-Transient SSD Results: Bulk Sample





Charge-Comparison SSD



First demonstration of SSD in scintillation measurements!

- Planned improvements:
  - Further reduce S-T cross-excitation
  - Employ multi-alkali PMT (green/red response)
  - PMT gain optimization
  - Better dichroic filter matching (isolation of prompt/delayed components)