PSD Scintillator Development at LLNL

Reactor Antineutrino Spectrum and Anomaly Measurements: U.S. Planning Meeting

December 11, 2012

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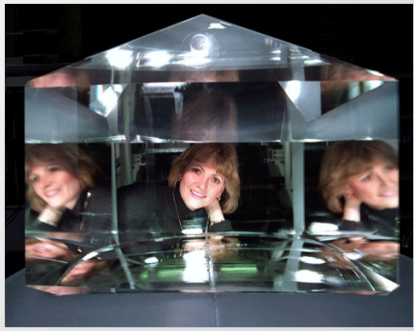
This work was supported by the National Nuclear Security Administration, Office of Nonproliferation Research and Development (NA-22) of the U.S.DOE.

LLNL-PRES-607694

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Team



Natalia Zaitseva (PI): Ph.D. Physics/Mathematics, Moscow State University, Russia.
Development of the Rapid Growth Techniques for production of super-large KDP-DKDP crystals; Crystal growth; Crystal characterization; Work planning and management.

Leslie Carman: Chemist, UC Santa Barbara. Played active part in NIF KDP development.
Crystal growth; Chemical analysis; Material purification; Solubility measurements; Crystallizer design modification.

Andrew Glenn: Ph.D. in High Energy Nuclear Physics, University of Tennessee.
Nuclear scientist, Neutron detection characterization, PSD data analysis, Design of electronic instrumentation.

Iwona Pawełczak: Ph.D. in (Nuclear) Chemistry, University of Rochester.
Neutron detection characterization, PSD data analysis, Spectroscopy, Crystal studies for incorporation in detection systems.

Paul Martinez: Ph.D. in Chemistry, UC San Diego.
Organic/inorganic synthetic techniques, Material purification, Chemical analysis, and Optical spectroscopy.

Michelle Faust: Lawrence Scholar Program graduate student, University of California – Davis.
Crystal characterization, Solubility measurements, Spectroscopic analyses, Crystallography.

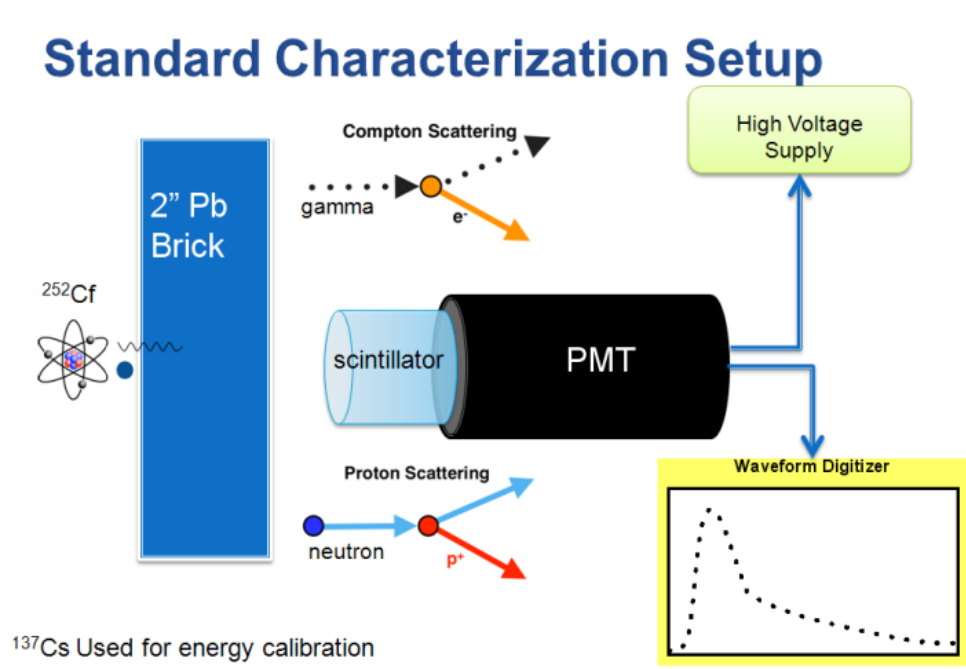
Keith Lewis: Mechanical technician – Crystallizer modifications and manufacturing, Crystal cutting procedures.

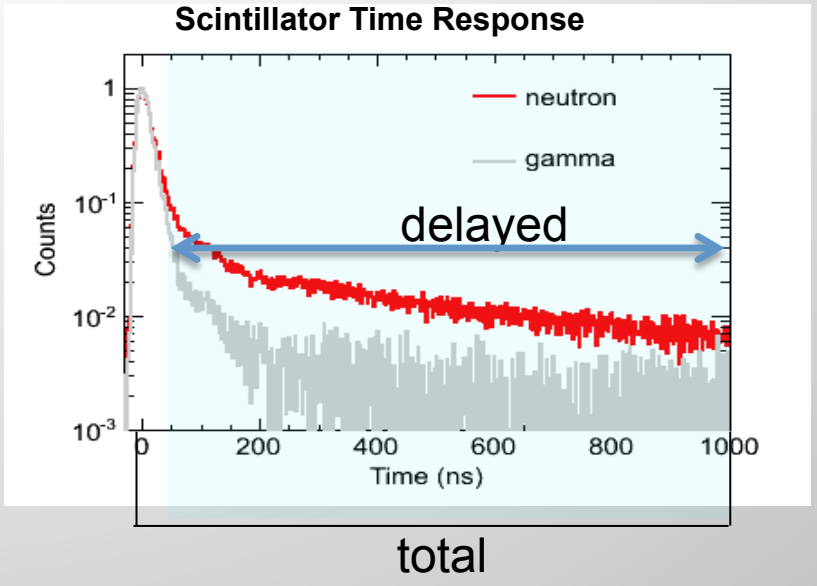
Stephen Payne (PM): Ph.D. Physical Chemistry, Princeton University.
Work coordination; Modeling; Data analysis and discussions.

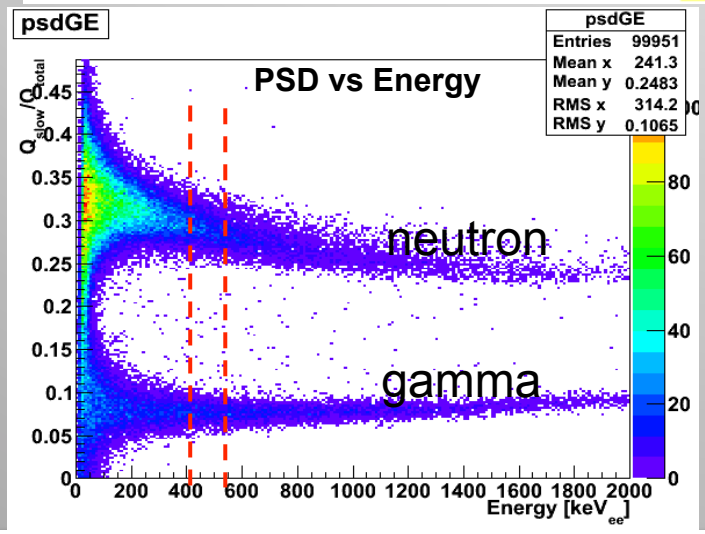
Goals and projects

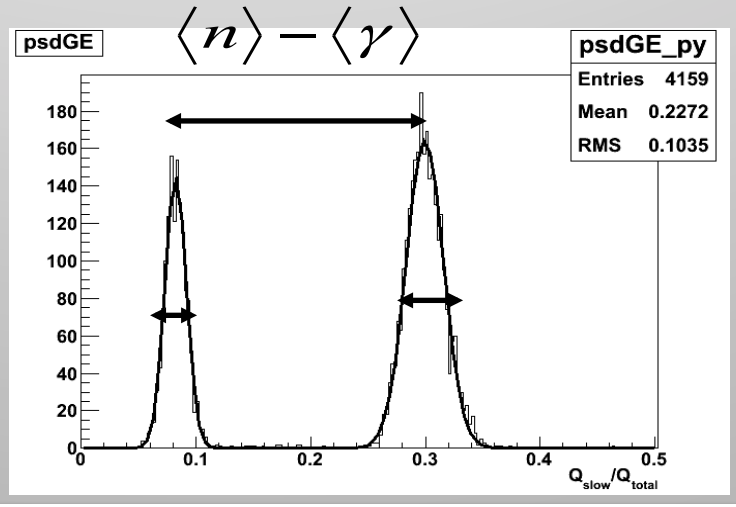
- **Develop advanced organic scintillators for radiation detection**
  - Emphasis on solid state neutron detectors
  - Enhance homeland security, safeguards and related capabilities
- Started with LDRD for survey and down selection of crystal scintillators with neutron/gamma pulse shape discrimination
- Ongoing DNDO funded stilbene growth project
- Ongoing NA22 funded advanced crystals/plastics
- Starting boron loaded plastics development for DTRA

Pulse Shape Discrimination









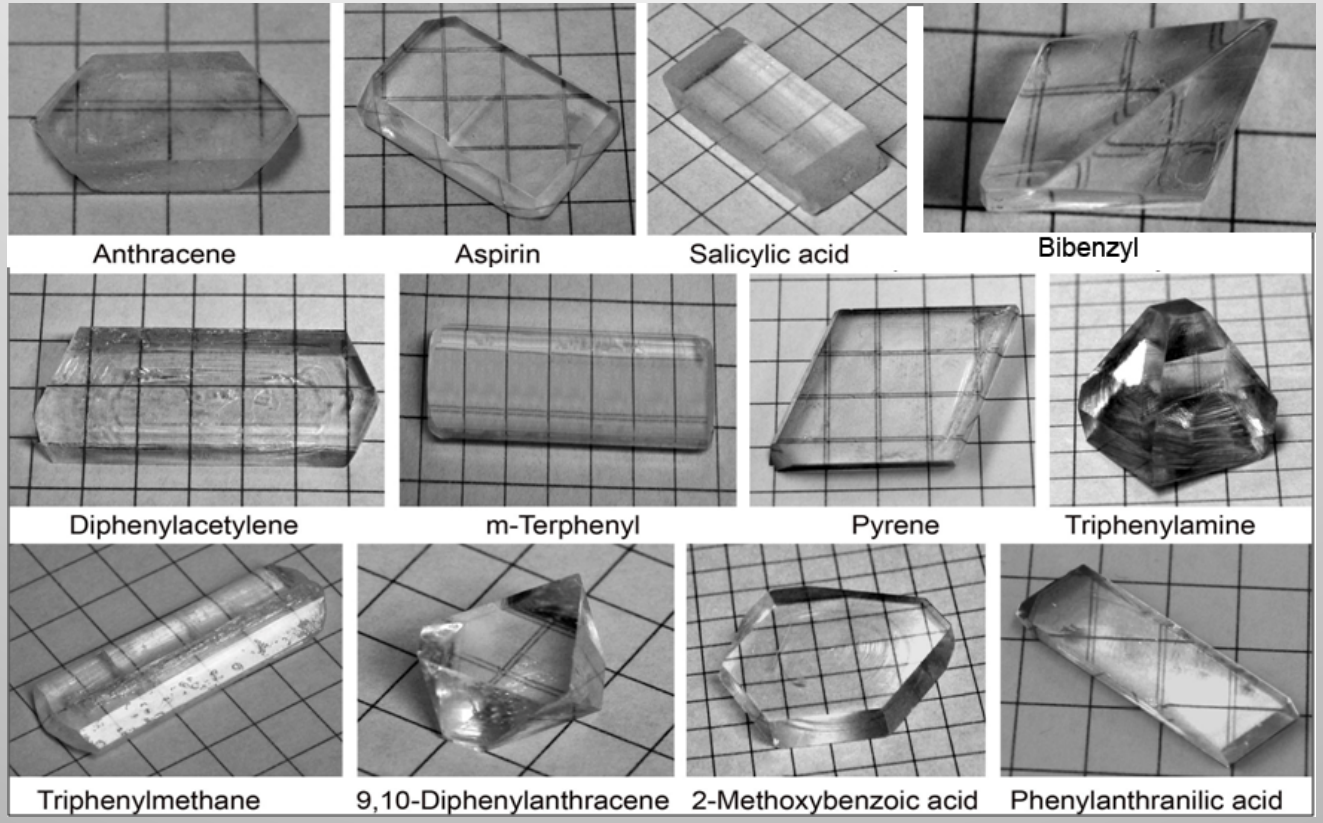
$$PSD = \frac{\int_{delayed} Qdt}{\int_{total} Qdt}$$

$$FoM = \frac{\langle n \rangle - \langle \gamma \rangle}{\Gamma_{FWHMn} + \Gamma_{FWHM\gamma}}$$

We conducted an extensive survey of aromatic compounds and found many new materials with efficient PSD

Solution technique applied to grow organic crystals traditionally grown from melt

Broad variety of organic compounds explored for neutron detection properties and PSD

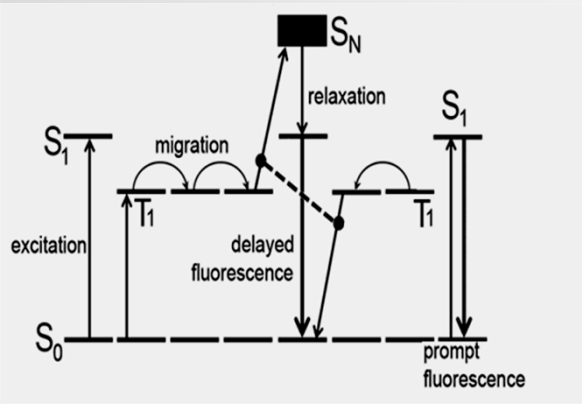


Background square size is 6.5 mm

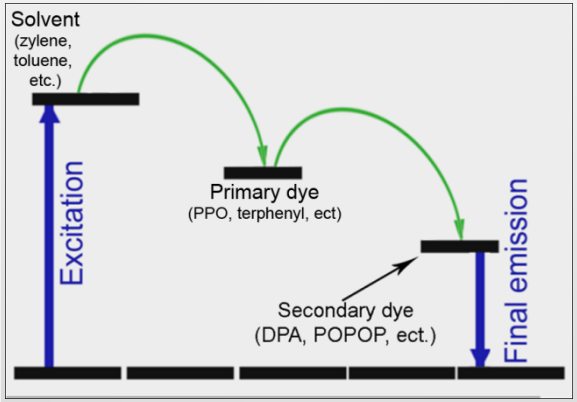
More than 150 organic crystals tested in survey of PSD phenomenon

Scintillation mixtures exhibit complex PSD behavior

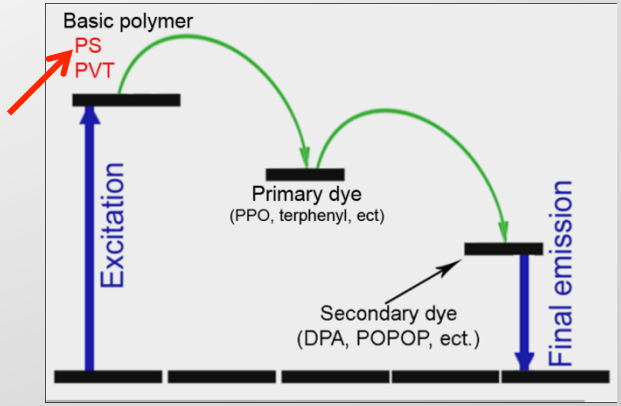
Liquid and plastic scintillators always prepared as mixtures of two or more organic compounds



Single-component system

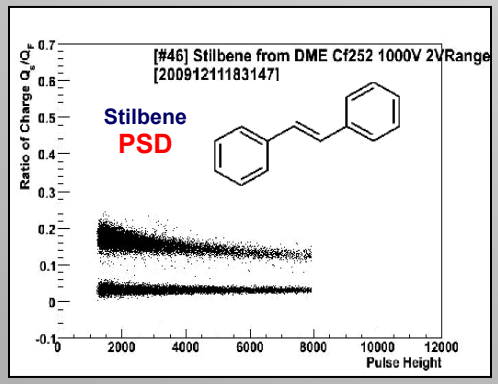


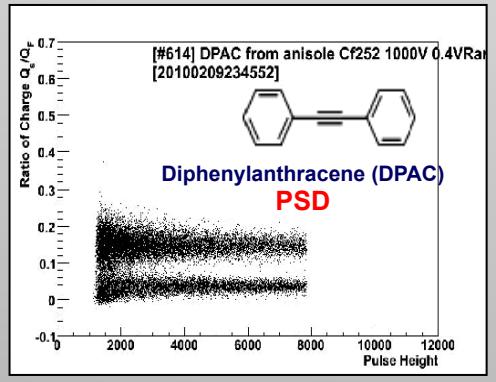
Liquid scintillator mixture

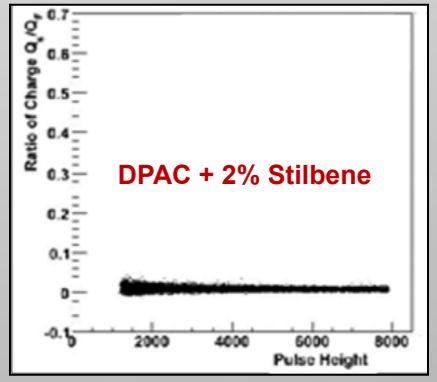


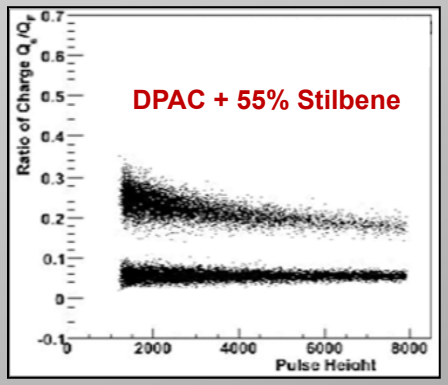
Plastic scintillator mixture

Studies of mixed crystals resulted in new understanding of PSD mechanisms







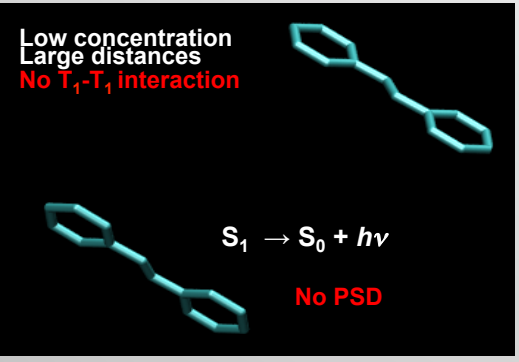


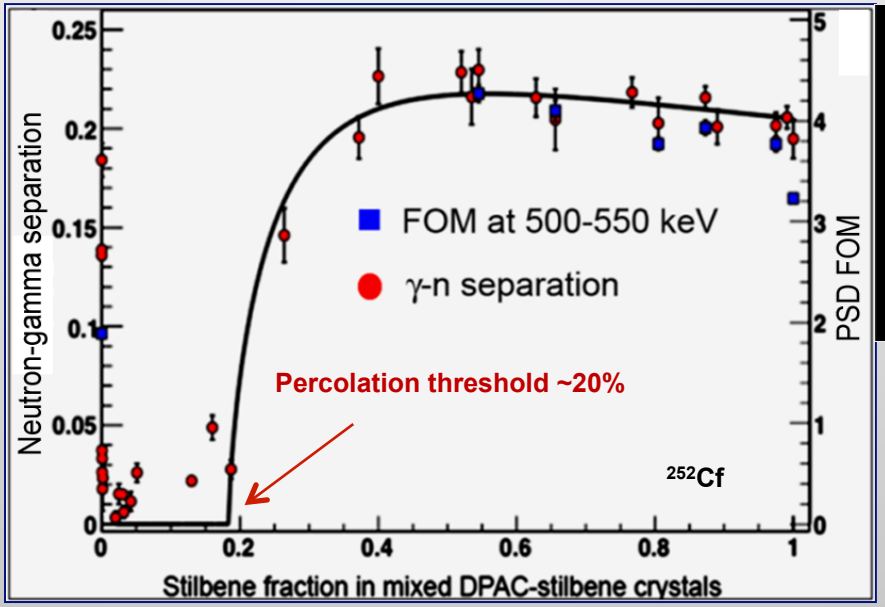
PVT = Polyvinyltoluene; PS = Polystyrene; PPO = 2,5-Diphenyloxazole

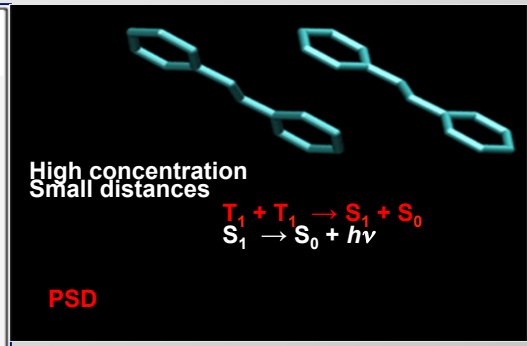
Nuclear Science, IEEE Transactions on , vol.58, no.6, pp.3411-3420, Dec. 2011

PSD in mixed crystals found to depend on the concentration of constituent dyes

Delay light and PSD formation require T_1-T_1 interaction of pairs of closely located molecules

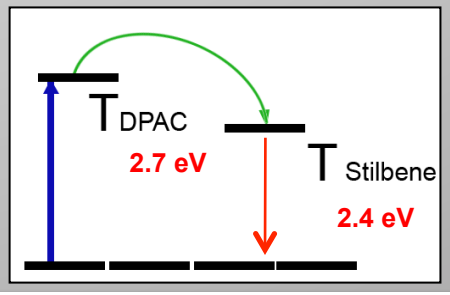






Nuclear Science, IEEE Transactions on , vol.58, no.6, pp.3411-3420, Dec. 2011

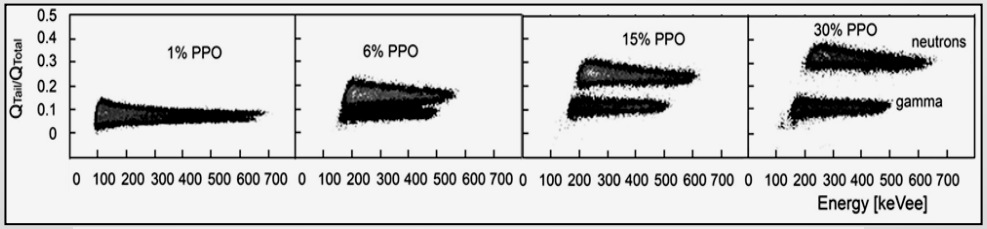
Excitation energy transferred to lower-band-gap dye (stilbene)



Studies conducted with crystals led to development of first plastic scintillators with efficient PSD

- Plastic scintillators traditionally prepared with low dye concentrations by analogy with liquids

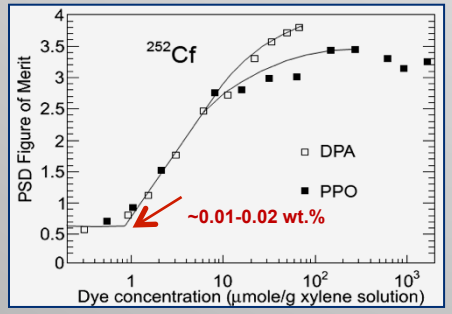
Plastics: PPO in PVT



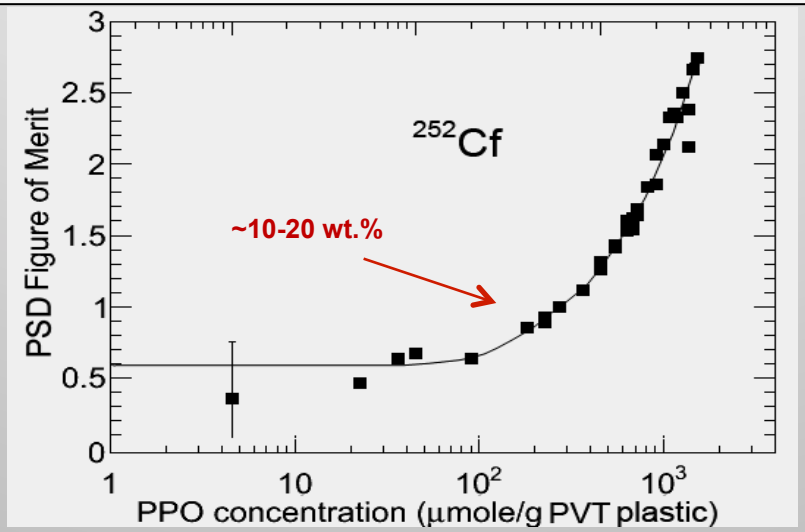
Low dye concentration is sufficient for PSD production in liquid scintillators

PSD in crystals requires 2-3 orders of magnitude higher dye concentration

Liquids

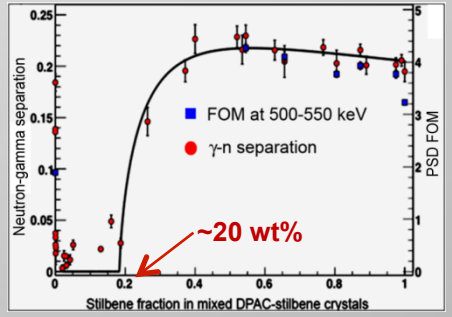


High diffusion mobility of molecular interaction



Efficient PSD at 10-20% (solid state)

Crystals



Fixed positions of molecules in crystal lattice

PSD in plastics requires concentration of a dye similar to that in crystals!

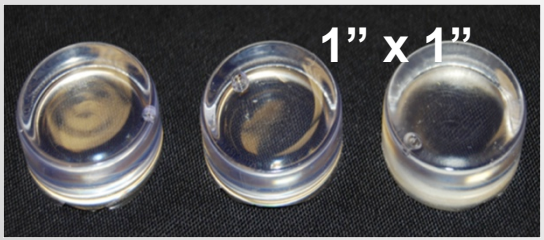
*) PVT = Polyvinyltoluene; PS = Polystyrene; PPO = 2,5-Diphenyloxazole

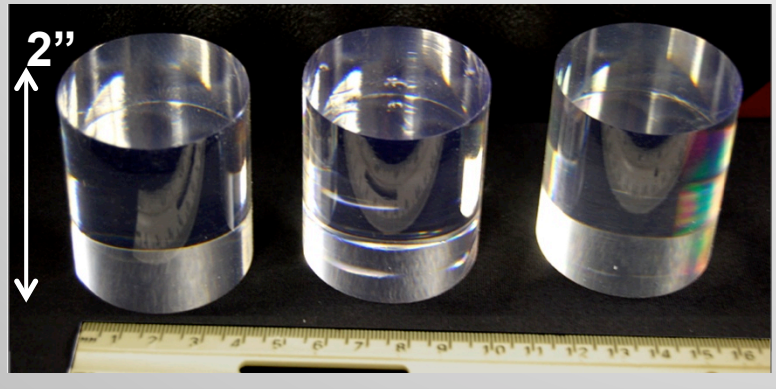
New PSD plastics: Easy to produce with traditional inexpensive ingredients, no major changes in existing technology

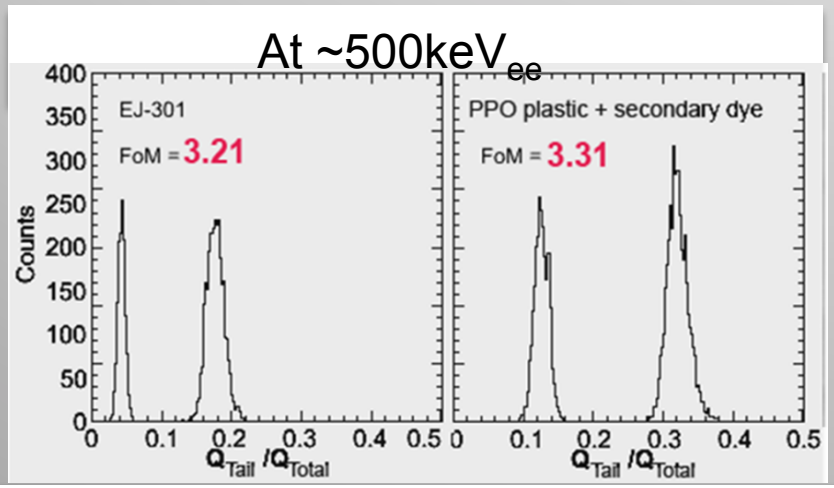
Quick transfer to industry!

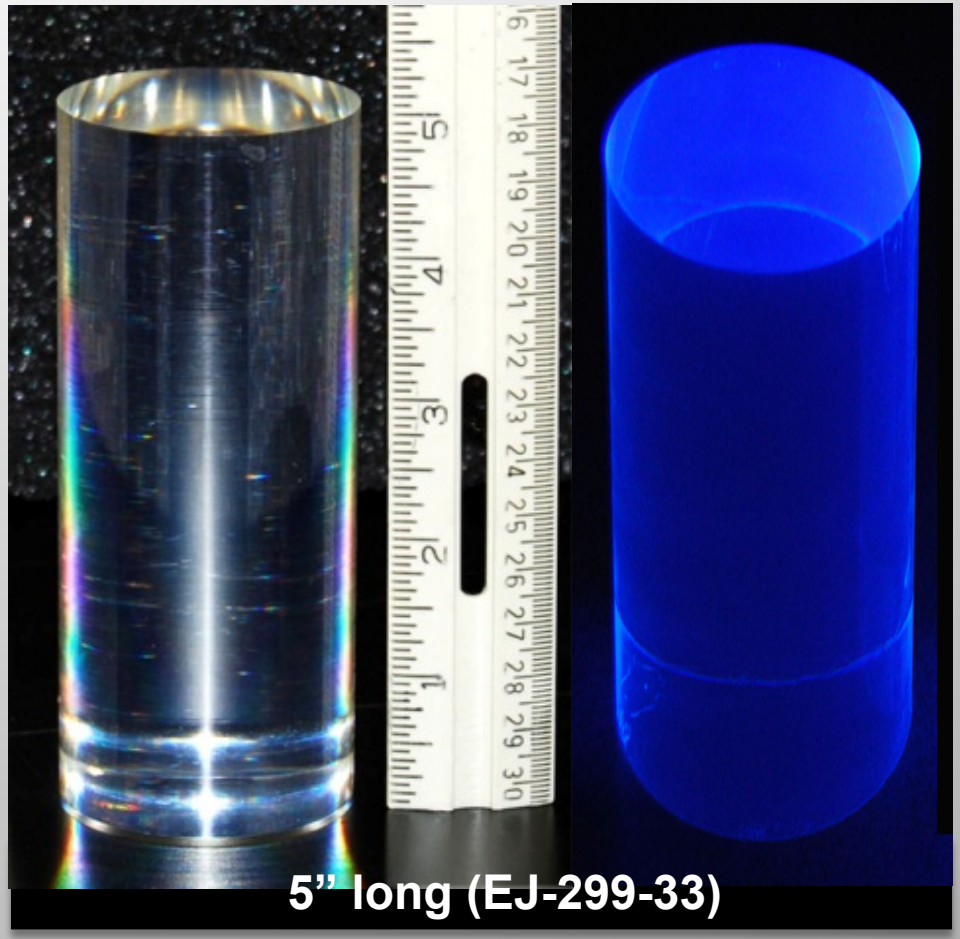
Eljen technologies is producing an implementation

A 2012 R&D100 Winner



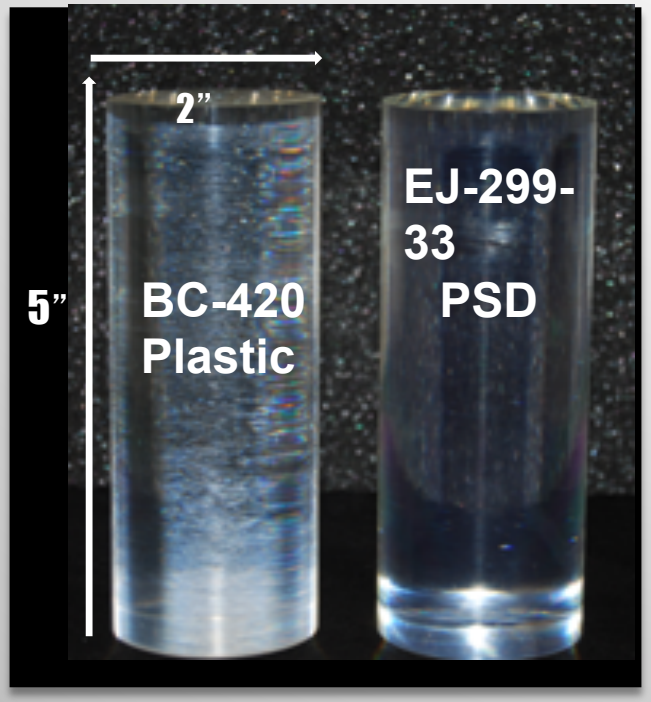


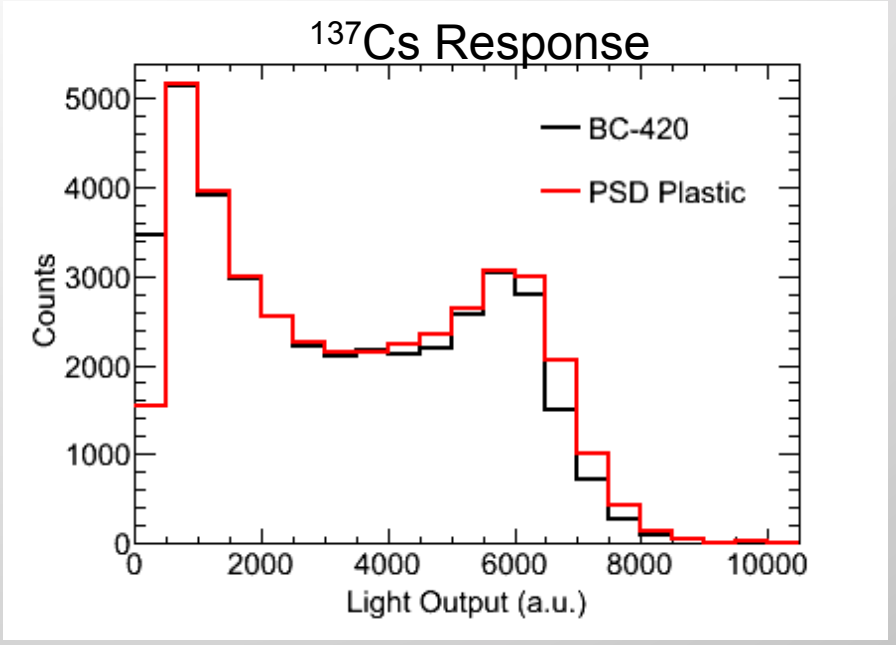




135mm x 175mm long cylinders have been produced

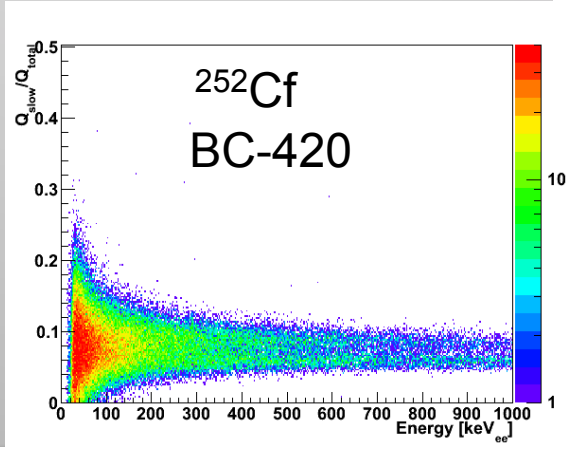
Light yield PSD plastic comparable to light yield in plastics with low-dye-concentration

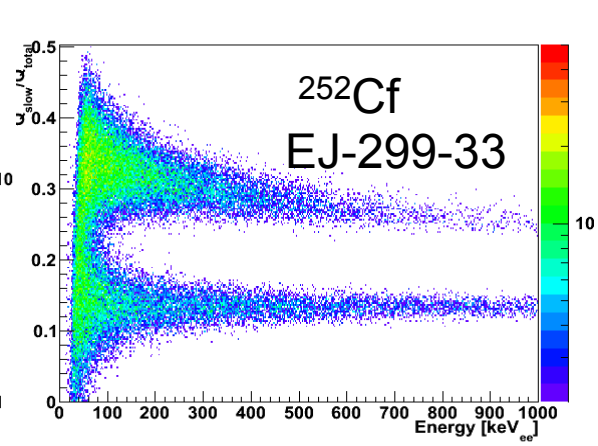




Higher excitation density of secondary dye molecules compensates light absorption of high concentration primary dye

No noticeable change in response to collimated ^{137}Cs along length





Challenges and solutions of High Dye Loading In PSD Plastic Scintillators

Challenges

- Precipitation of dyes
- Softening\Clarity
- Enhanced Absorption (Yellowing)
- Inhomogeneity at Scaling

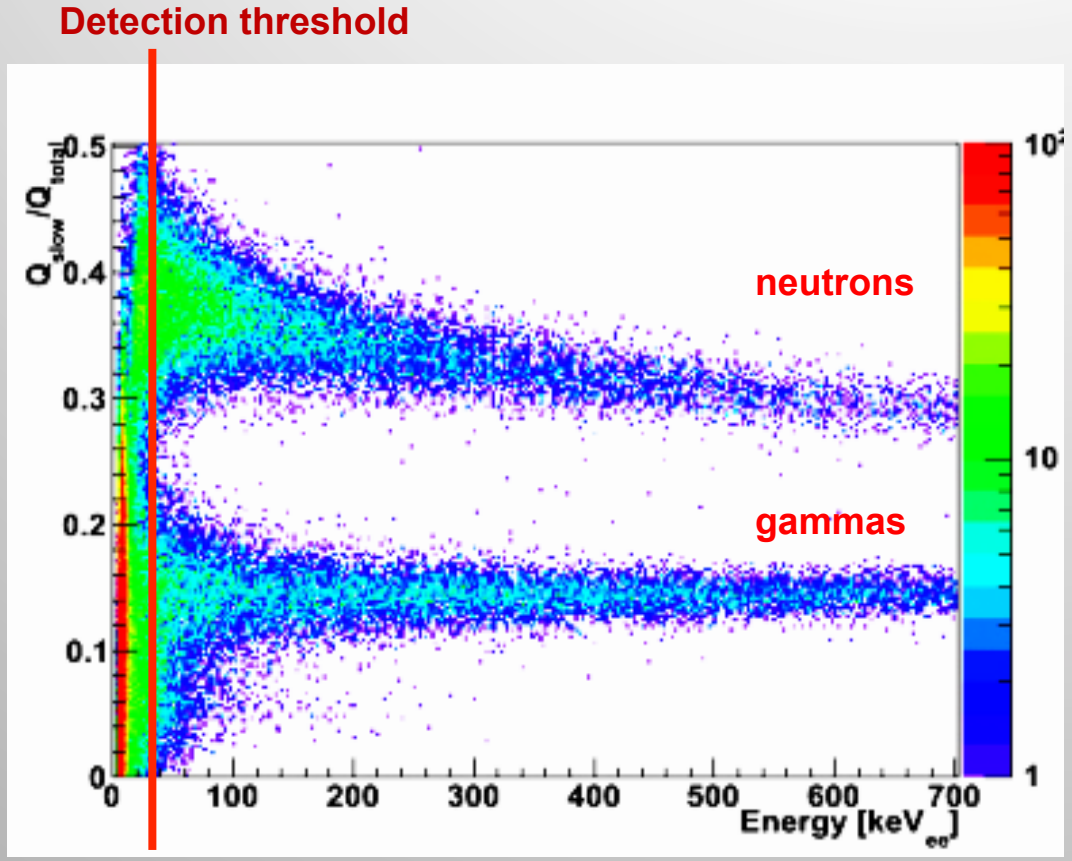
Solutions

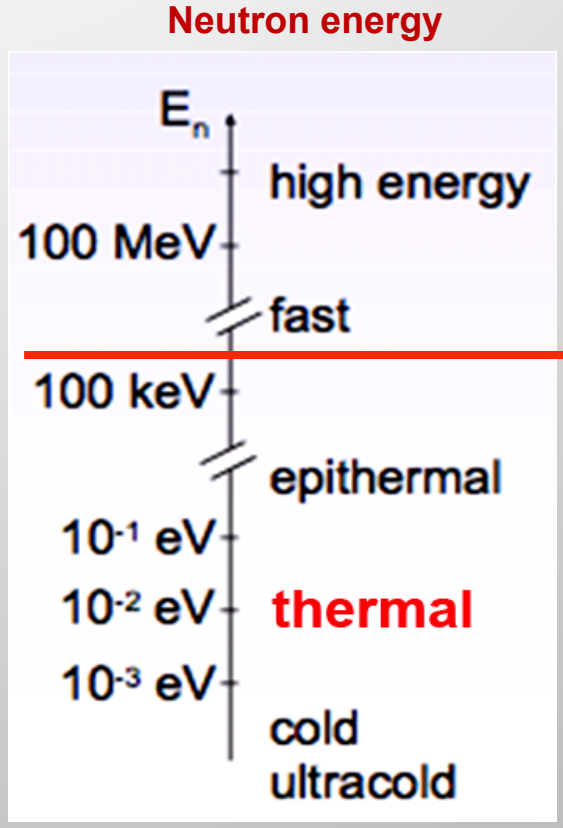
The addition of cross-linkers greatly limits any dye precipitation

The use of acrylate co-polymerization hardens and increases clarity

Slower curing time along with a temperature gradient aid both yellowing and scaling issues

These PSD plastics can be used only for fast neutron detection





~40-50 KeV gamma equivalent
~ 500 KeV neutron energy

PSD in existing plastics unsuitable for thermal neutron detection

Neutron detection in wide dynamic range: Incorporation of nuclei with large capture cross sections

Multi-MeV neutron detected by proton recoil

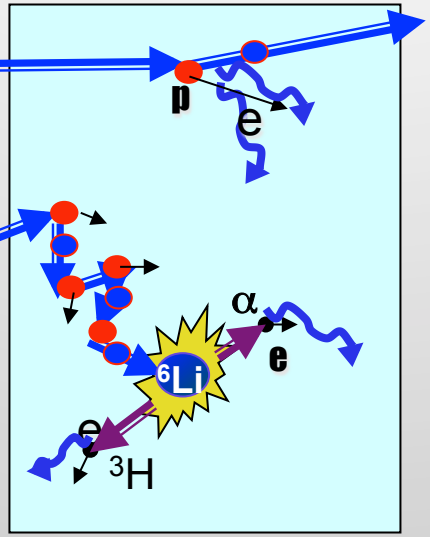
n1

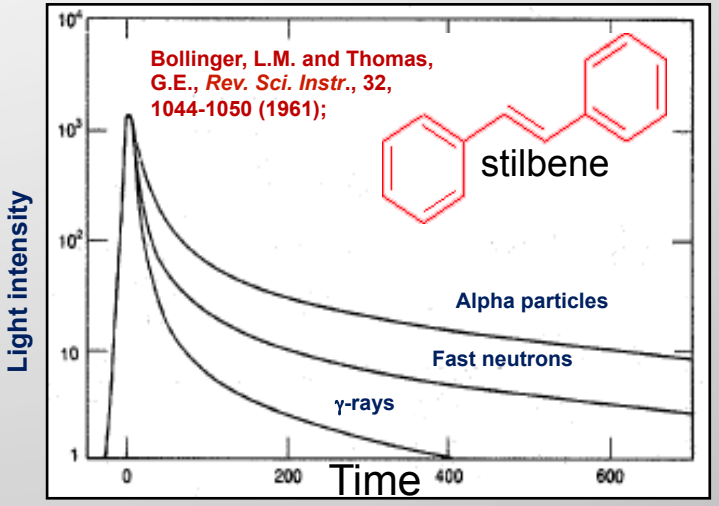
Neutron below the threshold for detection by proton recoil measured by capture reaction products

n2

Efficiency

PSD Scintillator Loaded with ^{6}Li



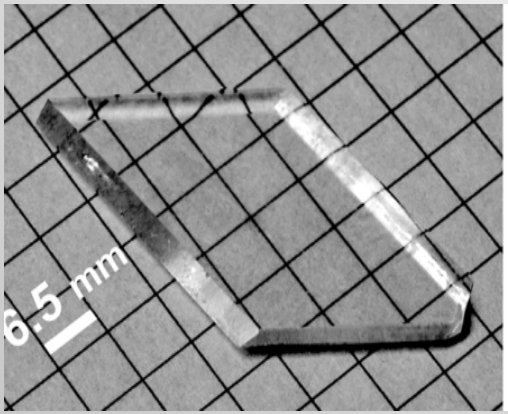


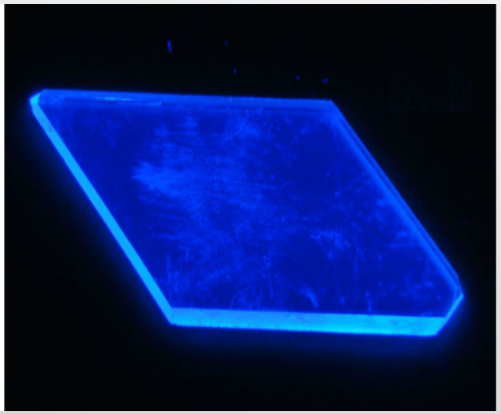
PSD – γ-ray background rejection

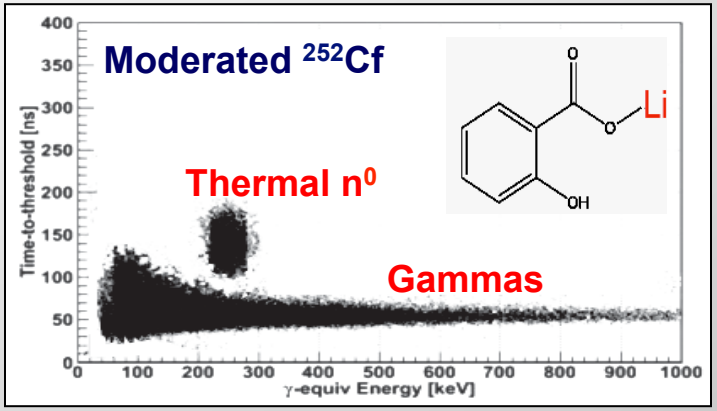
Thermal Neutron Capture Reaction		Cross Section (barn)	Q-value (MeV)	Natural Abundance (%)
^{10}B(n,^{4}He)^{7}Li ^{10}B(n,^{4}He γ(0.48MeV))^{7}Li	6% 94%	3840	2.792 2.310	19.8
^{6}Li(n,^{3}H)^{4}He		940	4.78	7.40

Some crystals grown as lithium salts for thermal neutron detection

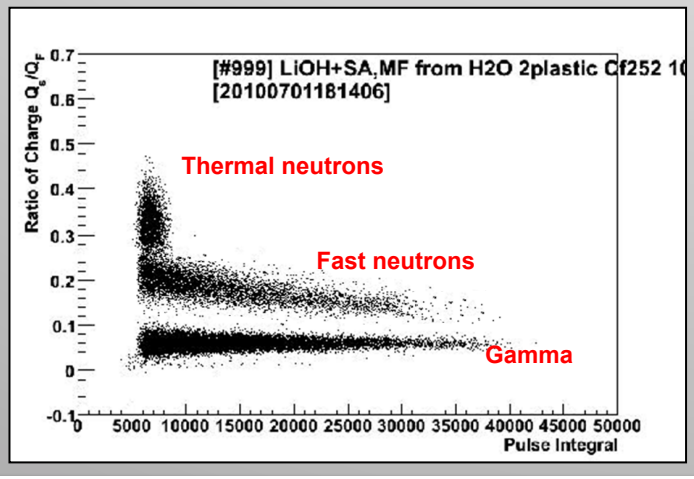
$^{6}Li + n^{o} = {}^{4}He + {}^{3}H + 4.8\ MeV$

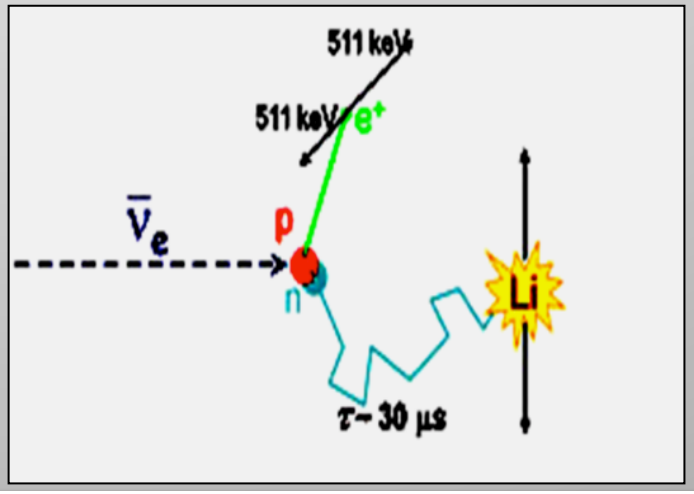






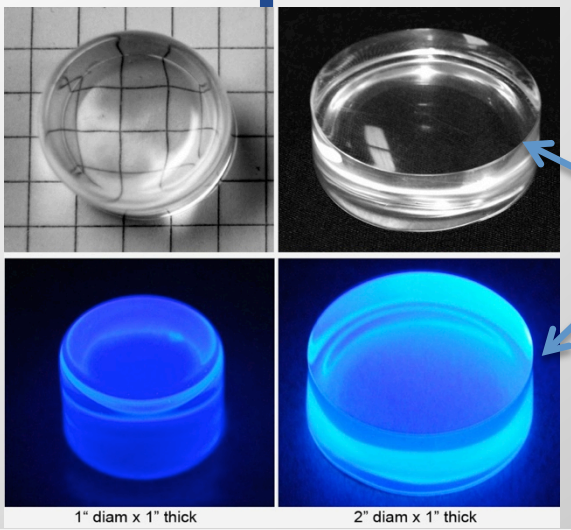
Simultaneous detection of fast and thermal neutrons serves a signature for anti-neutrinos

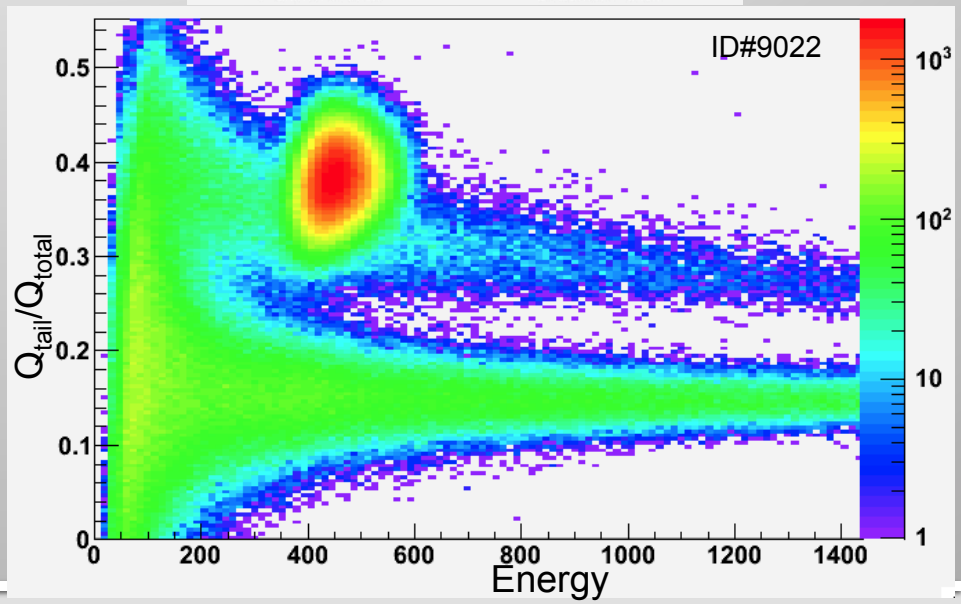




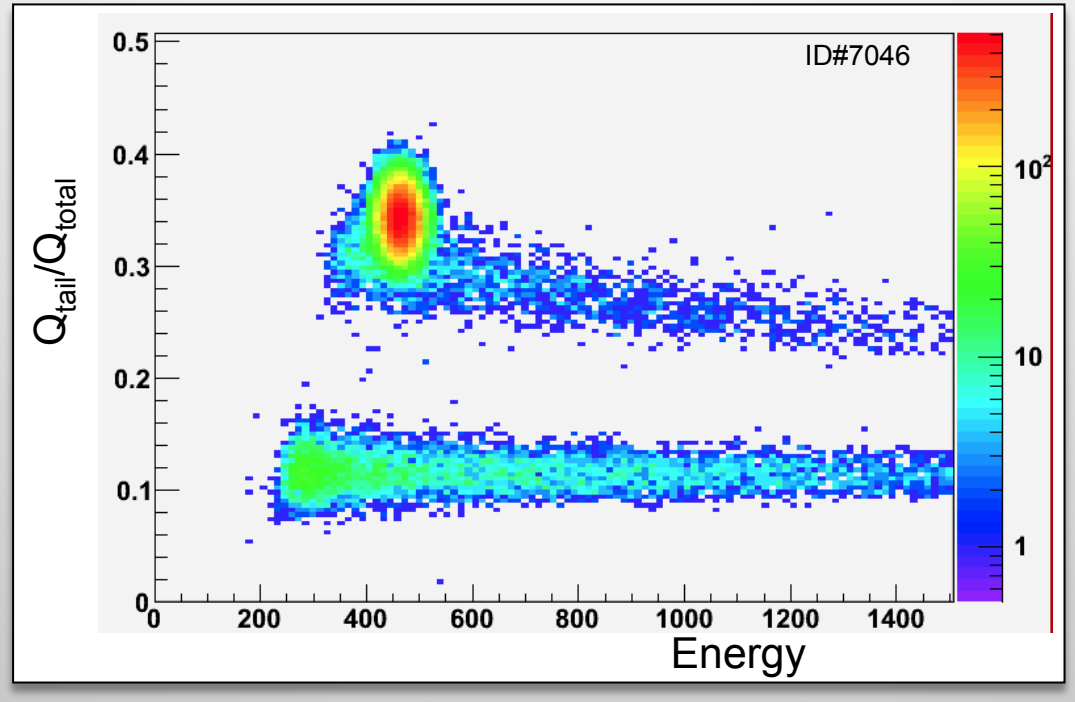
Organometallic lithium compounds can be incorporated in PSD plastic

- We have synthesized several organometallics which have allowed us to achieve homogeneous Li loadings of ~0.15 - 0.3 weight %
- We have ideas to increase loading
- No stability/shelf life issues have been observed
- Initial studies conducted with natural Li
- Now moving to enriched ^{6}Li
  - **$$, Cost could be reduced by large quantity purchase**
- We plan to test performance with PMTs selected by N. Bowden et. al. in the near future





Organometallic Li compounds can be incorporated in liquid scintillators



- Similar loading as plastics
- So far only Xylene based
  - Not suitable for deployment due to handling/safety
- Less information on stability
- We will try safer alternatives soon
  - Linear Alkyl Benzene (LAB)
  - EJ-309 liquid scintillator

Summary

- We are experienced in organic scintillator development
- We have developed the first plastic with efficient neutron/gamma PSD
  - And worked with industry to bring it to market
- We have developed the first ^{6}Li loaded plastic scintillators with PSD for thermal neutron, fast neutron and gamma detection
- The same method of Li incorporation appears applicable for liquid scintillators
- We look forward to working with the neutrino detection community