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A plastic scintillator with enhanced Alpha-/Beta- PSD. Part I: Rationale and preparation

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A Plastic Scintillator with enhanced Alpha-/Beta- PSD. Part I: Rationale and preparation

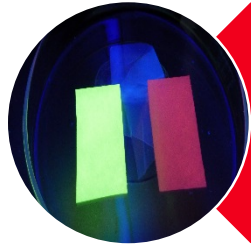
LSC 2020

Matthieu Hamel, Krasimir Mitev

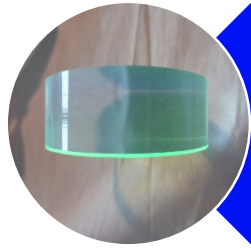
Université Paris Saclay, CEA List, Palaiseau, FRANCE

Faculty of Physics, University of Sofia, Sofia, BULGARIA





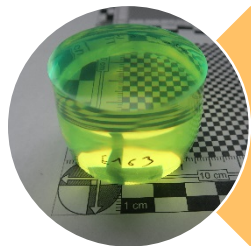
Introduction



^{222}Rn detection with organic scintillators



^{222}Rn detection with Pulse Shape Discriminating plastics



Conclusions

A rather old scientific topic... but still hot!

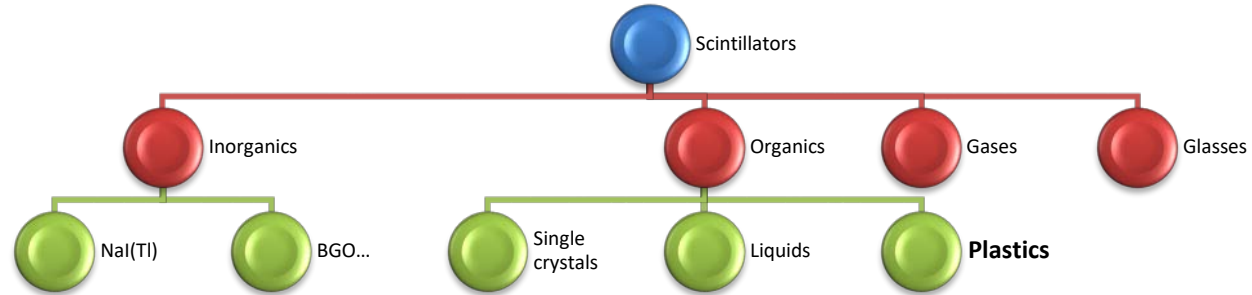
Uraninite in a cloud chamber (C. Wilson, 1911)



Not exhaustive: semiconductors, ionization chambers, **scintillators**

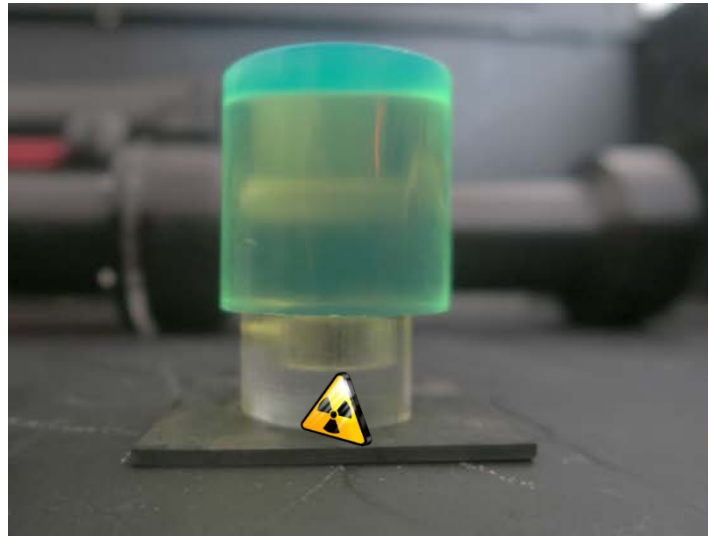
Definition

Material able to emit light upon interaction with radiation

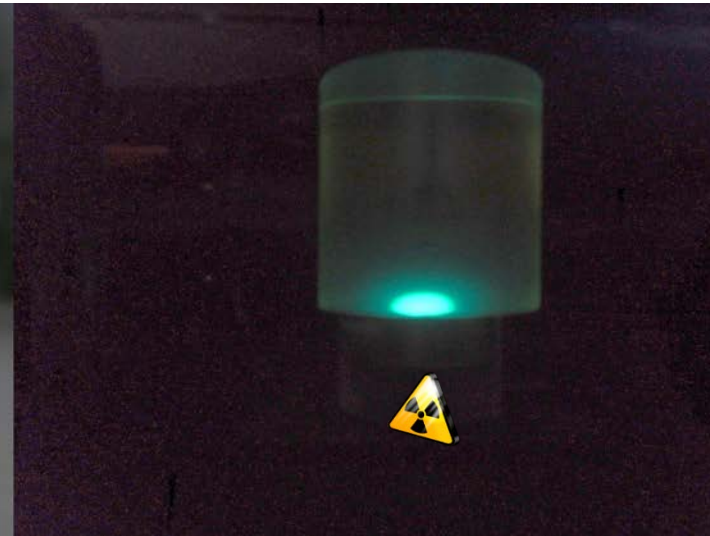


SP33 plastic scintillator (Nuvia) exposed to $^{90}\text{Sr}/^{90}\text{Y}$ beta emitting source

Visible image

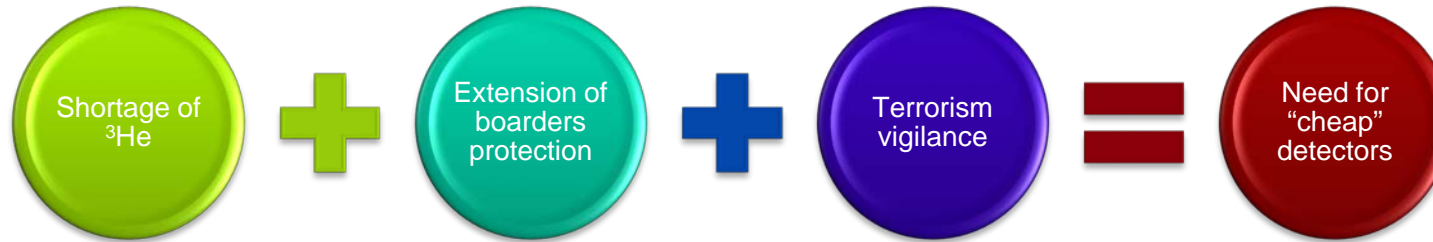


Dark image



Why new (plastic) scintillators?

Main motivation – Example for neutron detection



Goal of this lecture

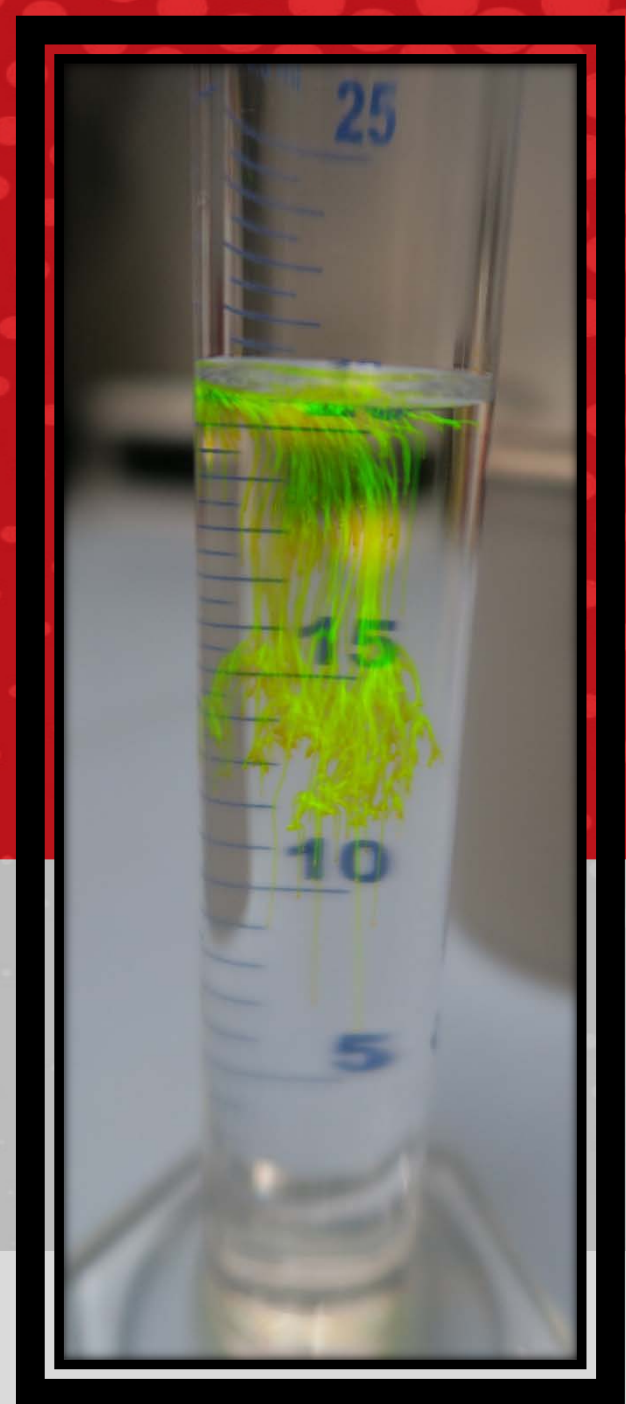
To demonstrate that plastic scintillators can afford a suitable solution

→ Even for gas detection

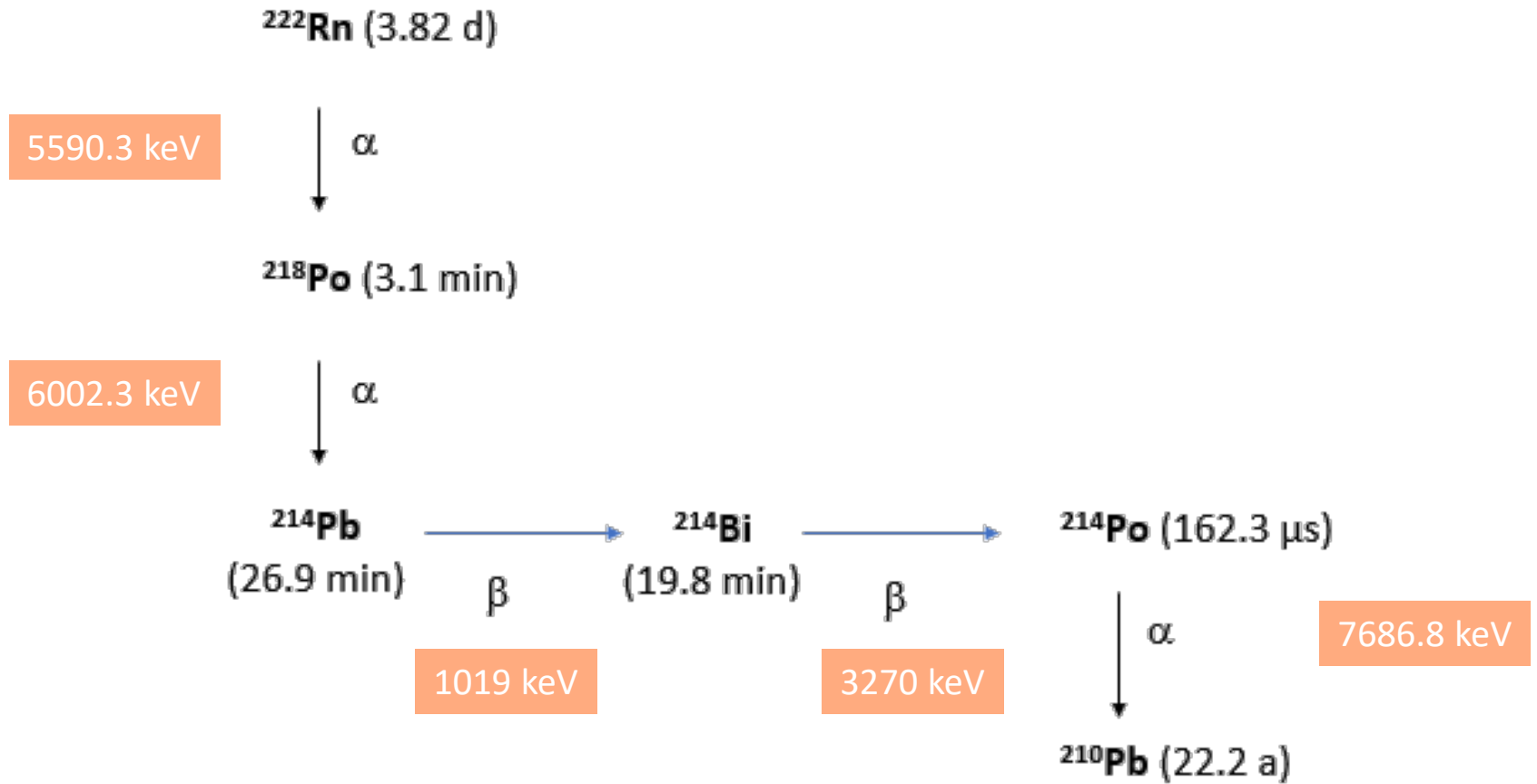
Versatility of plastic scintillators

- Dimensions
- Scintillation properties
 - Time response (ns)
 - Wavelength (nm)
 - Yield (photons per deposited MeV, ph/MeV)
- Design for special applications
- **Cost**

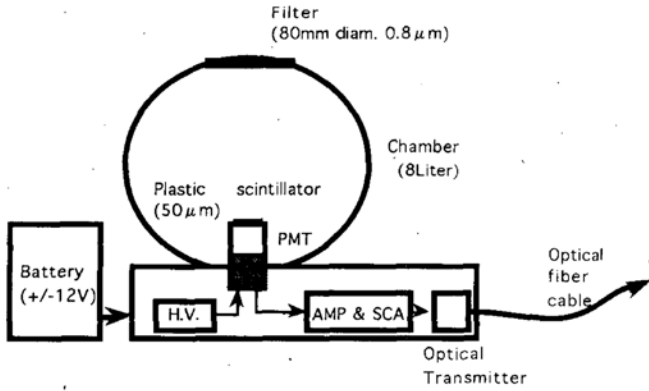
Radon-222 detection with organic scintillators



Radon-222: decay

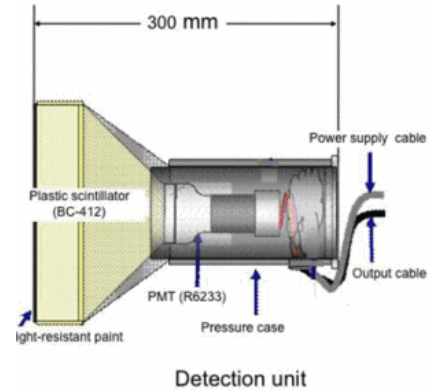


Radon-222: detection with organic scintillators

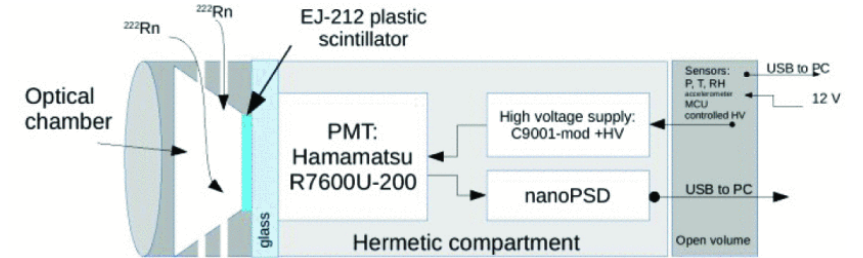


Electrostatic deposition on thin PS

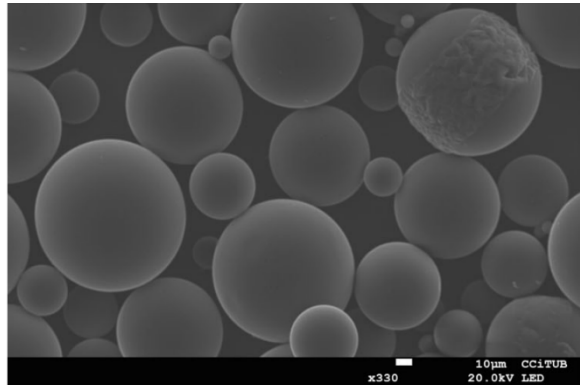
Yamamoto, S. et al., IEEE Trans. Nucl. Sci. 46, 1929 (1999)

Thin PS film for underwater ^{222}Rn measurement

Shitashima, K. et al., IEEE Sensors (2009)

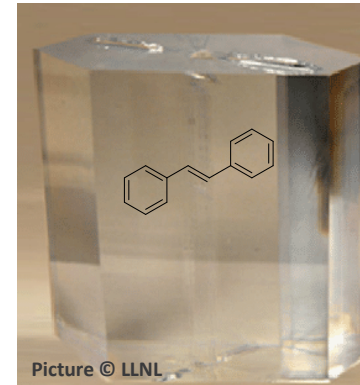
Thin PS film for ^{222}Rn continuous monitoring in soil

Mitev, K. et al., IEEE NSS/MIC Conf. Rec. (2018)



PS microspheres

Pelay, E. et al., J. Radioanal. Nucl. Chem. 314, 637 (2017)



Picture © LLNL



Picture © Eljen Technology

Trans-stilbene (left) and EJ-276 (right) scintillators

Morishita, Y. et al., Nucl. Instr. Methods A 935, 207 (2019)

Radon-222 detection with Pulse Shape Discriminating plastics



Radon-222: main issues

- Gas
 - A specific detection strategy is mandatory
- Both alpha and beta emissions
 - Low linear energy transfers
 - Necessity to separate ^{222}Rn from progenies
 - Good alpha resolution (^{222}Rn vs. ^{218}Po decays: 5590 keV vs. 6002 keV)
 - Gamma background?

Solutions

- Use of Pulse Shape Discrimination between particles showing different dE/dx
- Diffusion of the gas within the volume of a plastic scintillator

Various dE/dx imply various photophysics

- (1) Interaction of a beta
 → Excitation at the singlet state

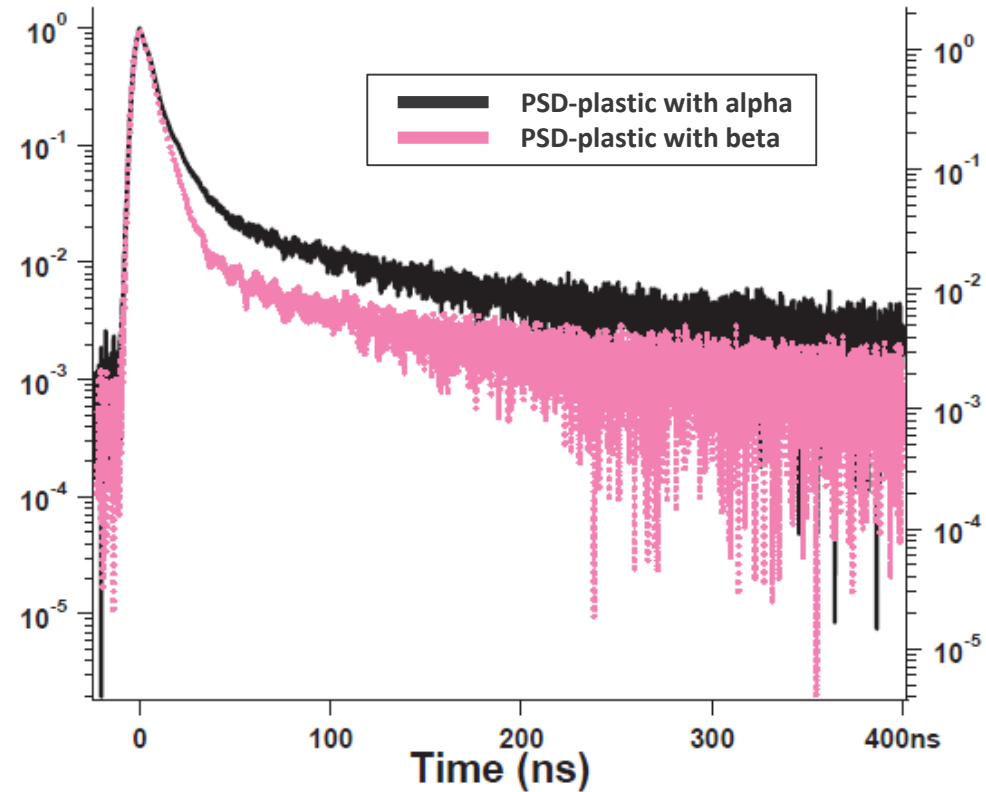


Prompt fluorescence

- (2) Interaction of an alpha
 → Excitation at the triplet state
 → Triplet-triplet annihilation



Delayed fluorescence



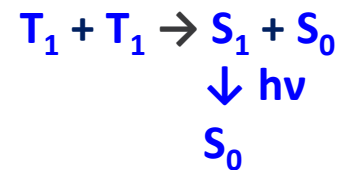
Problematic and Strategy

Hypothesis

It was assumed for a long time that plastic scintillators do not display n/γ pulse shape discrimination

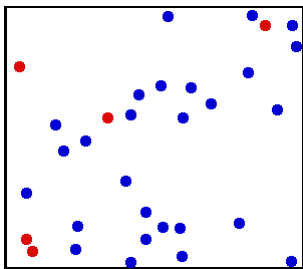
No Triplet-Triplet Annihilation (TTA) → No delayed fluorescence

→ Improvements of triplets generation



Brownian motion of molecules in liquids

Random motion of particles suspended in a fluid



- First fluorophore
- Second fluorophore

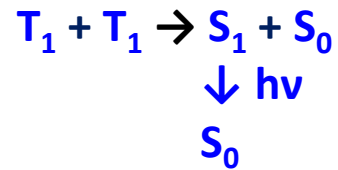


Brownian motion does not exist in plastics!

Problematic and Strategy

Hypothesis

Pulse Shape Discrimination is possible when delayed fluorescence is observable



Embed efficient n/γ discriminating systems in **composite scintillators**

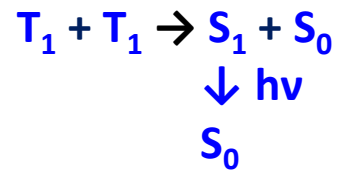
Increase of concentration of triplet states

Triplet-harvesting plastic scintillators

Problematic and Strategy

Hypothesis

Pulse Shape Discrimination is possible when delayed fluorescence is observable



Embed efficient n/γ discriminating systems in **composite scintillators**

Increase of concentration of triplet states

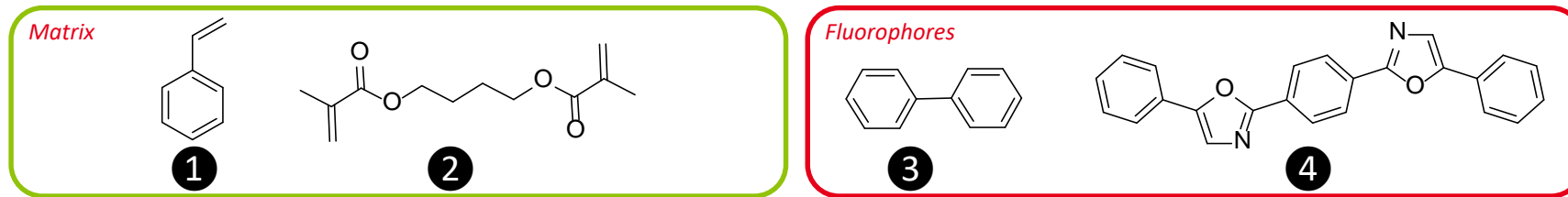
Triplet-harvesting plastic scintillators

Strategy: high concentration of primary fluorophore

Same strategy as for fast neutron/gamma discrimination which is well-documented

Primary fluorophore: biphenyl at content > 17 wt%

This high content allows triplet-triplet annihilation



- ① Styrene – main component
- ② 1,4-butanediol dimethacrylate – cross-linker agent
- ③ Biphenyl – primary fluorophore
- ④ POPOP – wavelength shifter

→ A high content of ③ grants the n/γ discrimination

→ The high concentration of ③ requires the high concentration of ② as well (mechanical properties)

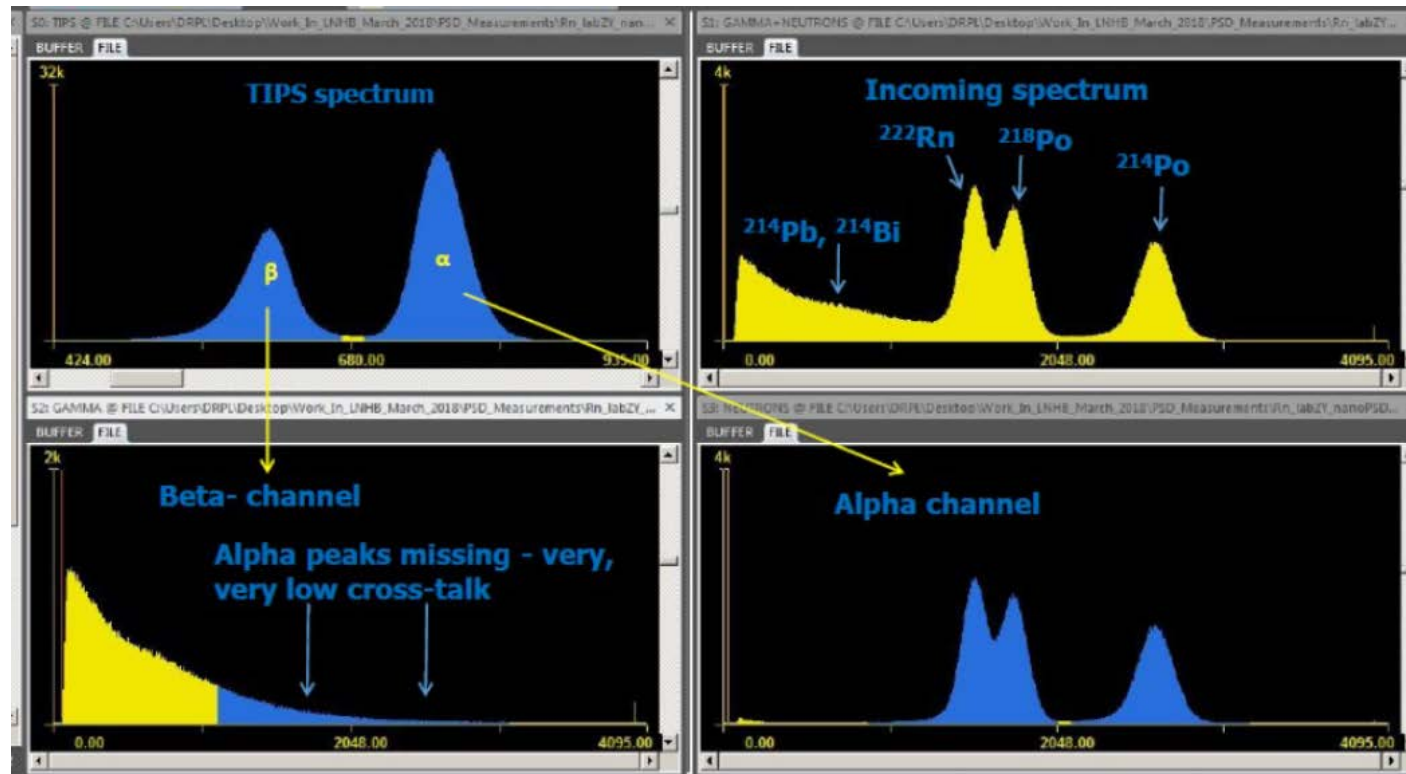
Strategy: high concentration of primary fluorophore

Same strategy as for fast neutron/gamma discrimination which is well-documented

Primary fluorophore: biphenyl at content > 17 wt%

This high content allows triplet-triplet annihilation

Fair to good isolation of ^{222}Rn against progenies

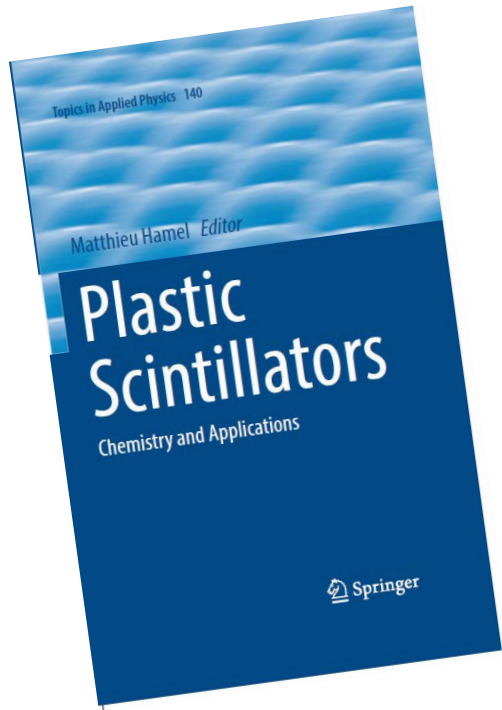


Conclusions

Following fast neutron/gamma discrimination development in plastic scintillators, analogy with alpha/beta discrimination can be performed

High quantity of biphenyl in a plastic scintillator leads to decent alpha/beta discrimination

Presentation of the results is ongoing with Dr. Mitev's talk



647 pages

15 chapters

1 appendix

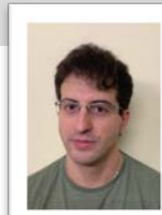
1 index

36 authors

7 countries



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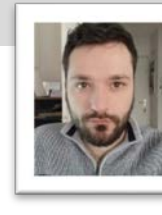
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Bertrand



Leslie
Carman



Joseph
Carlson



Pablo
Caron



Sara
Carturan



Philippe
Cassette



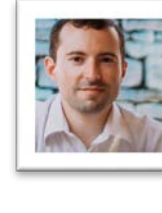
Sebastien
Celestin



Priscilla
Cushman



Christophe
Dujardin



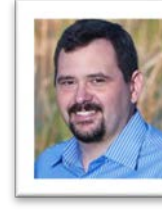
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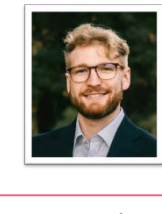
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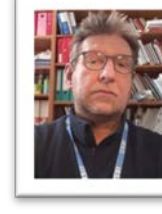
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François
Therriault-
Proulx



Mathieu
Thevenin



François
Trompier



Natalia
Zaitseva



THANK YOU!

Reviews, book and book section from our group:

Plastic scintillators: chemistry and applications, Springer-Nature, Cham, 2021.

Bertrand, G. H. V.; Hamel, M.; Sguerra, F. *Chem – Eur. J.* **2014**, *20*, 15660-15685.

Bertrand, G. H. V.; Hamel, M.; Normand, S.; Sguerra, F. *Nucl. Instr. Methods A* **2015**, *776*, 114-128.

Dumazert, J.; Coulon, R.; Lecomte, Q.; Bertrand, G. H. V.; Hamel, M. *Nucl. Instr. Methods A* **2018**, *882*, 53-68.

Hamel, M.; Carrel, F. In *New Insights on Gamma Rays*; Maghraby, A., Ed.; InTech: 2017, p 47-66.