WEIZMANN INSTITUTE OF SCIENCE

DireXeno

Directional and temporal pattern of scintillation from liquid xenon

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Experiments with liquid xenon

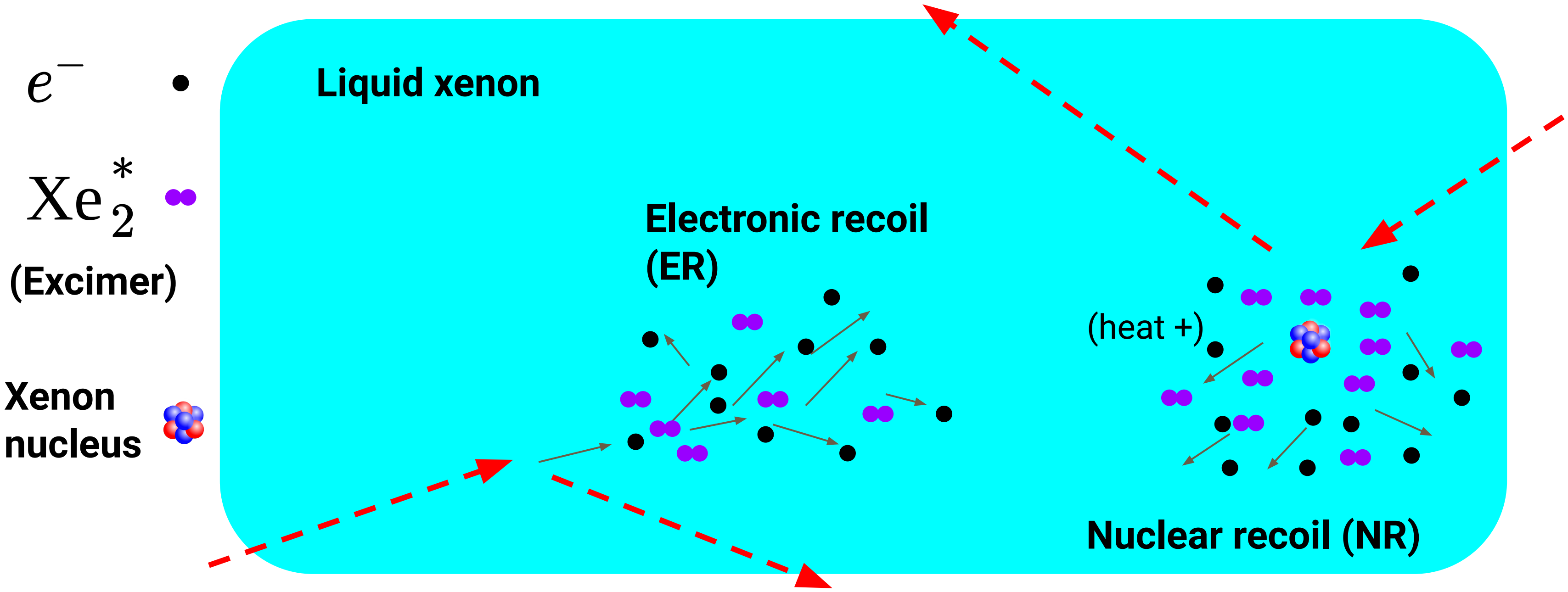
In dark matter searches:

- XENON
- LUX
- PandaX
- XMASS
- ...

In neutrino detectors:

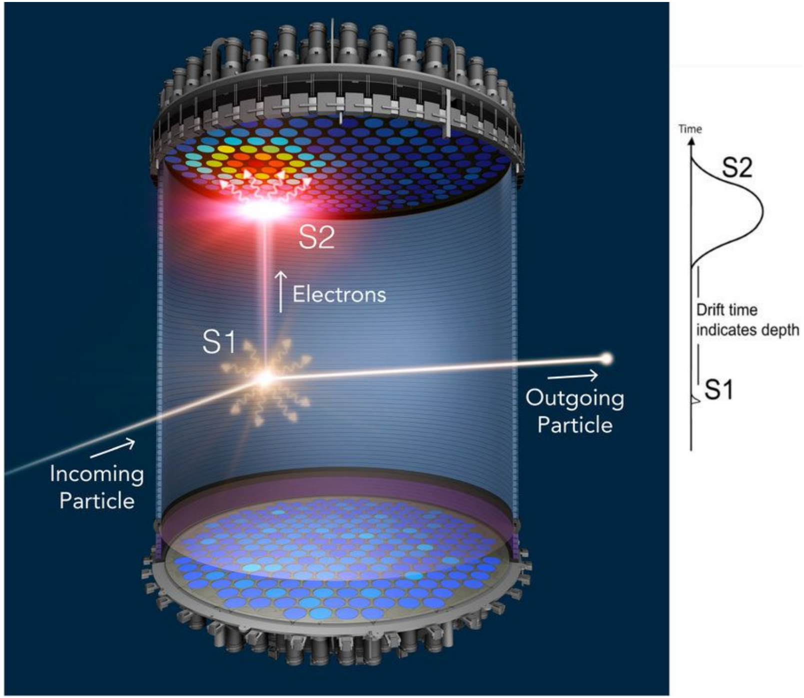
- EXO
- KamLAND-Zen
- NEXT
- ...

Interaction of a high energy particle in liquid xenon



- Recombination of electron ion pairs produce additional excimers.
- Excimers emit VUV photons when de-excite.

Discrimination between ERs and NRs



ERs: $e^{\pm}, \mu^{\pm}, \gamma \dots$

NRs: $N, \nu,$ Dark Matter (?)$\dots$

Picture from: Vitaly, Recent Results from LUX and Prospects for Dark Matter Searches with LZ.

Electronic Recoil:

Low energy transfer $\longrightarrow$ large track $\longrightarrow$ low ionization density $\longrightarrow$ easy to extract electrons from interaction cite.

Nuclear Recoil:

High energy transfer $\longrightarrow$ short track $\longrightarrow$ high ionization density $\longrightarrow$ hard to extract electrons from interaction cite.

Why do we care?

ERs: $e^{\pm}, \mu^{\pm}, \gamma \ldots$ NRs: $N, \nu,$ Dark Matter (?)$\ldots$

Bottom line

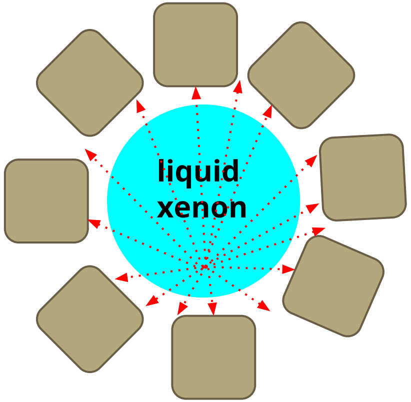
- Ionization + excitation signal ⟶ Energy of interaction.
- Ionization / excitation signal ⟶ Interaction type (ER or NR).

(Not so straight forward) Scintillation model dependent issues:

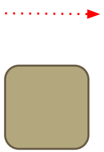
- How much energy lost for heat?
- What is ionization to excitation branching ratio? How its depends on energy and interaction type?
- How much ionized electrons recombine despite the electric field? How its depends on energy and interaction type?
- ...

Accurate Scintillation model is crucial for liquid xenon based detectors.

DireXeno (Directional Xenon)

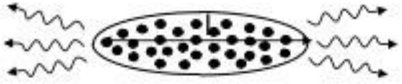


- **Objective**: studying the temporal and directional scintillation pattern from liquid xenon.
- **Method:** Estimate each photon’s time of emission and its direction.
- **Goal:** Produce an accurate scintillation model.
- **Discover:** hypothetical Superradiant emission where there is a directional correlation between the photons on a sub ns scale.



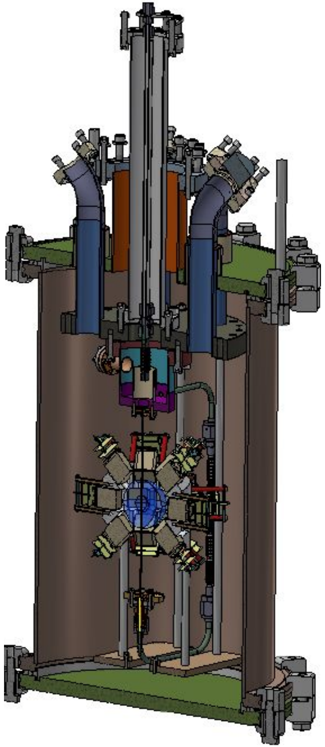
Scintillation photon

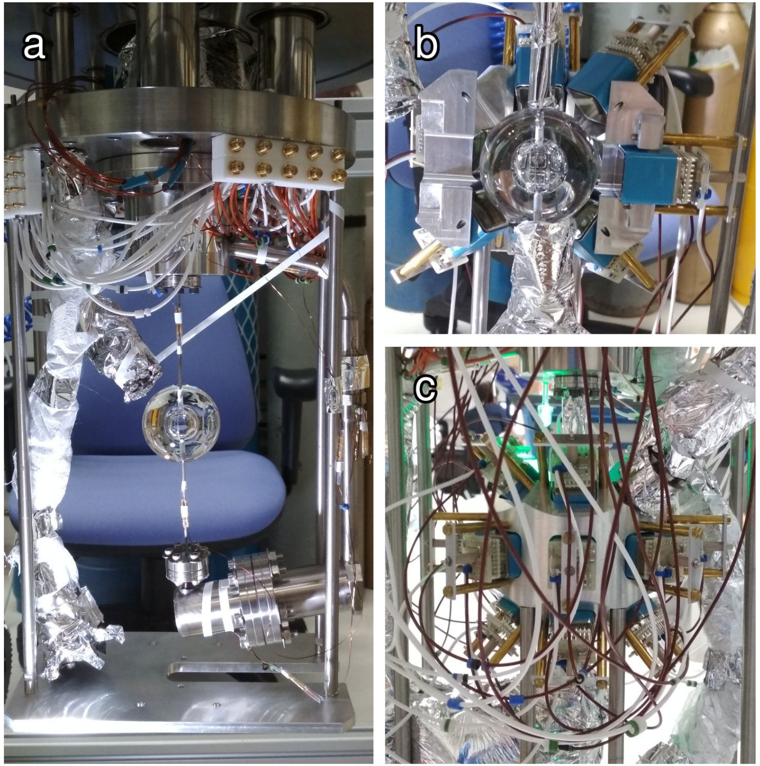
Photon detector



Superradiance, T<1ns.

DireXeno



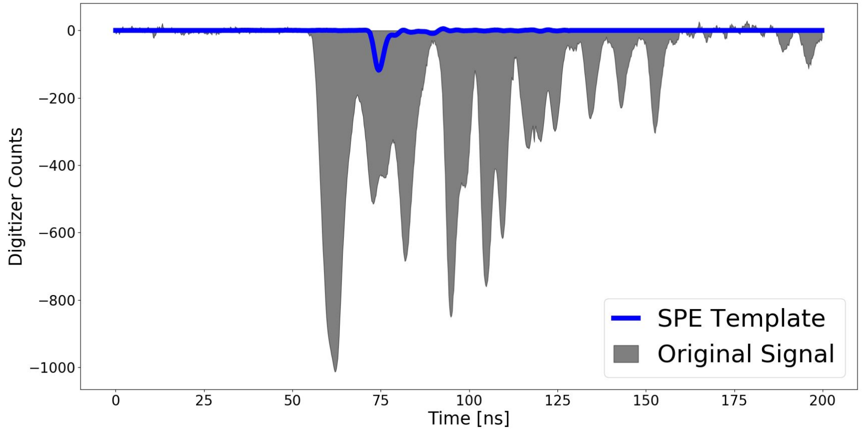


Irradiation

^{137}Cs – 662 keV γ

^{57}Co – 122 keV γ

D-D fusion source - 2.45 MeV Neutrons



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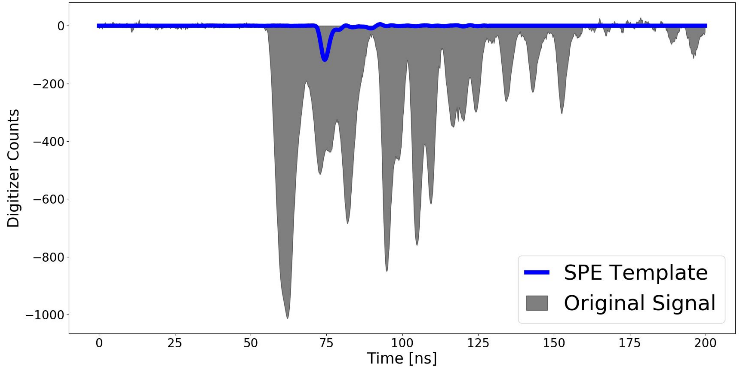
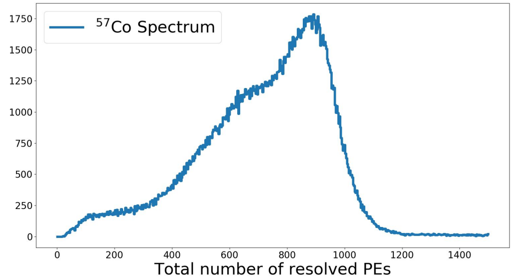
D-D fusion source - 2.45 MeV Neutrons

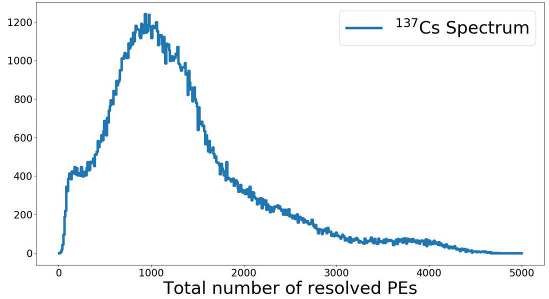


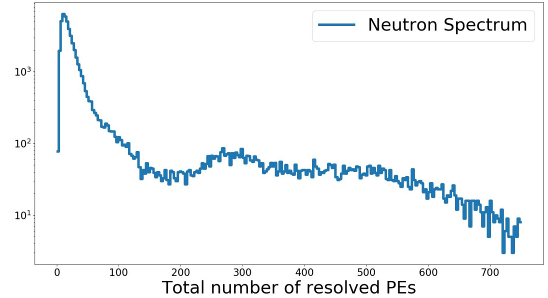
<u>Number of Photos in a signal:</u>

$$\frac{\text{Area of the signal}}{\text{Average area of a single photon}}$$

Scintillation spectra

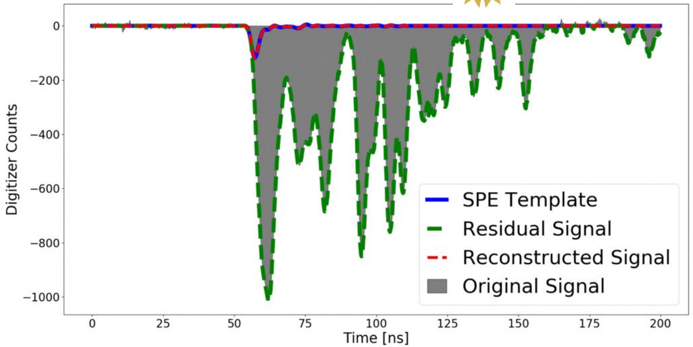


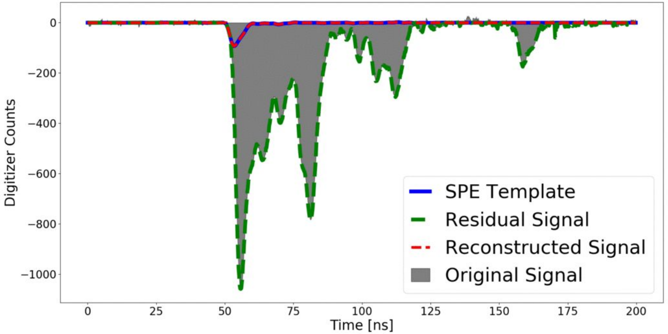


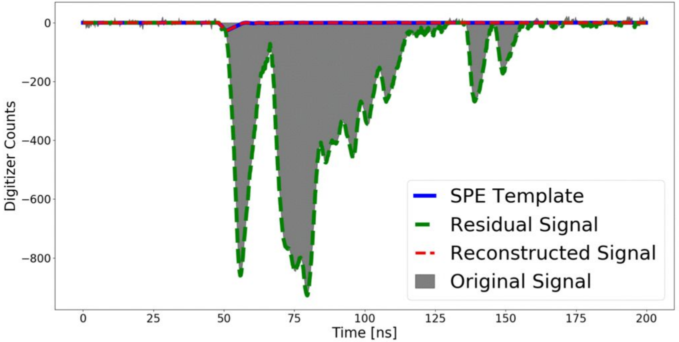


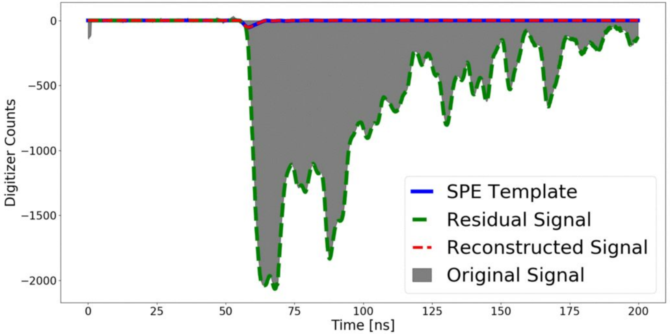
Signal reconstruction

The temporal resolution is ~1ns .

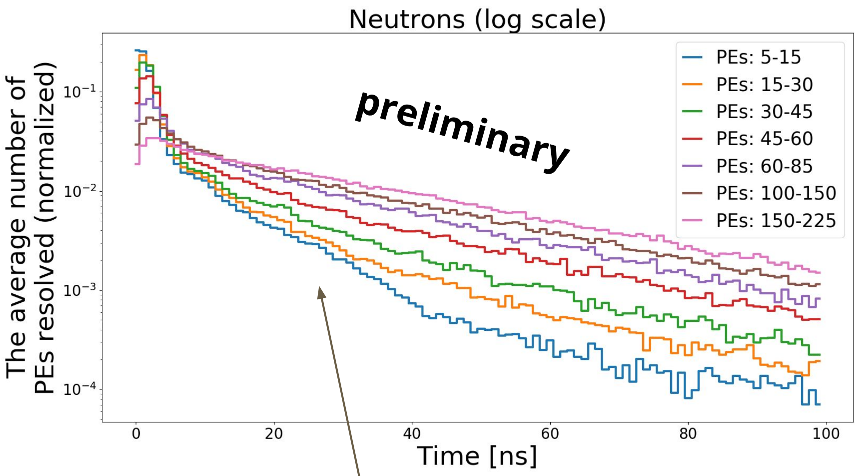


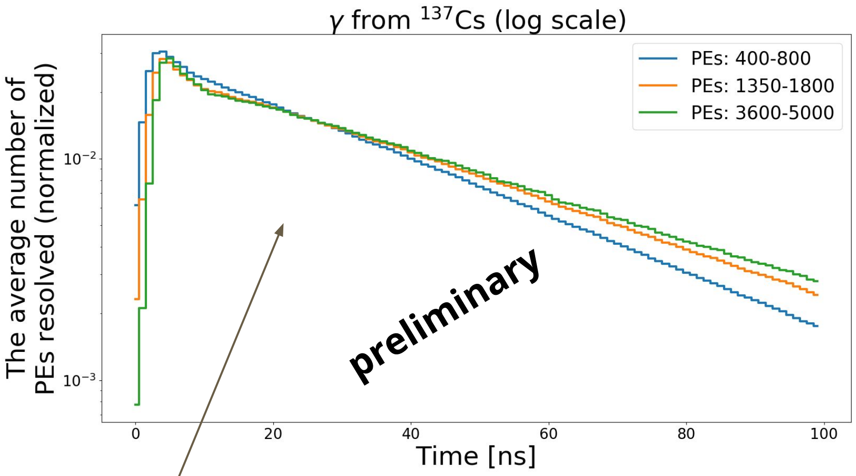






Temporal structure of scintillation





The average number of photons that were resolved at a given time

Temporal model

- Excimers may be in two states: singlet and triplet.
- The singlet decay fast ~ 2-4 ns.
- The triplet decay slow ~ 25-40 ns.

$$I_{ex}(t) = \frac{F}{\tau_{fast}} e^{-t/\tau_{fast}} + \frac{1-F}{\tau_{slow}} e^{-t/\tau_{slow}}$$

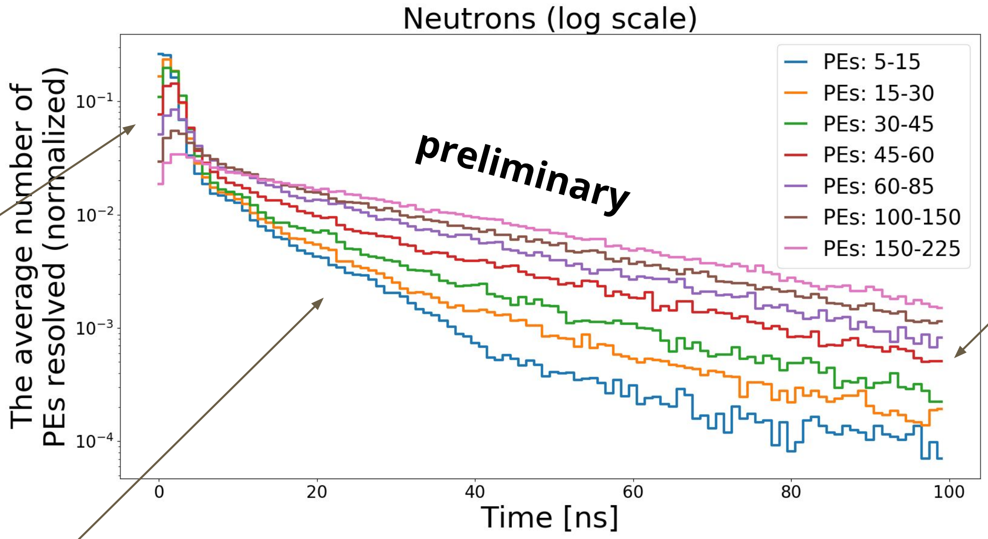
- Recombination has a characteristic time of ~ 45 ns.

Temporal pattern of recombination

$$I(t) = (1-R) I_{ex}(t) + R \int_0^t Y(\tilde{t}) I_{ex}(t-\tilde{t}) d\tilde{t}$$

Temporal structure of scintillation for NRs

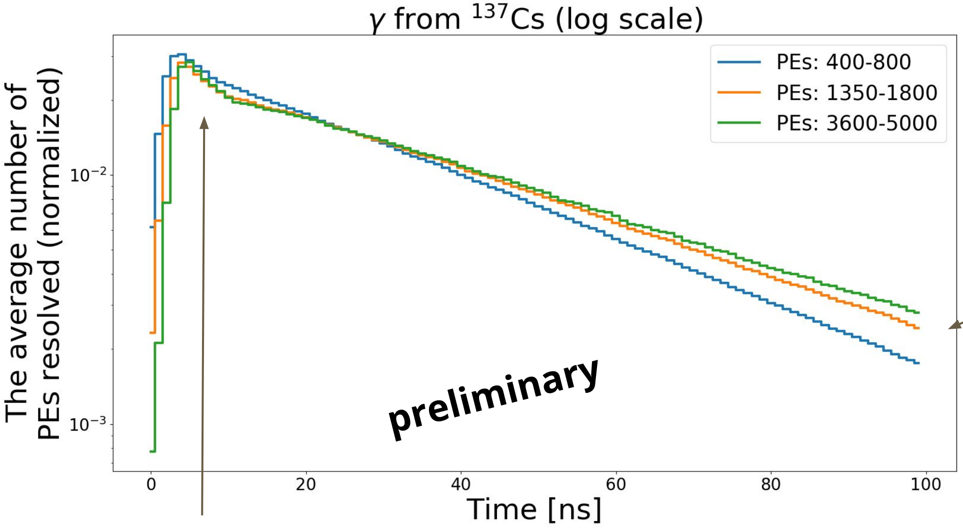
Fast component of the singlet decay. Singlet/triplet branching ratio decrease with energy.



Slow exponential component with the same slope for all energies : Dominated by the triplet decay.

Possibly a third component which is manifested only in low energies, maybe it's the recombination signal.

Temporal structure of scintillation for ERs



Large non-exponential slow component. Different temporal pattern for each energy. Probably dominated by recombination.

Singlet component.