

# Analysis of X-arapuca

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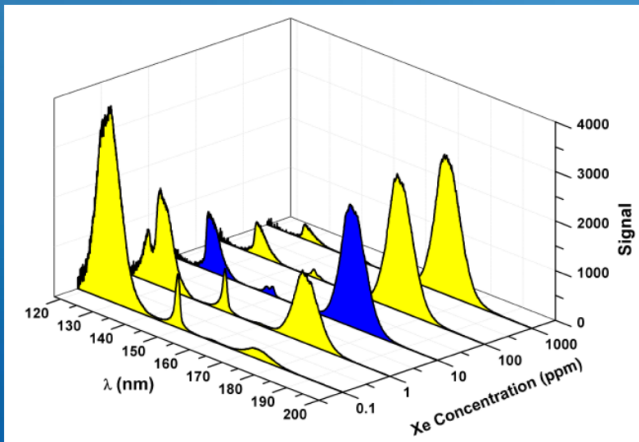
ProtoDUNE-SP

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In the following, we focus on the shifting and evolution of the LAr slow scintillation component only. We assume that the fast LAr scintillation is not affected by the N<sub>2</sub> quenching and the Xenon doping and it can anyway be treated analogously. Under these conditions, the quenching, the shifting and the scintillation processes can be described with these three equations:

## What happens in the vacuum ultraviolet:



- Cheshnovsky\_JCP
- Hofmann-EPJ-C20
- Kubota\_NIM196\_B
- Suzuki-NIM-A327
- Ulrich-Ar-Xe-mix.p



- 1 the  $\text{ArAr}^*$  excited dimer (AA) disappears by scintillation (at 128 nm), quenching through nitrogen, and shifting to  $\text{ArXe}^*$  (AX) through the process:
  - $\text{ArAr}^* + \text{Xe} \rightarrow \text{ArXe}^* + \text{Ar}$
- 2 the  $\text{ArXe}^*$  dimer is formed from  $\text{ArAr}^*$  dimer and disappears through scintillation (at 150 nm) and shifting to  $\text{XeXe}^*$  (XX) through the process
  - $\text{ArXe}^* + \text{Xe} \rightarrow \text{XeXe}^* + \text{Ar}$
- 3 the  $\text{XeXe}^*$  dimer is formed from the  $\text{ArXe}^*$  dimer and disappears through scintillation (at 175 nm)
  - $\text{XeXe}^* \rightarrow \text{Xe} + \text{Xe}$

(arXiv:1511.07721) (arXiv:1403.0525)



$$\begin{aligned} \frac{dAA}{dt} &= -\frac{AA}{\tau_{128}} - \frac{AA}{\tau_{N2}} - \frac{AA}{\tau_{AX}} \\ &= -\frac{AA}{\tau_{TA}} \end{aligned} \quad (1)$$



$$\begin{aligned} \frac{dAX}{dt} &= +\frac{AA}{\tau_{AX}} - \frac{AX}{\tau_{150}} - \frac{AX}{\tau_{XX}} \\ &= +\frac{AA}{\tau_{AX}} - \frac{AX}{\tau_{TX}} \end{aligned} \quad (2)$$



$$\frac{dXX}{dt} = +\frac{AX}{\tau_{XX}} - \frac{XX}{\tau_{175}} \quad (3)$$

These equations can be solved analytically resulting in the following solutions.



$$A(t) = K e^{-t/\tau_{TA}} \quad (4)$$



$$AX(t) = K \tau_{TA} \frac{\tau_{TX}}{\tau_{AX}} \left( \frac{e^{-t/\tau_{TA}} - e^{-t/\tau_{TX}}}{\tau_{TA} - \tau_{TX}} \right) \quad (5)$$



$$\begin{aligned} XX(t) = K \frac{\tau_{TA}}{\tau_{XX}} \frac{\tau_{TX}}{\tau_{AX}} & \left( \frac{\tau_{175}}{\tau_{TA} - \tau_{TX}} \right) \\ & \left[ \left( \frac{\tau_{TA}}{\tau_{TA} - \tau_{175}} \right) e^{-t/\tau_{TA}} - \left( \frac{\tau_{TX}}{\tau_{TX} - \tau_{175}} \right) e^{-t/\tau_{TX}} \right. \\ & \left. - \left( \frac{\tau_{TA}}{\tau_{TA} - \tau_{175}} - \frac{\tau_{TX}}{\tau_{TX} - \tau_{175}} \right) e^{-t/\tau_{175}} \right] \quad (6) \end{aligned}$$

Where  $K^*$  is initial amount of excited dimers  $\text{ArAr}^*$  in the triplet state. Note that the extended expression for  $XX(t)$  is valid also in case of two different  $\tau_{175}$  (a fast and a slow one), with two additional coefficients to take into account the relative splitting between the two components.



If  $\tau_{175}$  is much smaller than  $\tau_{TA}$  and  $\tau_{TX}$ , it is easily seen that the expression of  $XX(t)$  can be approximately simplified as follows:

$$XX(t) = K \frac{\tau_{TA}}{\tau_{XX}} \frac{\tau_{TX}}{\tau_{AX}} \left( \frac{\tau_{175}}{\tau_{TA} - \tau_{TX}} \right) \left( e^{-t/\tau_{TA}} - e^{-t/\tau_{TX}} \right) \quad (7)$$

## scintillation

From the above expressions, we can directly derive the expected rate of scintillation for the three expected decay processes, in the assumption that  $\tau_{175}$  is much faster than the other  $\tau$ 's :

1

$$\frac{dAA}{dt}(scint) = K \frac{\tau_{TA}}{\tau_{128}} \frac{e^{-t/\tau_{TA}}}{\tau_{TA}} \quad (8)$$

2

$$\frac{dAX}{dt}(scint) = K \frac{\tau_{TA}}{\tau_{150}} \frac{\tau_{TX}}{\tau_{TAX}} \left( \frac{e^{-t/\tau_{TA}} - e^{-t/\tau_{TX}}}{\tau_{TA} - \tau_{TX}} \right) \quad (9)$$

3

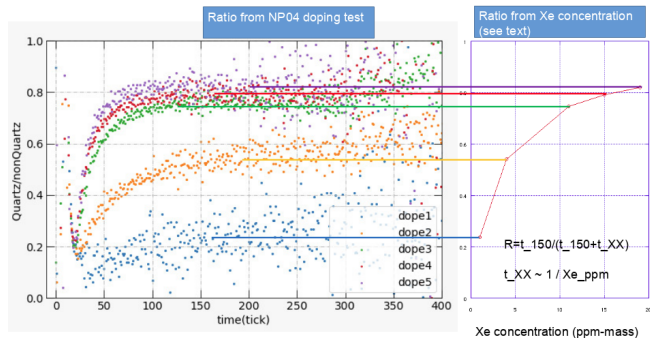
$$\frac{dXX}{dt}(scint) = K \frac{\tau_{TA}}{\tau_{XX}} \frac{\tau_{TX}}{\tau_{AX}} \left( \frac{e^{-t/\tau_{TA}} - e^{-t/\tau_{TX}}}{\tau_{TA} - \tau_{TX}} \right) \quad (10)$$



- The X-Arapuca with no Quartz window (XN) would see the sum of the three spectra. The X-Arapuca with the Quartz window (XQ) would only be sensitive to the third spectrum (the one from  $\text{XeXe}^*$ ).
- At times  $\gg 3\tau_{TA}$  the first spectrum should be negligible, hence the ratio  $\text{XQ}/\text{XN}$  should be constant and its value should be  $\frac{\tau_{150}}{\tau_{XX} + \tau_{150}}$ . For  $\tau_{XX} \ll \tau_{150}$  (higher xenon concentration) the ratio should tend to 1. The deviation from 1, at high Xenon concentration, gives the inter-calibration (ic) factor between XN and XQ.
- The following plot shows that the experimental data can actually be nicely described by the above calculation with  $\tau_{XX} \sim \tau_{150} 3/[\text{Xe ppm}]$  and  $\text{ic} = 1/0.95$ .

# inter-calibration

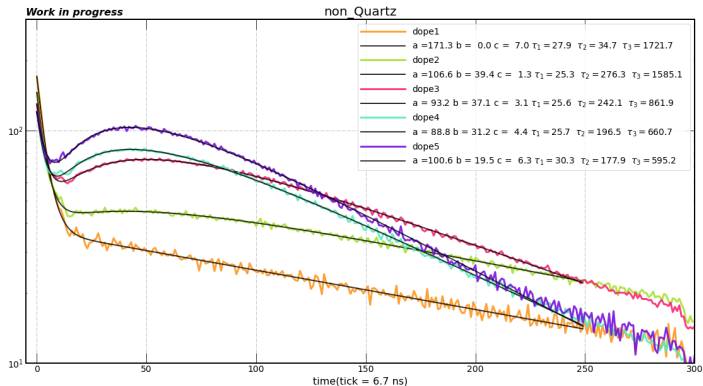
The difference  $XN - ic * XQ$  should be sensitive to the sum of the first and second spectra only. A fit to the data will allow to determine in the exponential functions.



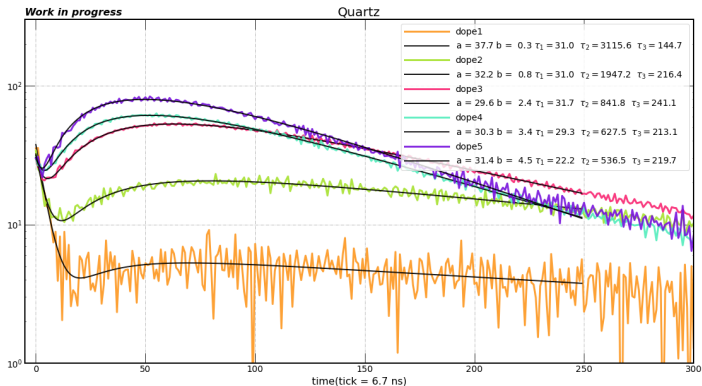
A ratio of the integrals of the first and second spectra will then be proportional to  $\frac{\tau_{128}\tau_{TX}}{\tau_{150}\tau_{AX}}$ . The  $\tau_{T150}$  can then be evaluated.

# Non Quartz

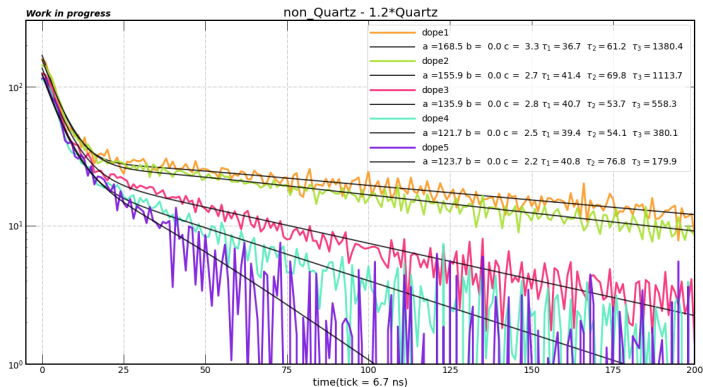
Each Run deconvoluted and averaged for each Xe injections



Each Run deconvoluted and averaged for each Xe injections



$nonQ - Q * (Icalibration)$



$Icalibration = 1.2$

end