Update on the Xe-LAr simulation for GRAIN

GRAIN WG simu-reco – 09/06/2022

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Review of known effects of Xe-doping

1. Scintillation light is shifted to 174nm
   (affects only the SLOW component, fast remains at 127nm)

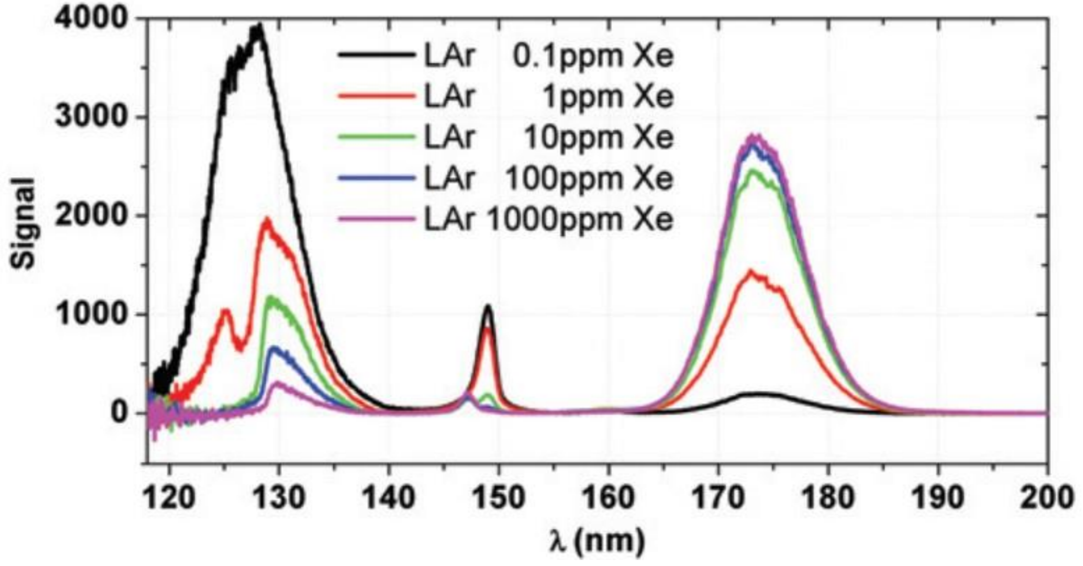
2. Fast component is reduced
   (not shifted + partially absorbed by Xe)

3. Slow component is shortened
   (shifted to 174nm, τ_S is lower at increasing Xe concentrations)

4. Globally the total light yield increases

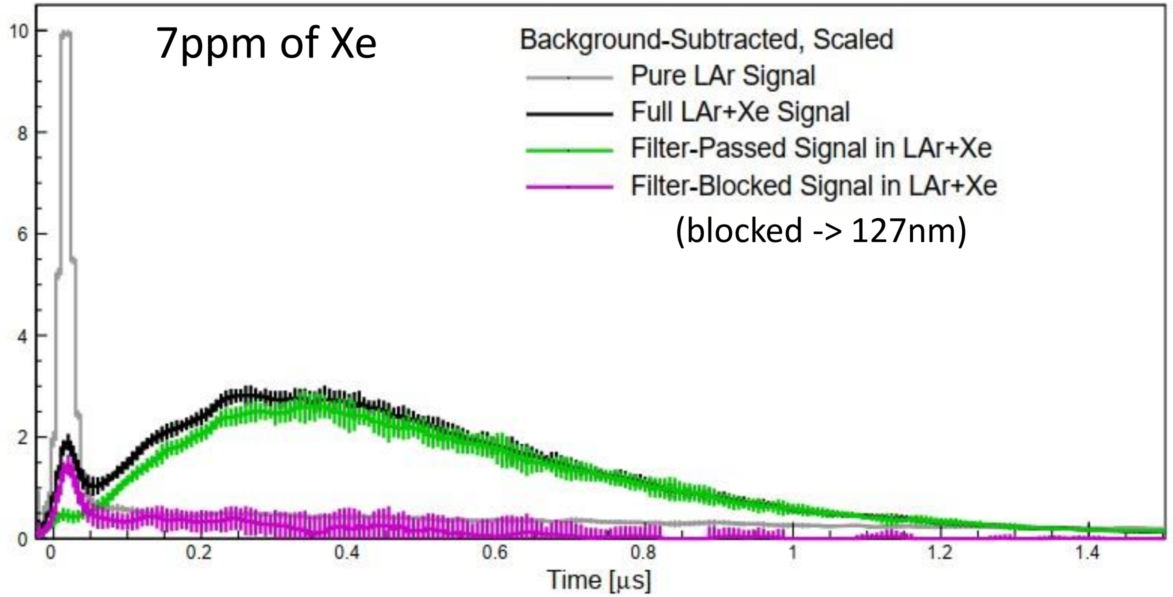
****Every source agrees on the general trends, but numbers vary a bit**

1. Shift to 174nm



Note: The spectra were corrected applying the detector response function. However, below 140 nm the spectra are overestimated by a factor of approximately two due to a systematic error in the detector response in that wavelength region.
(A. Neumeier *et al* 2015 *EPL* **109** 12001)
https://doi.org/10.1209/0295-5075/109/12001

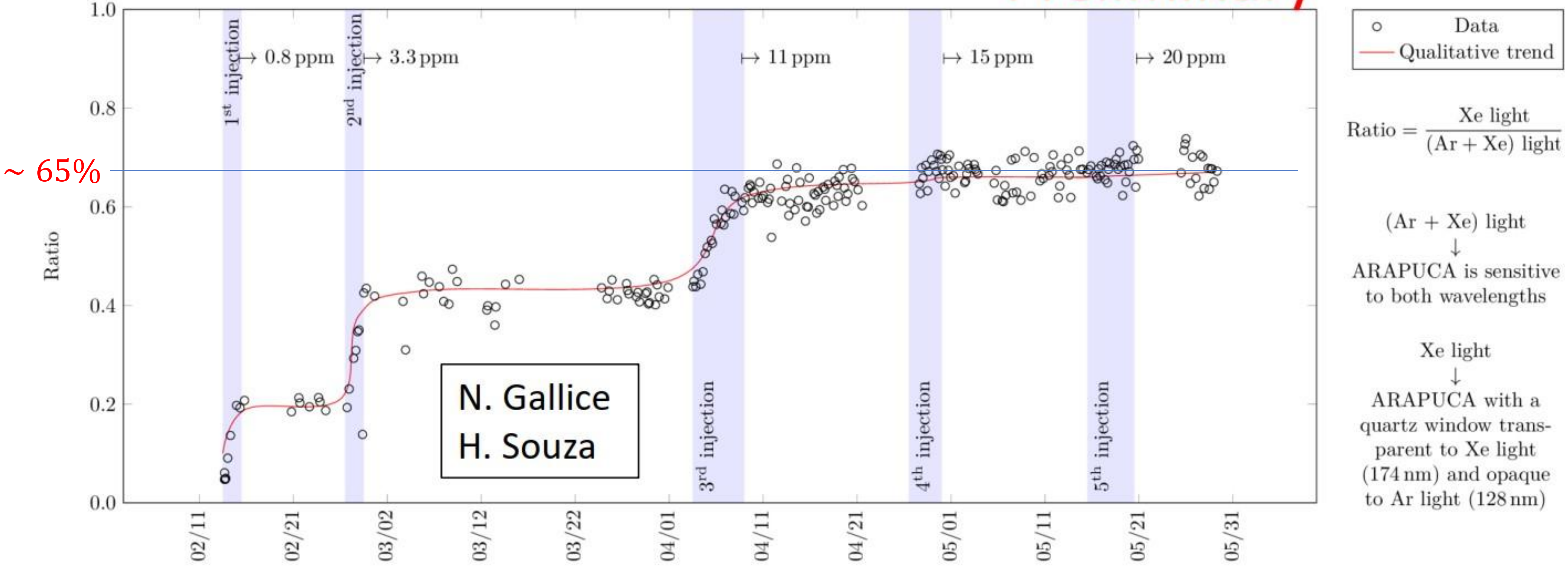
(D. Whittington, DUNE-doc-11965)



Light remaining at 127nm is the fast component only,
Only the fast component is shifted to 174nm.

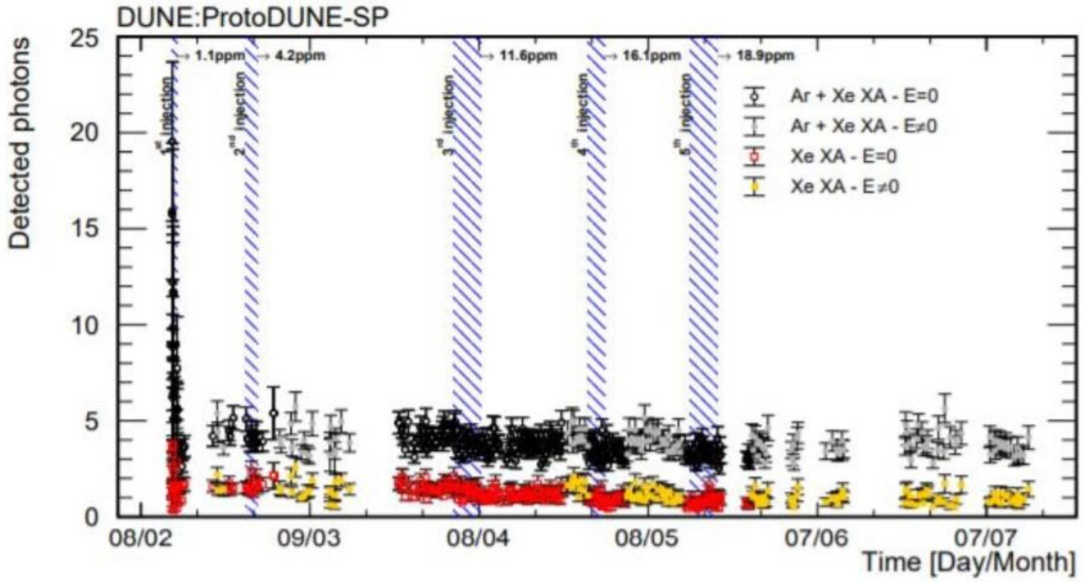
1. Transfer satures at 10ppm

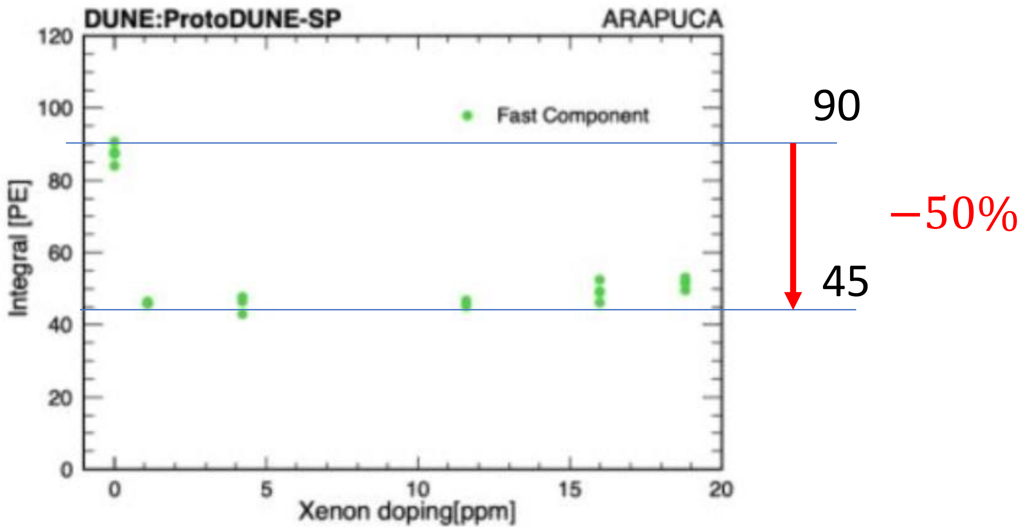
(DUNE Physics Week, June 2020: https://indico.fnal.gov/event/24397/) **Preliminary**



(we can assume all Xe light here is SLOW component)

2. Fast component is reduced

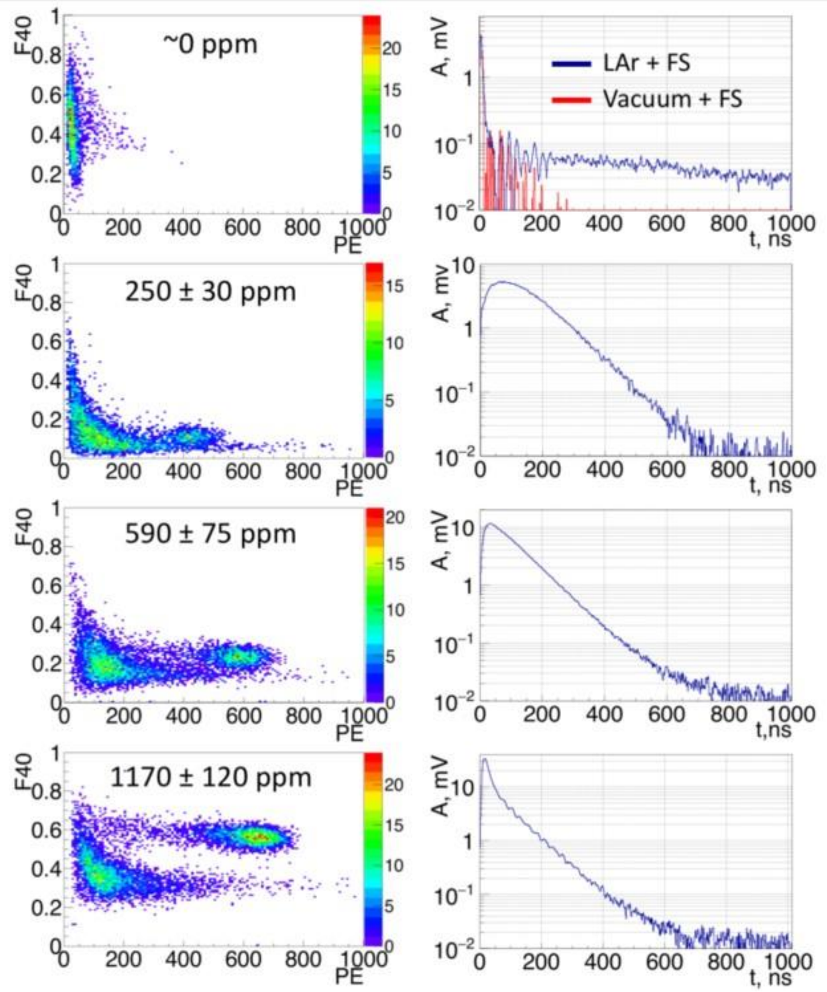




- Light emitted in the singlet (fast) component decreases significantly, already with 1.1 ppm of Xe
- Measured by X-ARAPUCAs and ARAPUCAs, but also in ProtoDUNE-DP
- Possibly due to Xe atoms absorbing Ar singlet light, already documented in literature

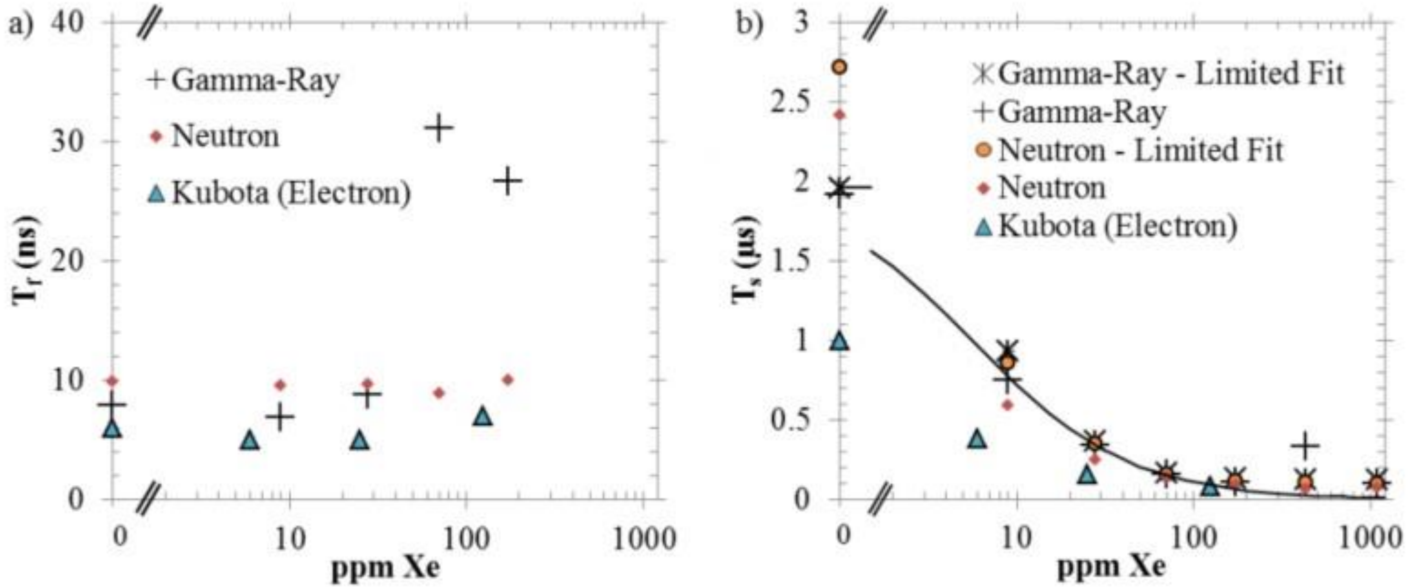
L. Bomben, DUNE-CM May 2021 - https://indico.fnal.gov/event/46503/

2. Recovering the fast component



- Pulse-shape discrimination with 174nm light → shows that the fast component is recovered at 174nm for **Xe > 1000ppm**
- D. Akimov et al. (2019) https://doi.org/10.1088/1748-0221/14/09/P09022

3. Time constants



(Wahl et al. 2014, https://doi.org/10.1088/1748-0221/9/06/P06013)

(Kubota et al. 1993, https://doi.org/10.1016/0168-9002(93)91413-H)

Decay times τ_1 and τ_2 and T_d in ns without and with an electric field of 8 kV/cm

Liquid/solid	Exciton luminescence (with $E = 8$kV/cm)			Total luminescence (without E)			reference
	τ_1	τ_2	T_d	τ_1	τ_2	T_d	
Liquid							
Pure argon	5	900		6	1000		[a]
6 ppm Xe	4	350	200	5	380	200	[a]
25 ppm Xe	3	150	160	5	160	150	[a]
125 ppm Xe	4	70	45	7	85	–	[a]
2500 ppm Xe		70	–	12	90	–	[a]
19000 ppm Xe	8	80	–	12	90	–	[a]
Pure Xe	2	27	–				[2]
Solid							
pure argon				5	1100	–	[a]
6 ppm xenon					1100	–	[a]

[a] This experiment.

4. Light yield

- Relative increase to pure Ar (+ 20%) despite known fast component suppression
- This higher light-yield before propagation (not just a consequence of higher RLS or sensor QE)
- (E. Segreto 2021, https://doi.org/10.1103/PhysRevD.103.043001)

	LAr (128nm)	Xe (175nm)
RLS (m)	1 [1]	8.3 [1]
Abs. L. (m)	20	20
Refl.	27%	27%

[1] M. Babicz et al 2020 JINST 15 P09009

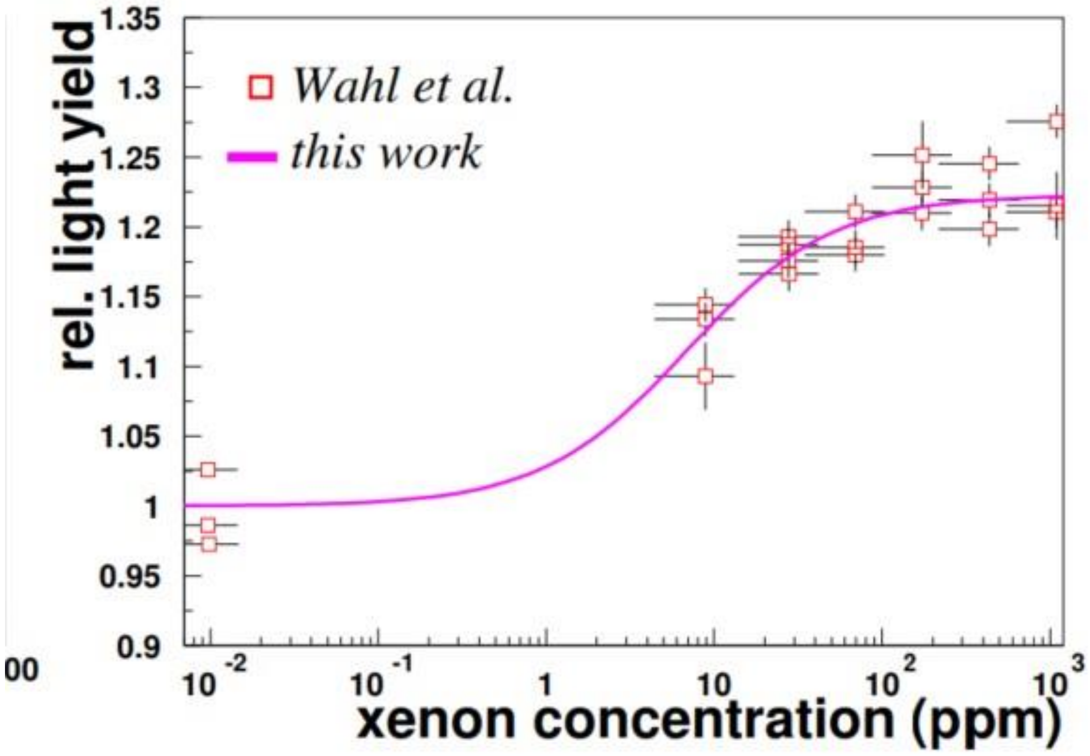


FIG. 4. Variation of the LY of LAr and xenon shifted photons as a function of the xenon concentration in pppm (mass). The experimental points at zero xenon concentration have been shifted to 10^{-2} ppm to facilitate the visualization. The model prediction is shown as a magenta line.

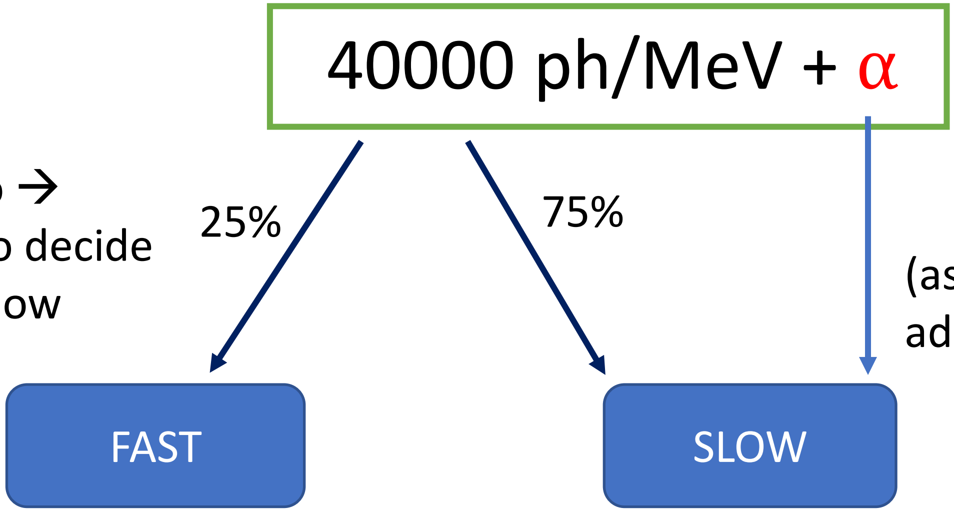
What Xe-doping do we need?

- Fast component:
  - Lost immediately (already at 1ppm).
  - It can be recovered only at very high concentrations (1000ppm), probably too expensive?
- Slow component:
  - At least 10ppm needed to saturate its conversion to 174nm
  - Higher Xe-doping → shorter τ_S: 200ns at 25ppm, 90ns at 125ppm
  - What time constant do we need? It depends on the time window we will have, which depends on the expected background.

25ppm implementation

α chosen so that the effective LY at the end is **1.2*LY in pure Lar** (from Wahl et al.)

Singlet-triplet ratio → same as pure LAr to decide how much is fast/slow



(assume this addition is all slow)

Xe-doping: 25-30ppm

- Keep τ_F as pure LAr (5-6ns)
- Keep at 127nm (gaussian pdf)
- Apply a 50% cut

(from ProtoDUNE-SP)

- Generate 90% at 174nm, 10% at 127nm, summing two gaussian pdfs.

(close to saturation, having Xe > 10ppm)

- Use $\tau_S = 200ns$ at 25ppm

(from Kubota et al.)

Comments

- Increase in LY is uncertain → difficult to correctly estimate it in complex setups.
  - Keep pure LAr LY to be conservative
- Fast component reduction is doubtful: protoDUNE had issues with purity which may strongly affect the fast component.
  - →investigate what to do
- High concentrations can be bad for physics (different nucleus, different cross-section), but are not too expensive + Xe is very soluble.
  - → investigate higher limit from Physics