Fast component in Xe-doped LAr

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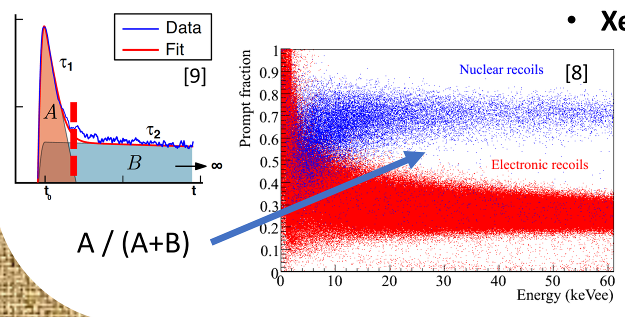
Motivation

LAr as a scintillator

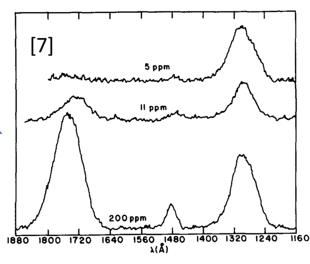
- Easy to clean
- Cheap
- Relatively high density
- Detector scaling possibility
- Two scintillation components Fast (τ_1) 7 ± 1 ns Slow (τ_2) 1600 ± 100 ns
- Pulse shape discrimination (PSD) ability



A / (A+B)

Problems

- There is no photodetectors with large photocathod sensitive to LAr scintillation (λ = 128 nm)
- Hard to make effective wall-reflector
- One have to use wavelength shifters (WLS)
  - Tetraphenyl butadiene (TPB)
  - Other film WLS
  - **Xe-dopant** (λ = 175 nm)



TPB problems:

1. Light reabsorption
2. Bad holding
3. Degradation under UV light
4. Non-uniformity of covering
5. 4π-reemission

Advantages of Xe-dopant:

1. Volume distributed WLS
2. Clean
3. No additional structure inside the detector
4. No degradation
5. No reabsorption of emitted light

- **Does Xe-dopant reemit fast component?**
- **PSD analysis effectiveness?**
- **Mixture stability?**

Previous studies

	Эксп.	Теор.	S	F	PSD_{low}	PSD_{high}	IR	Long continuous run
[1]	✓	✓(*)	+	–	✗	✗	✗	✗
[2]	✓	✓(**)	+	±	–	+(?)	✗	✗
[3]	✓	✗	+	–	–	+(?)	✗	✗
[4]	✓	✗	+	–	–	✗	✓	✓(***)
[5],[6]	✗	✓	+	+	✗	✗	✗	✗

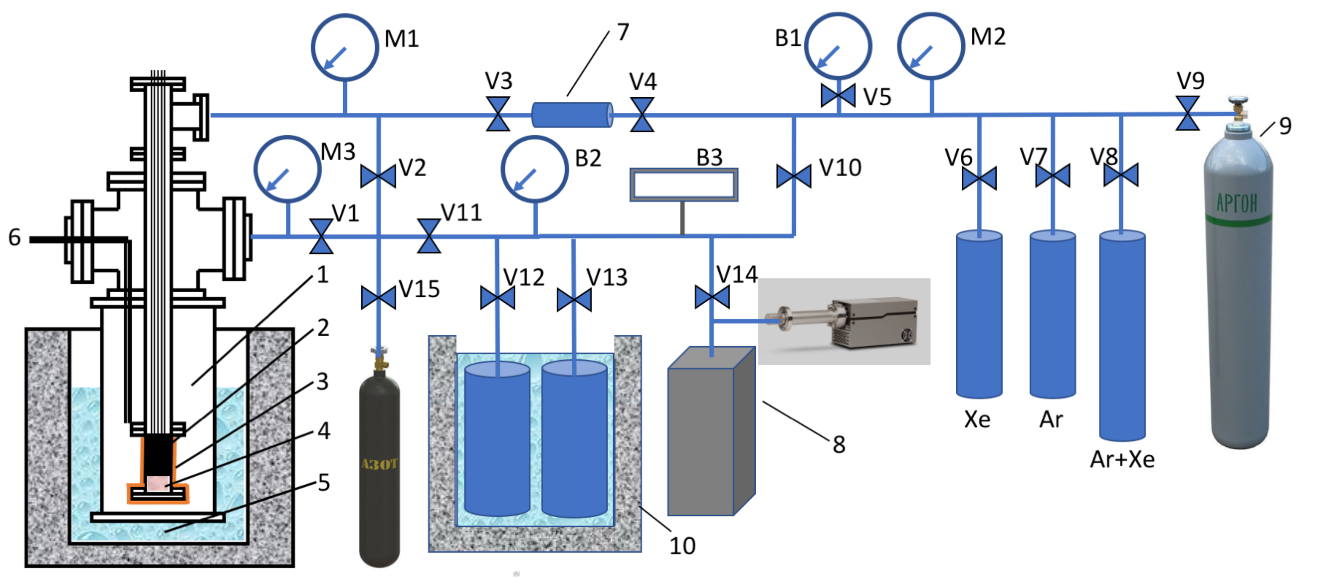
(*) $Ar_2^* + Xe$ + migration → $(ArXe)^* + Ar$
$(ArXe)^* + Xe$ + migration → $Xe_2^* + Ar$

(**) $I = A_f e^{-\frac{t}{T_f}} + A_s e^{-\frac{t}{T_s}} - A_d e^{-\frac{t}{T_d}}$

(***) Shown in Summer 2018

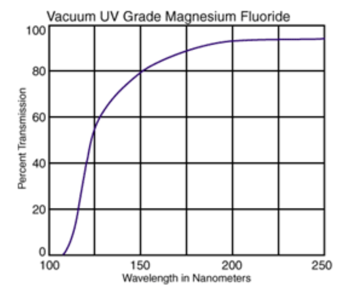
There was no experimental confirmation of fast component reemission in Xe-doped LAr before

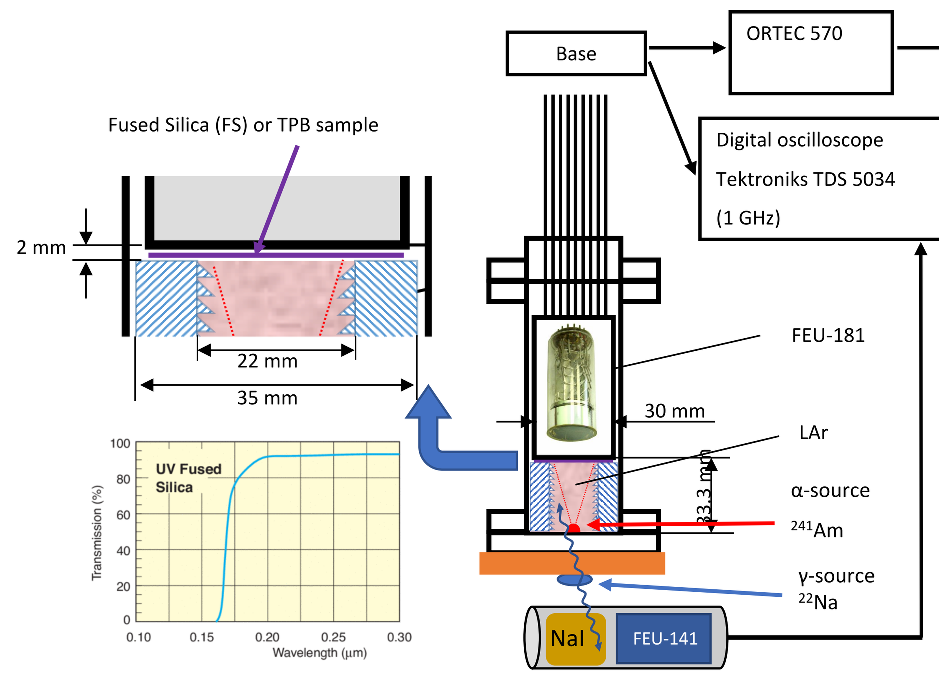
LAr test chamber: gas system



1 – vacuum vessel, 2 – PMT, 3 – copper housing, 4 – LAr volume, 5 – LN_2 bath, 6 – heater & termocontrol, 7 – gas filter Mycrolys, 8 – magnetoelectrical pump Nord & RGA, 9 – Ar (purity 99,9995%), 10 – cryogenic pump; B1– B3 – vacuummeters; M1 – M3 – manometers; V1– V15 – valve.

LAr test chamber

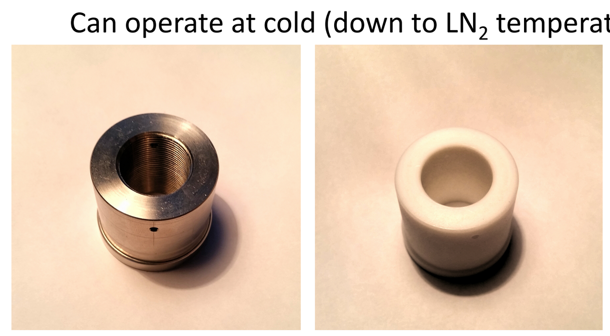




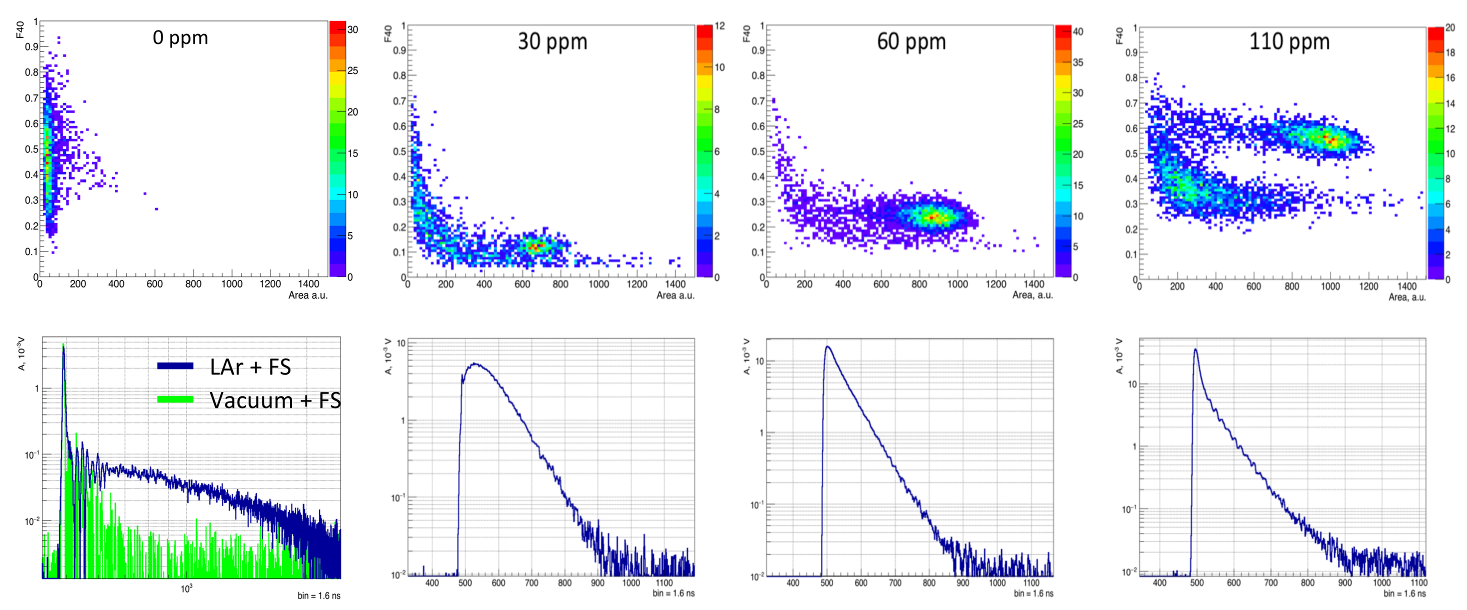
PMT FEU-181 (MELZ, Moscow)

VUV sensitive: MgF_2 window multialkali photocathod

Can operate at cold (down to LN_2 temperature)



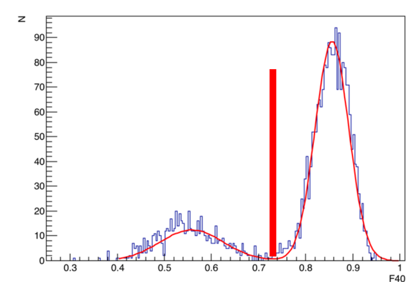
PSD plots and averaged WF with increasing of Xe concentration



At the concentration of 60 ppm (by mol) Xe in LAr one can see the beginning of the process of fast component reemission by Xe.

PSD quality and mixture stability

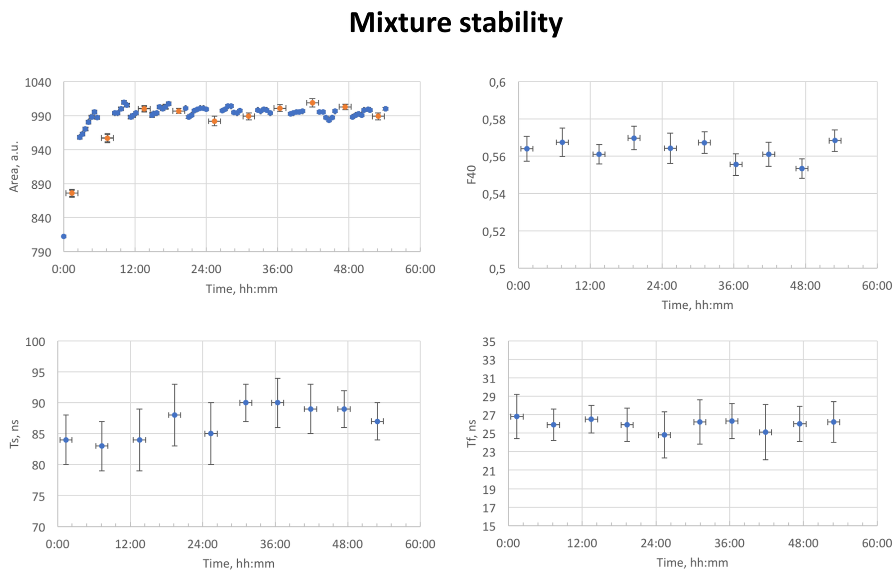
PSD quality Q_{PSD}(%) = part of α-particles obtained after cut by F40-parameter, γ-background reduced by factor of 1000.



Test chamber configuration	Xe, ppm	Q_{PSD} %
Black walls; no samples (Direct light registration)	1 ± 1	99.9 ± 0.4
Black walls, TPB	1 ± 1	87.3 ± 0.7
Black walls, TPB	30 ± 5*	87.2 ± 0.9
Teflon walls, TPB	1 ± 1	60 ± 2
Teflon walls, FS	110 ± 32	100.0 ± 0.3

(*) Up to 30 ppm Xe Q_{PSD} is lower then for pure LAr with TPB.
It is consistent with previous experiments [2-4].

Mixture stability



Lower P, T at the beginning of long run => PMT parameters may vary.
F40, T_f, T_s don't depend on PMT parameters.
Mixture is stable.

Averaged WF analysis

- Up to 60 ppm Xe by mol one can use 3-terms fitting model proposed by C.G. Wahl et al [2]

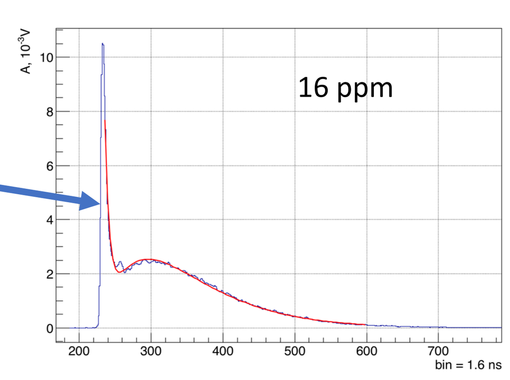
$$I = A_f e^{-\frac{t}{T_f}} + A_s e^{-\frac{t}{T_s}} - A_d e^{-\frac{t}{T_d}}$$

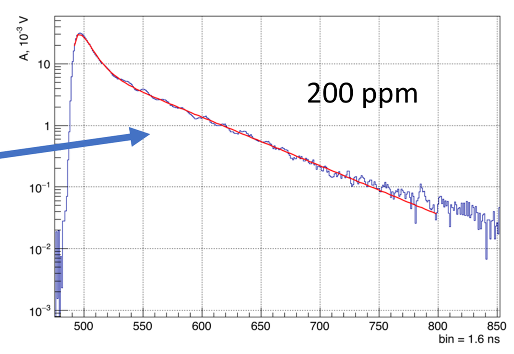
T_f, T_s – decay times for the fast and slow component correspondently, T_d – transfer time (the same parameter for the fast and slow component according C.G. Wahl et al)

- According to A. Hitachi [5]:
  - Transferring constant for the fast component in 3 times larger then for the slow component
  - Transfer mechanism for the fast component start working at big concentrations of Xe (200 ppm by mass)
- In this case light emission function should consist of 4 terms:

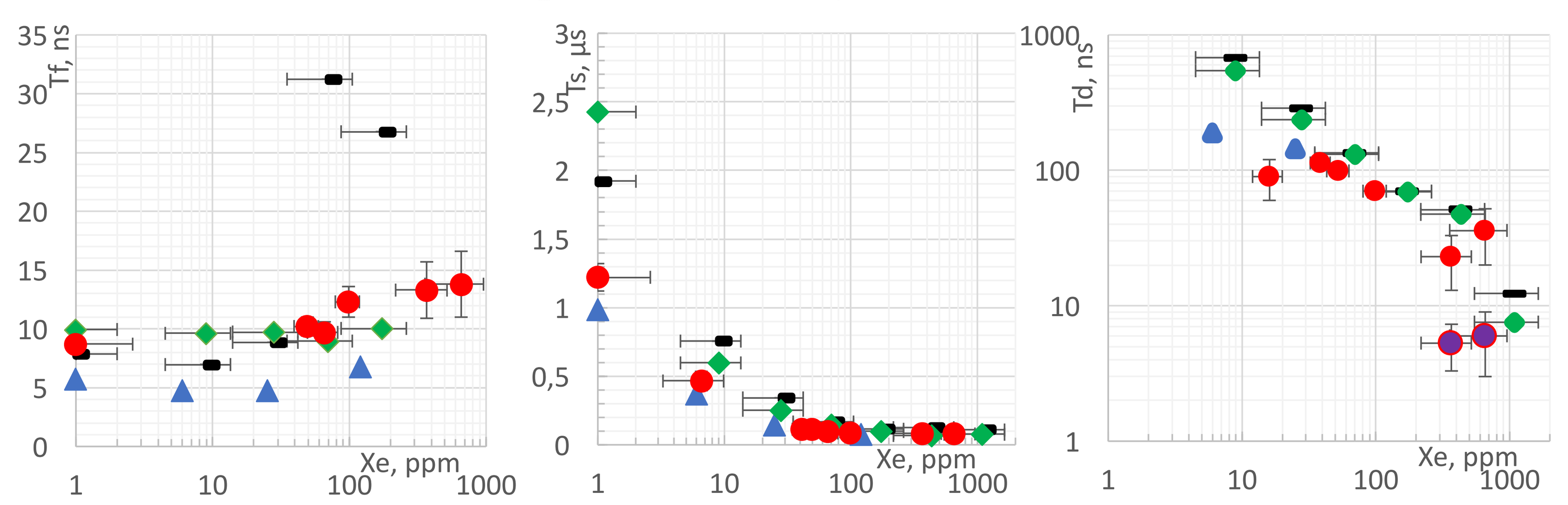
$$I = A_f e^{-\frac{t}{T_f}} + A_s e^{-\frac{t}{T_s}} - A_{df} e^{-\frac{t}{T_{df}}} - A_{ds} e^{-\frac{t}{T_{ds}}}$$

T_{df}, T_{ds} – transfer time for the fast and slow components correspondently





Averaged WF time parameters



- Kubota (electrons)
- Wahl (neutrons)
- Wahl (gamma)
- This work (alpha)
- This work (alpha, T_{df})

- First experimental measurement of interaction constant for the fast component : **k_f = (4.5 ± 2.9) × 10^{-11} см^{3}с$^{-1}$**
- Theoretical prediction (A. Hitachi [5]): **k_f = 3.3 × 10^{-11} см^{3}с$^{-1}$**

Conclusion

- We confirmed experimentally for the first time that the fast component is reemitted by high concentration of Xe-dopant
- Mixture stability was shown
- First experimental measurement of the transfer constant k_f was done
- PSD quality was shown to be better then for the pure LAr with TPB WLS

- Thus Xe-dopant with concentration of 200 ppm by mol can be used as the only one WLS in LAr detector

References

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[3] P. Peiffer et al *Pulse shape analysis of scintillation signals from pure and xenon-doped liquid argon for radioactive background identification* JINST (2008) 3

[4] A. Neumeir et al *Intense vacuum ultraviolet and infrared scintillation of liquid Ar-Xe mixtures* EPL (2015) 109

[5] A. Hitachi *Photon-mediated and collisional processes in liquid rare gases* NIM (1993) 327

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