Light production in liquid and gaseous argon

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LIDINE2022: Light Detection in Noble Elements
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Introduction

It is known that noble elements, when excited by ionizing radiation, emit light not only in the vacuum ultraviolet (VUV) region but also at longer wavelengths, up to the near-infrared (NIR)

Several studies have been published but questions remain on the nature of this scintillation (origin, light yield, spectral and time structure)

Dedicated experiments have been performed at Fermilab in the past

Study of visible-light emission in pure and methane-doped liquid argon

A. Bondar[1,2], E. Borisova[1,2], A. Buzulutskov[1,2], E. Frolov[1,2], V. Nosov[1,2], V. Oleynikov[1,2] and A. Sokolov[1,2]

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Journal of Instrumentation, Volume 17, September 2022

Citation A. Bondar *et al* 2022 *JINST* 17 P09009

Compilation of the results on light emission in liquid Ar in the visible and NIR range

Reference	Excitation source	Electric field (kV/cm)	Spectrum range (nm)	Light yield in visible and NIR range (photon/MeV)	Comments
Heindl 2010 Heindl 2011	12 keV e^-	0	300-1000	Observed	Spectrum measured
Buzulutskov 2011 Bondar 2012	25 keV X-rays	0-30	400-1000	510 ± 90	Field independent
Neumeier 2014 Neumeier 2015	12 keV e^-	0	500-1000	Not observed Observed in NIR	
Alexander 2016	511 keV γ-rays	0	715-900	Observed	τ_f <100 ns $\tau_s \approx 2-4\ \mu s$ Field independent
Auger 2016	HV breakdown	≤200	400-800	Observed	Spectrum measured
Bondar 2022	25 keV X-rays	0-0.62	400-1000	200 ± 50	τ_f <100 ns $\tau_s = 1 \pm 0.3\ \mu s$
Jones 2013	5.3 MeV α	0	300-650	Not observed	<10 ph./MeV
Hofmann 2013	0 MeV protons	0	300-1000	Observed	Spectrum measured
Escobar 2018	5.4 MeV α	0	715-900	Observed	
Bondar 2022	5.5 MeV α	0.3-0.62	400-1000	92 ± 23	τ_f <100 ns No slow comp. Field independent

Near-infrared scintillation of liquid argon: recent results obtained with the NIR facility at Fermilab

C. O. Escobar[1], P. Rubinov[1] and E. Tilly[2]

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Journal of Instrumentation, Volume 13, March 2018

Light Detection in Noble Elements (LIDINE2017)

Citation C. O. Escobar *et al* 2018 *JINST* 13 C03031

Introduction

While there is a large amount of data and theoretical understanding of the scintillation process in liquid argon, much less is known about the scintillation in cold gaseous phase

Molecular densities in low pressure gas phase are three orders of magnitudes lower than in liquid, hence the scintillation dynamics can be very different. Studies of gas scintillation may help with the better understanding of liquid emission, in particular in different spectral ranges

Existing studies by groups of researchers:
Ulrich, Heindl, Neumeier, Bressi, Borghesani, Lindblom, Santorelli…

Our motivation for the performed studies is that there is very little experimental information about the scintillation in low temperature argon gas

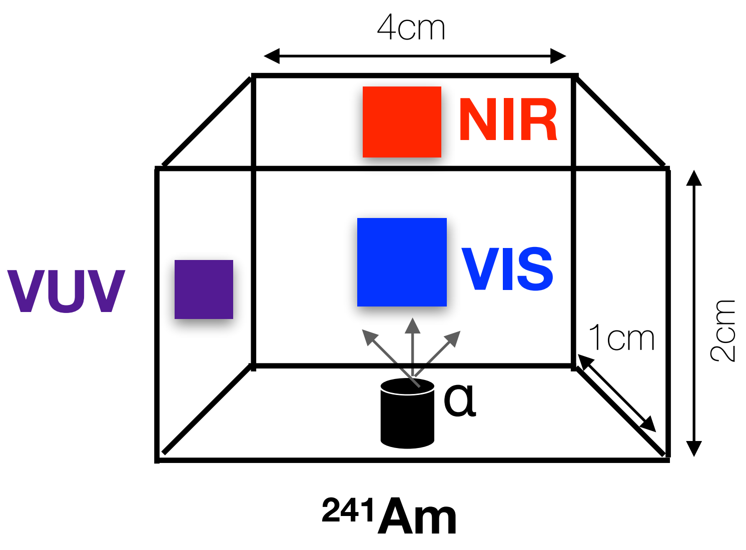
Scintillation light produced by energy depositions in the gas ullage volume above the liquid levels may be relevant in various experimental situations

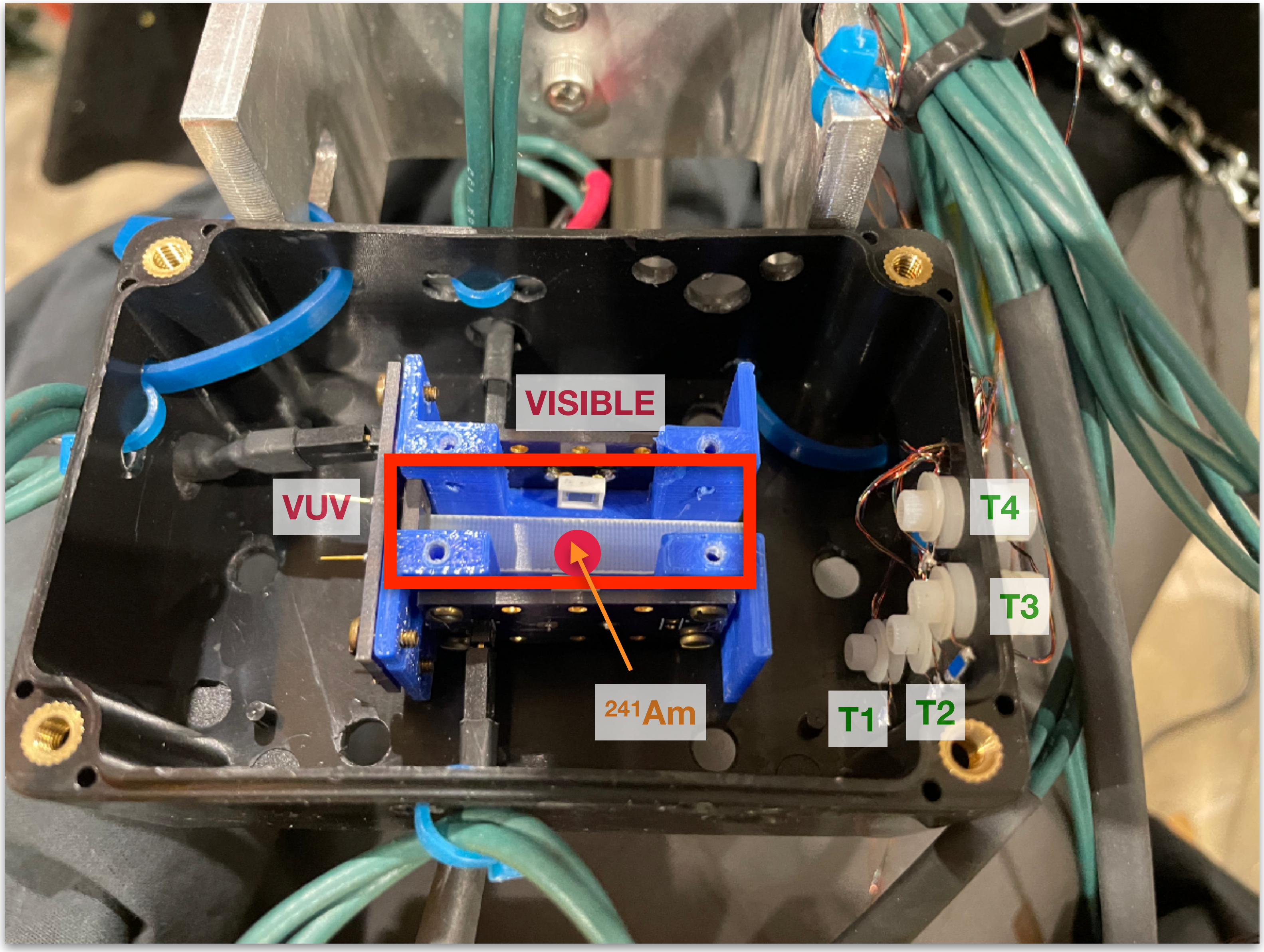
Current experimental setup consists of an ^{241}Am α-source and three SiPMs with different spectral sensitivities from VUV to NIR

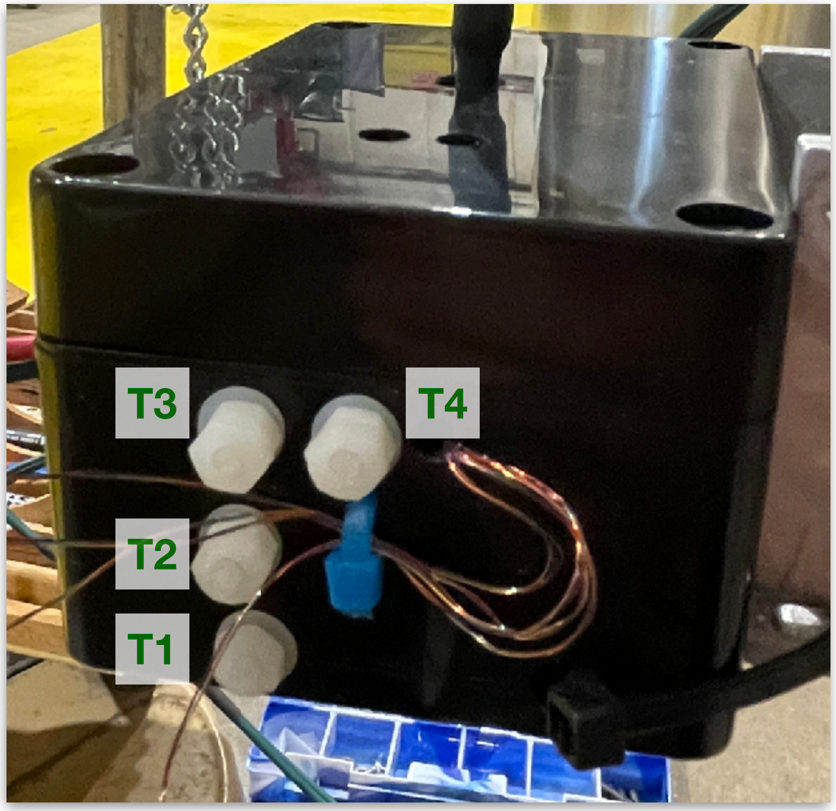
Experimental setup

An ^{241}Am α-source (0.1μCi) is installed in a small box, with three photosensors with different spectral sensitivity: near-infrared – top, vacuum ultraviolet and visible on the sides
Sensors have different dimensions and solid angle coverage

Instrumentation with four temperature probes (Pt-100):
- one at the height of the source
- one at the height of the lateral SiPMs
- two redundant above the height of the active volume



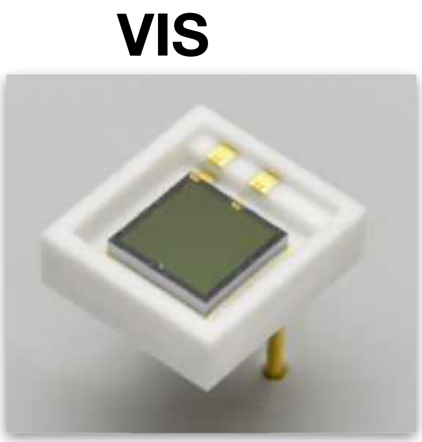


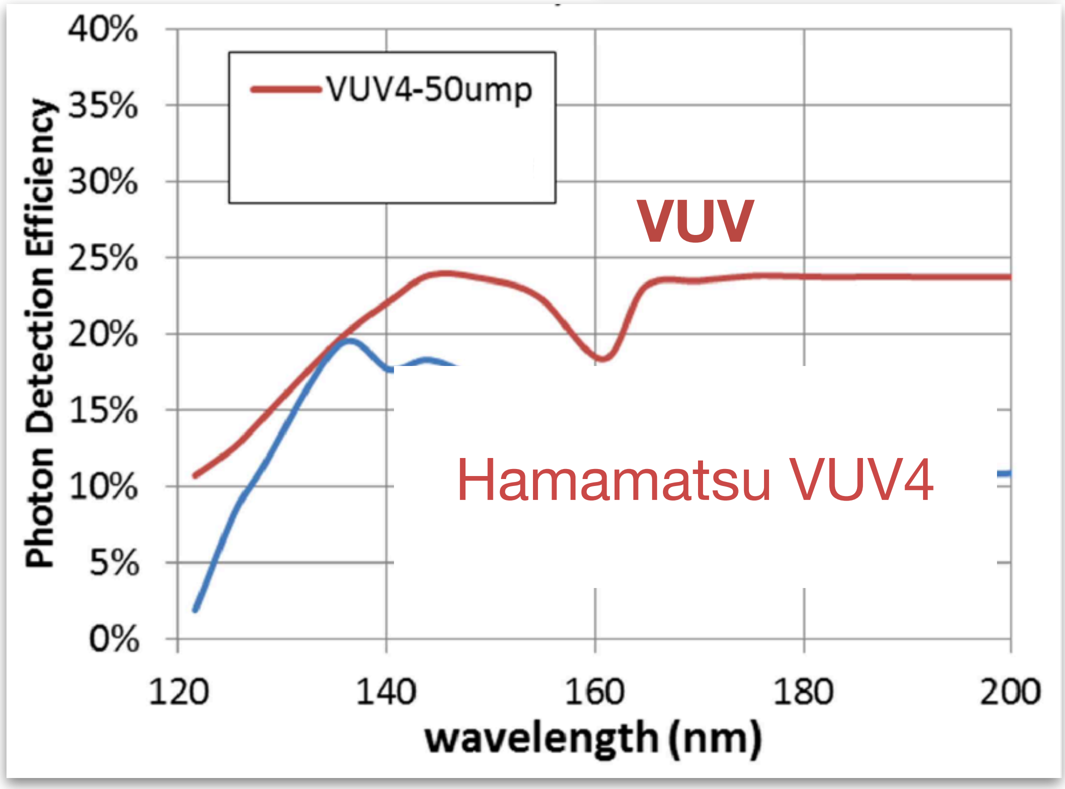


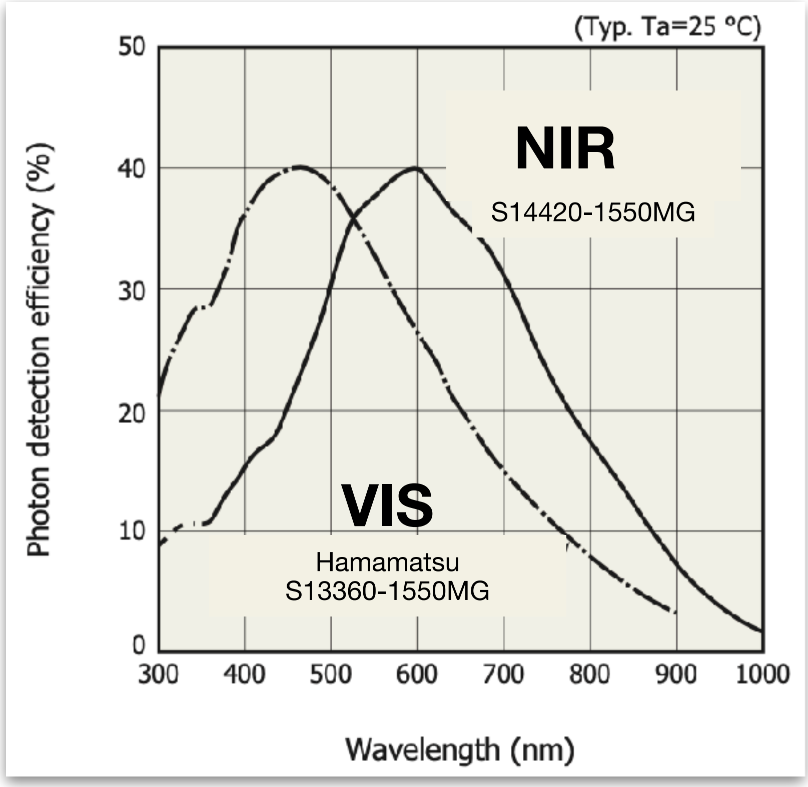
Spectral sensitivity of photosensors

Three sensors from Hamamatsu are used in the experiment

Sensitivities of VUV >200nm and VIS & NIR <300nm are unknown at this time







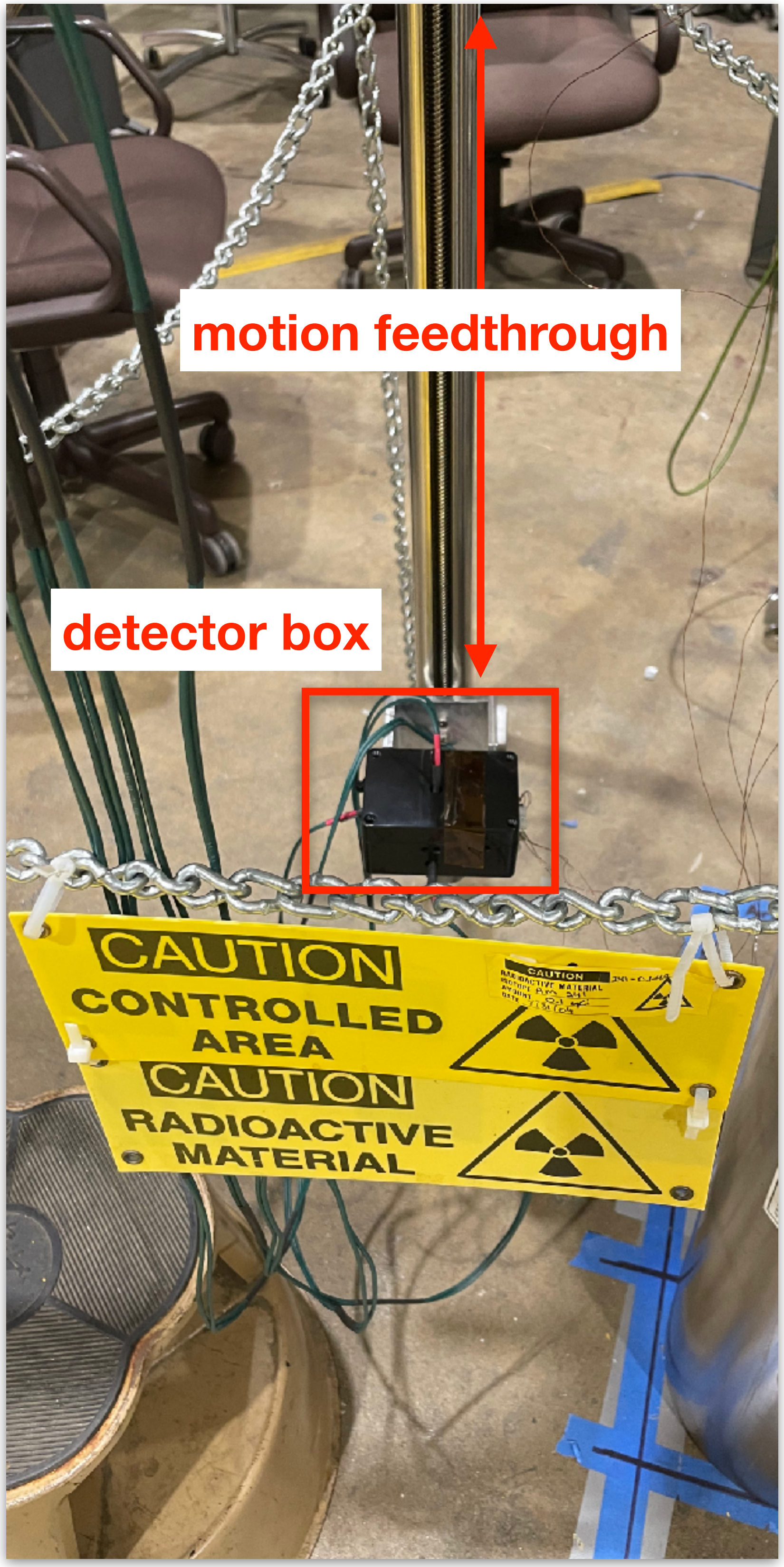
SiPMs register photons produced by scintillation induced by the energy deposition of α-particle in the corresponding spectral range

Observed signals reflect a convolution of the scintillation spectrum with SiPM spectral sensitivity and geometrical acceptance

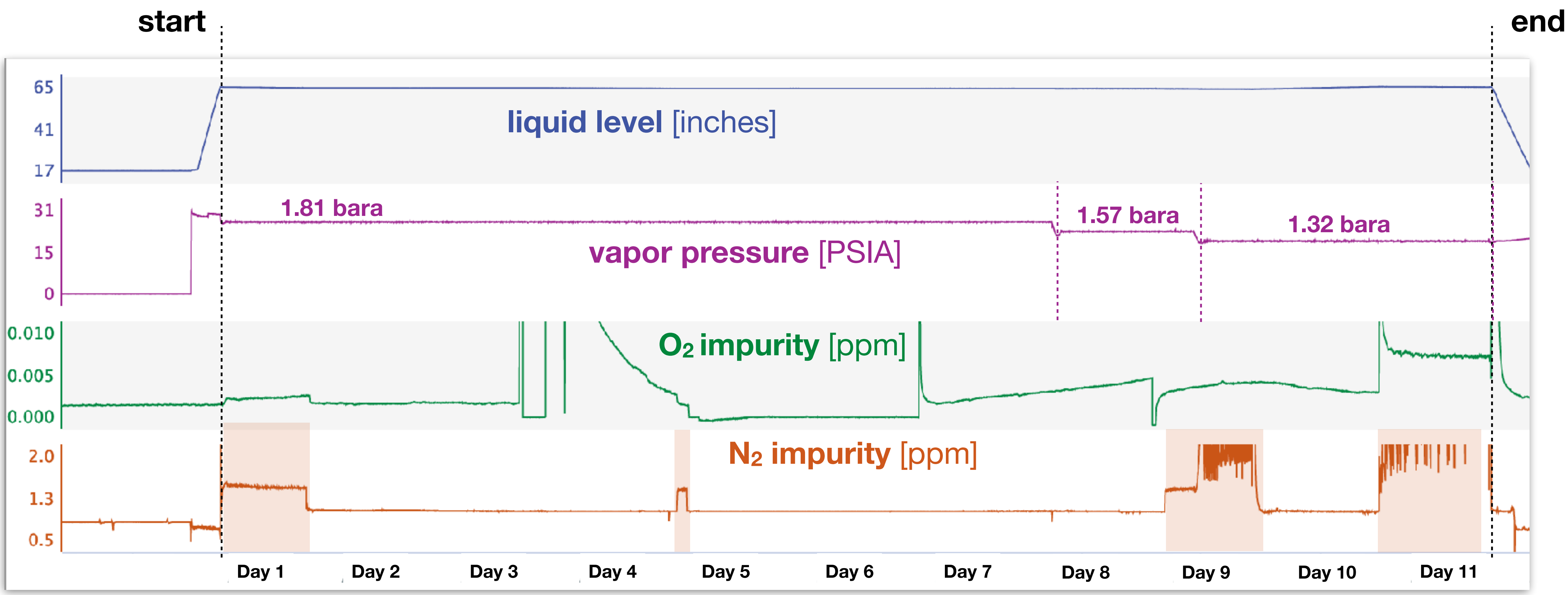
In liquid α-track is short, hence signal corresponds to the energy deposition of ~5 MeV. In the gas phase observed signal corresponds to a fraction of the full α-trajectory

Setup at the Proton Assembly Building (PAB)

The detector is installed in a tall cryostat vessel with a long motion feedthrough, which allows to travel to various positions in liquid and gaseous phases



Experimental conditions



Data acquired varying vapor pressure (1.8, 1.6, 1.3 bars) and vertical position of the box (temperature):

– Liquid argon 92 – 94K
– Cold argon gas 95 – 140K
– Warm argon gas 180 – 190K

Nitrogen and oxygen impurity contamination was measured in the cryostat ullage volume during the experiment:

N_2 contamination on average ~1.4 ppm (three times lower in LAr)
O_2 contamination ~(1.5–4.5) ppb (and is the same in liquid)

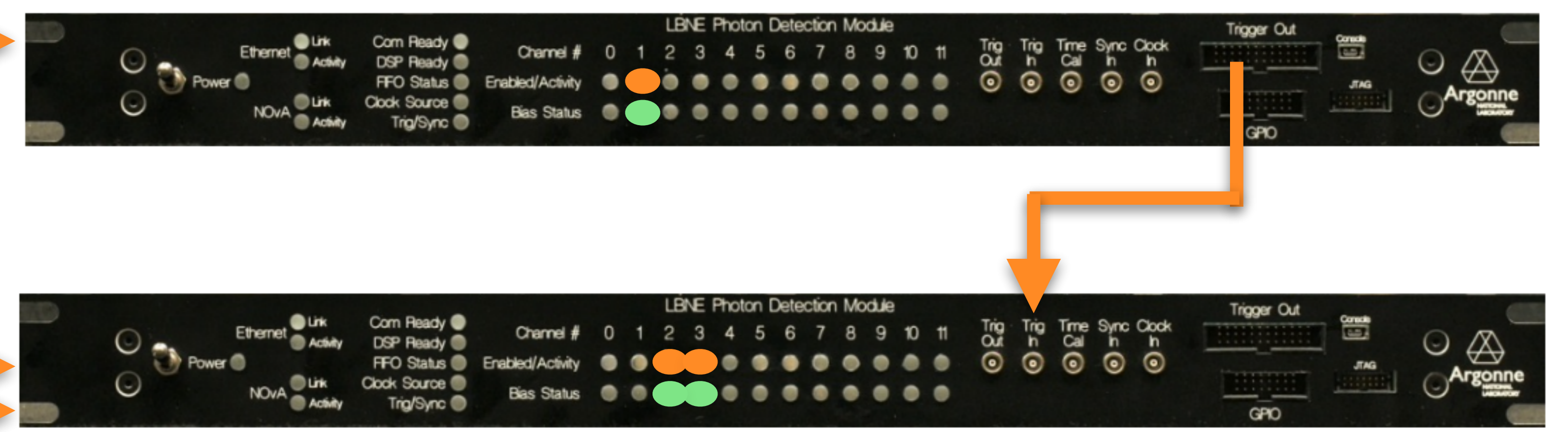
Data acquisition

Trigger was provided by one of the three channels (NIR, VUV, VIS) with a leading edge discriminator
Trigger is provided by one channel, and the other two channels are analyzed. The triggered trace is not analyzed to avoid bias due to set trigger threshold

An SiPM signal processor (SSP) is used to bias and readout SiPMs, originally developed at the Argonne National Lab for LBNE (signal amplification and shaping)

Trigger SiPM (e.g.VUV)
Leading edge discriminator

Two other channels
(e.g. VIS & NIR)
→ analysis



The SiPM pulses and shaping time of the SSP leads to fundamental pulses with the total width of 200–400ns. For this reason we are not attempting studies of the fast and slow components of argon scintillation, but rather focus on the time structure in the microseconds range

Data was acquired with different sampling:
150MHz – 6.6 ns – short 13.3 μs traces
37.5MHz – 26.4 ns – long 53.3 μs traces

In analysis, the following temporal components are defined:
Fast: < 1.5 μs
Slow: 1.5 to 8 μs
Long: 8 to 12 μs
Very long: 12 to 25 μs

Experimental results: VUV signal

(Trigger on visible or NIR sensor)
(Analysis is based on averaged waveform traces)

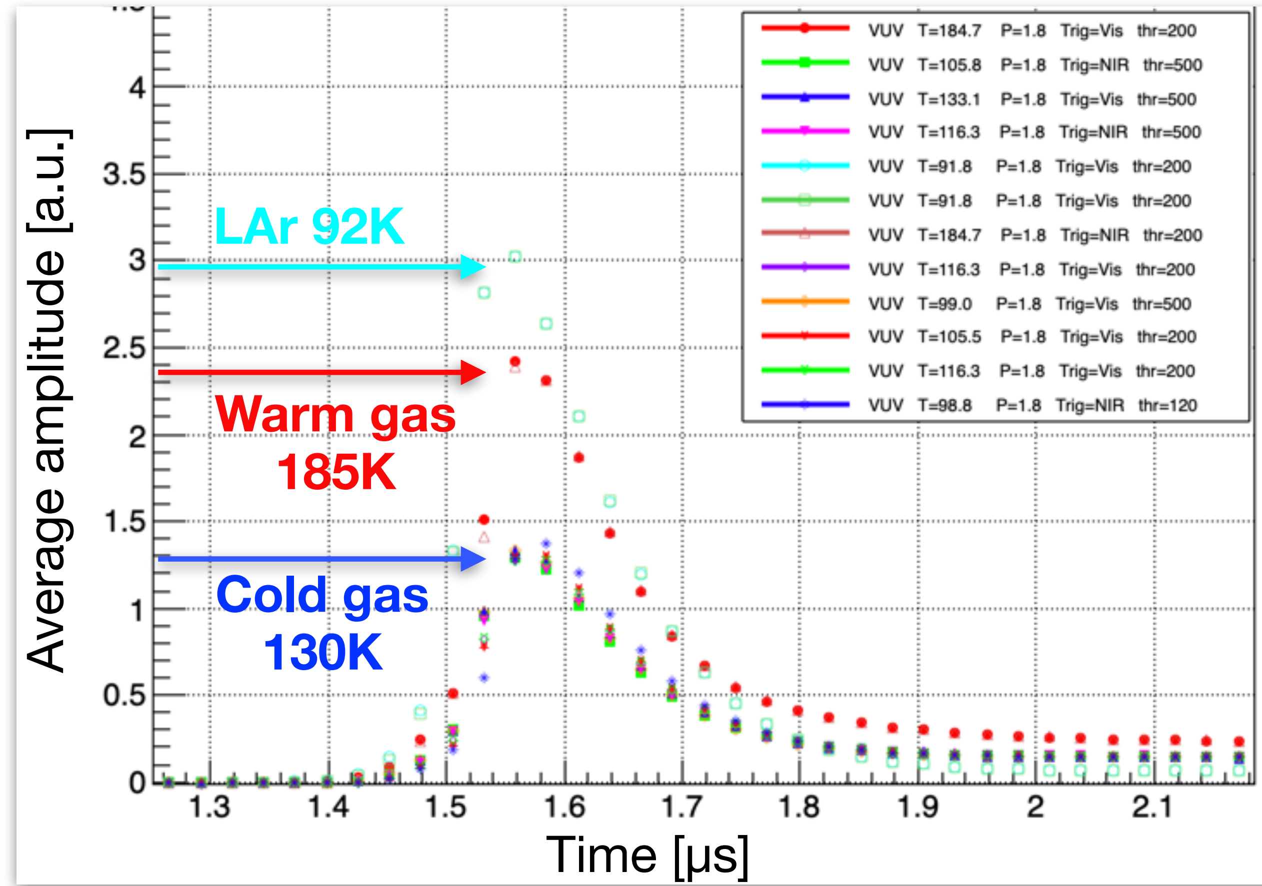
- Observed fast component of the VUV signal reduced in cold gas, compared to the liquid

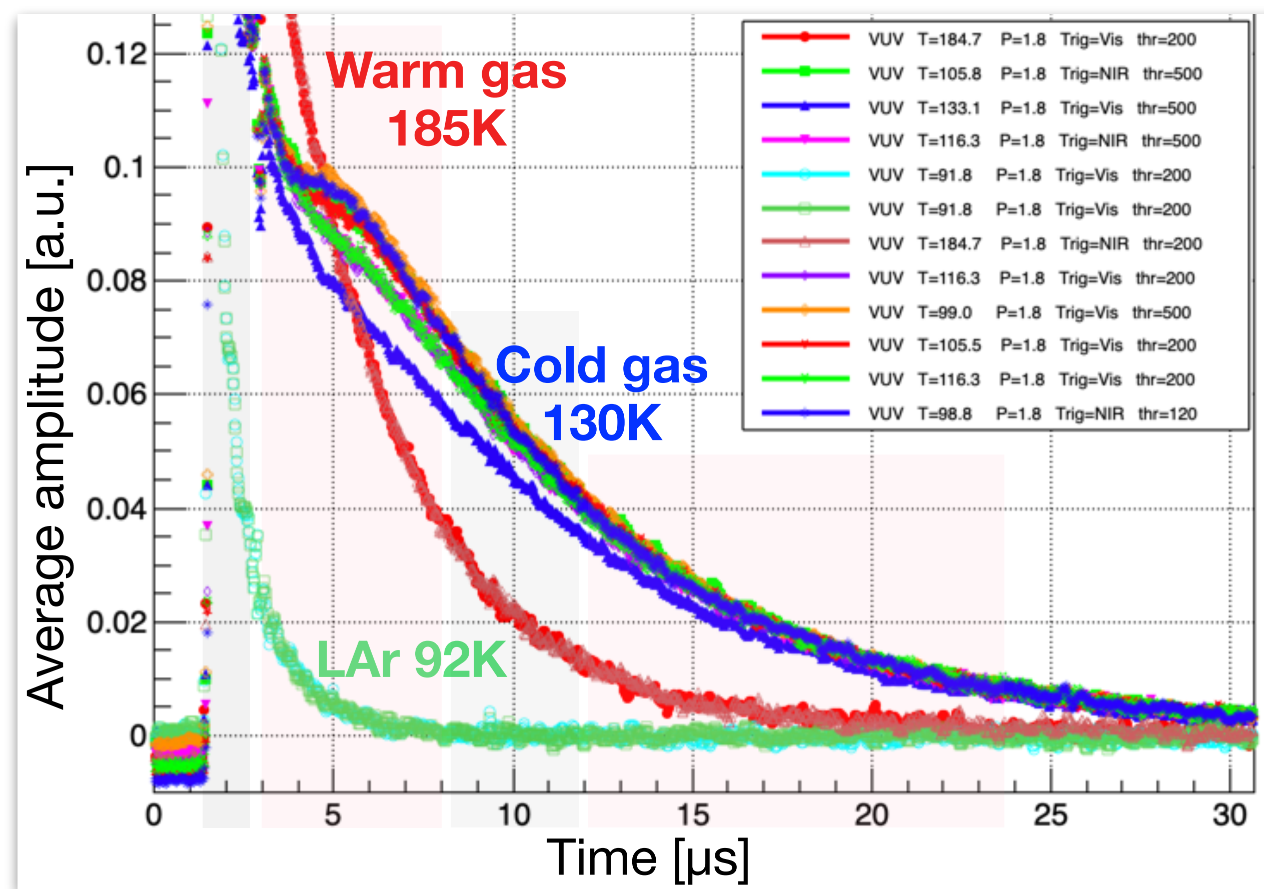
  Fast component in warm gas exceeds signal in liquid by 20% (while the energy deposit is expected to be factor few smaller)

- No slow component beyond τ=1.5μs is observed In liquid (as known)

- Signal in cold gas is dominated by the slow component extending up to ~25μs

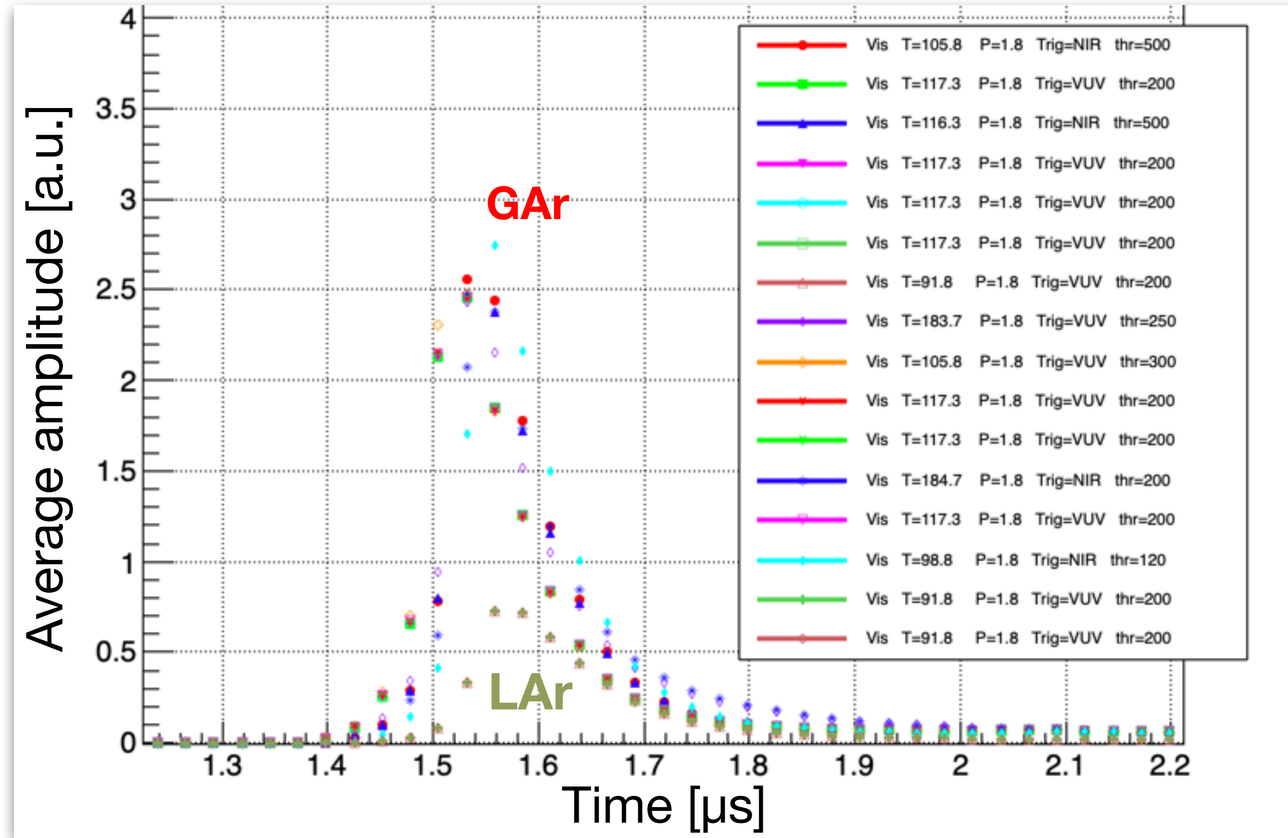
- Slow component of scintillation in warm gas is quite different from the one in cold gas





Experimental results: VIS signal

(Trigger on VUV and NIR signal, shown to produce consistent results)



- Fast signal is observed in liquid, increasing by factor ~3 in gas (cold and warm)

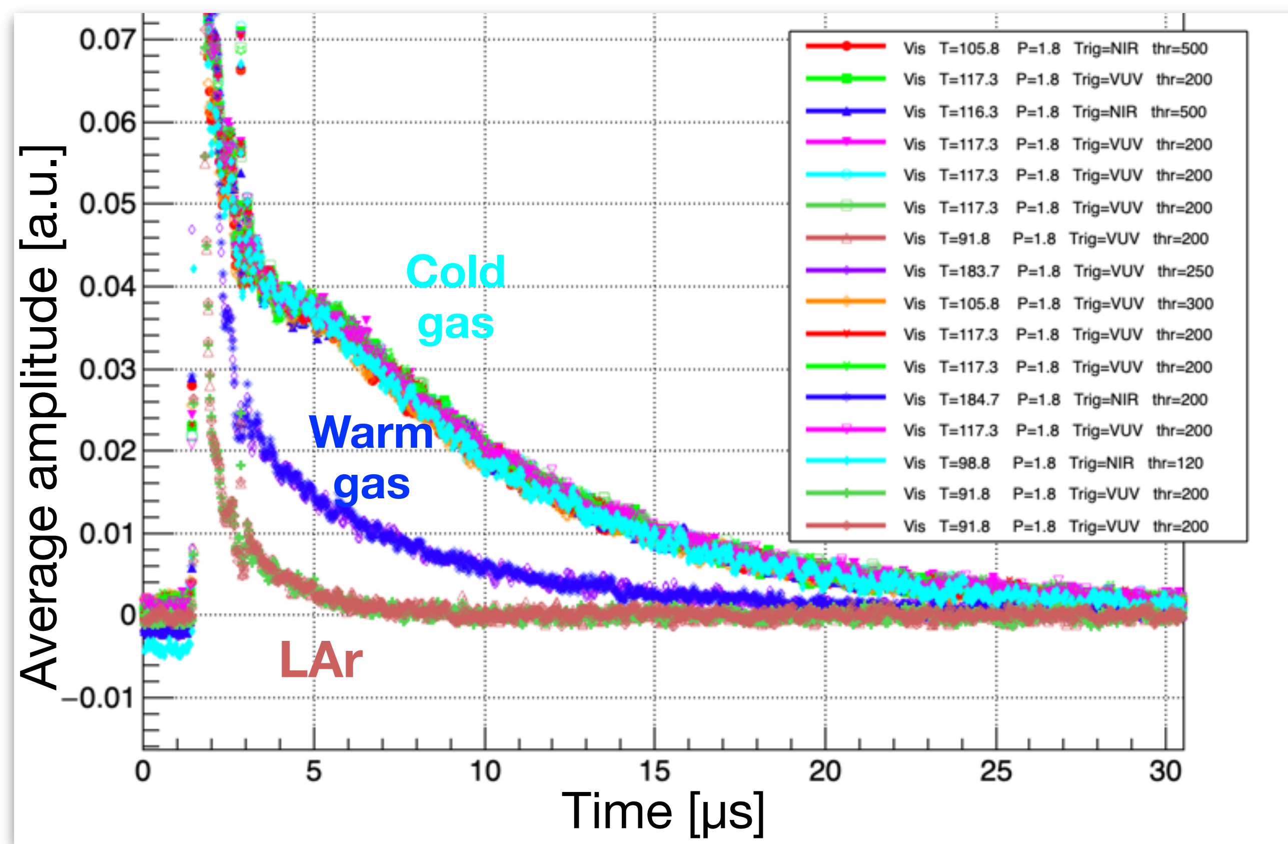
  Energy deposit in gas is expected to be smaller than in liquid

- Temporal characteristics of the slow component are similar to VUV:

– absence in liquid

– presence in cold gas with extension to ~25μs

– reduction in size and different time constant in warm gas



Experimental results: NIR signal

(Triggered by VUV or VIS channels)

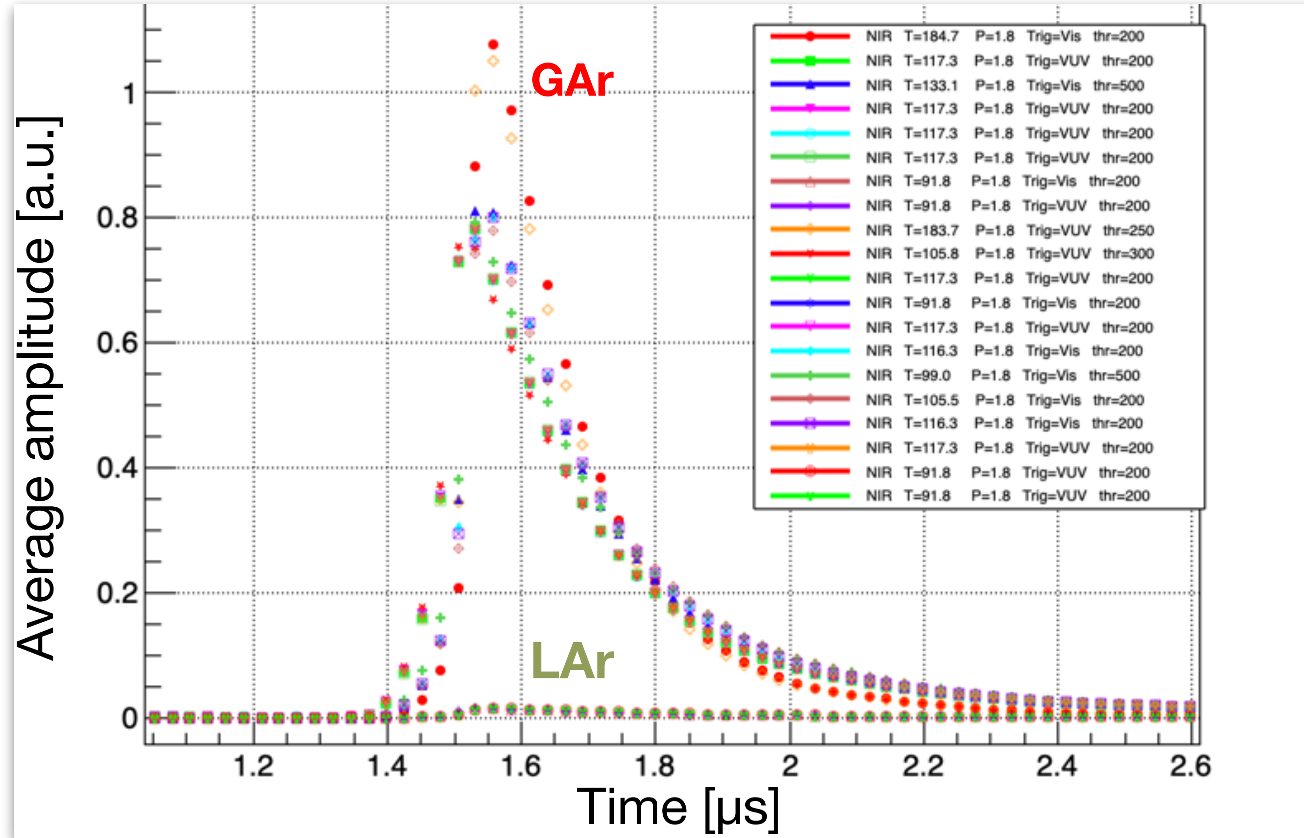
・Fast component is very small in liquid, increasing to ~8PE in gas (cold and warm)

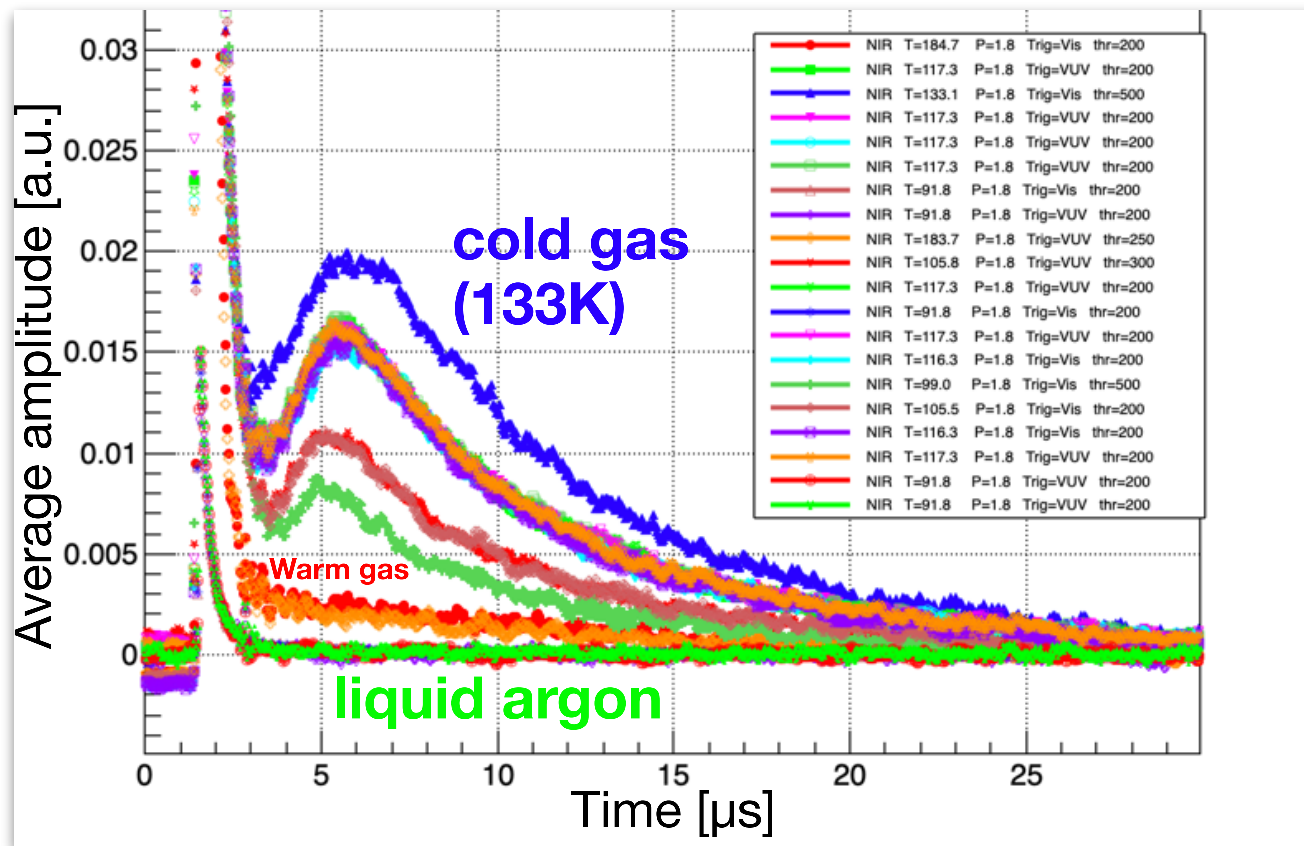
・Slow component is absent in liquid. It appears in cold gas

Temperature-dependent delayed “bump” can be observed

It is peaked around 3-4μs from the start of the fast pulse

This component disappears in warm (185K) gas

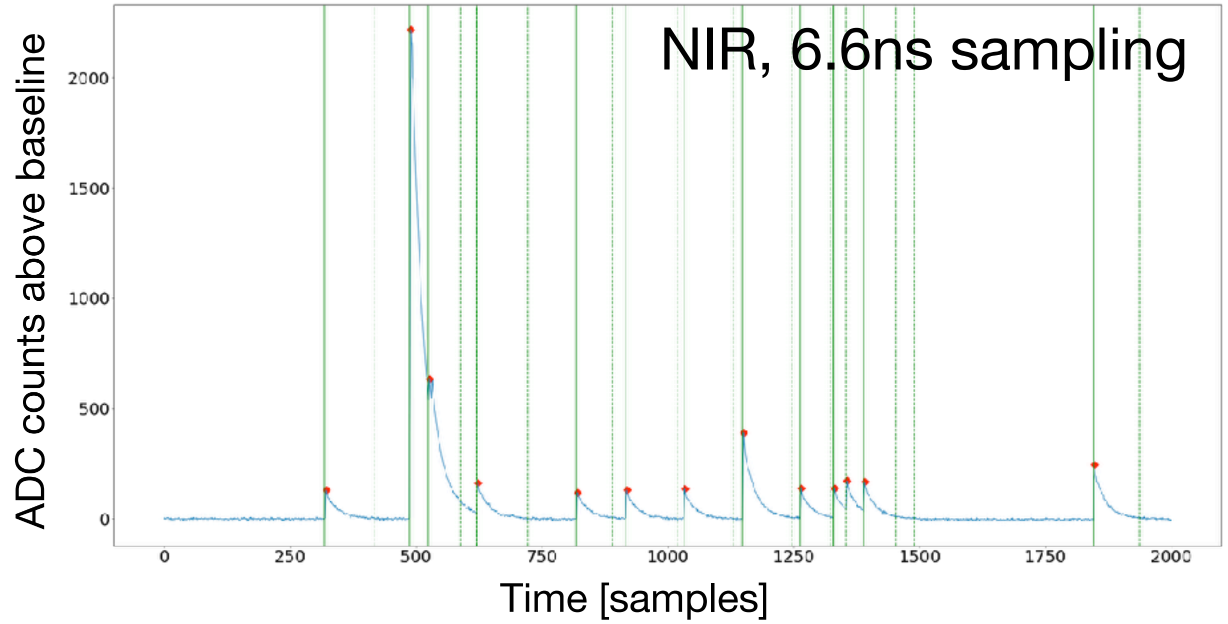




Experimental results: peak-based analysis

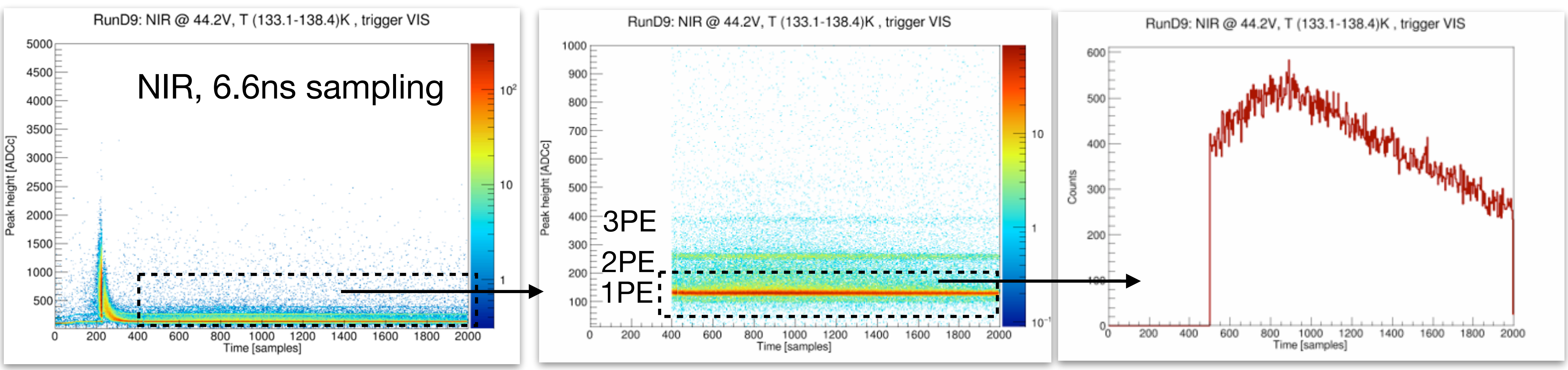
Individual peaks are identified in all traces with find_peaks/prominence algorithm in Python signal processing package

Example of cold gas run (1.8bara, 133K), trigger VIS



Peak heights are plotted with the start time of peaks

Slow component appears to consist of pulses with small amplitude, mainly SPE signals, clustered in time

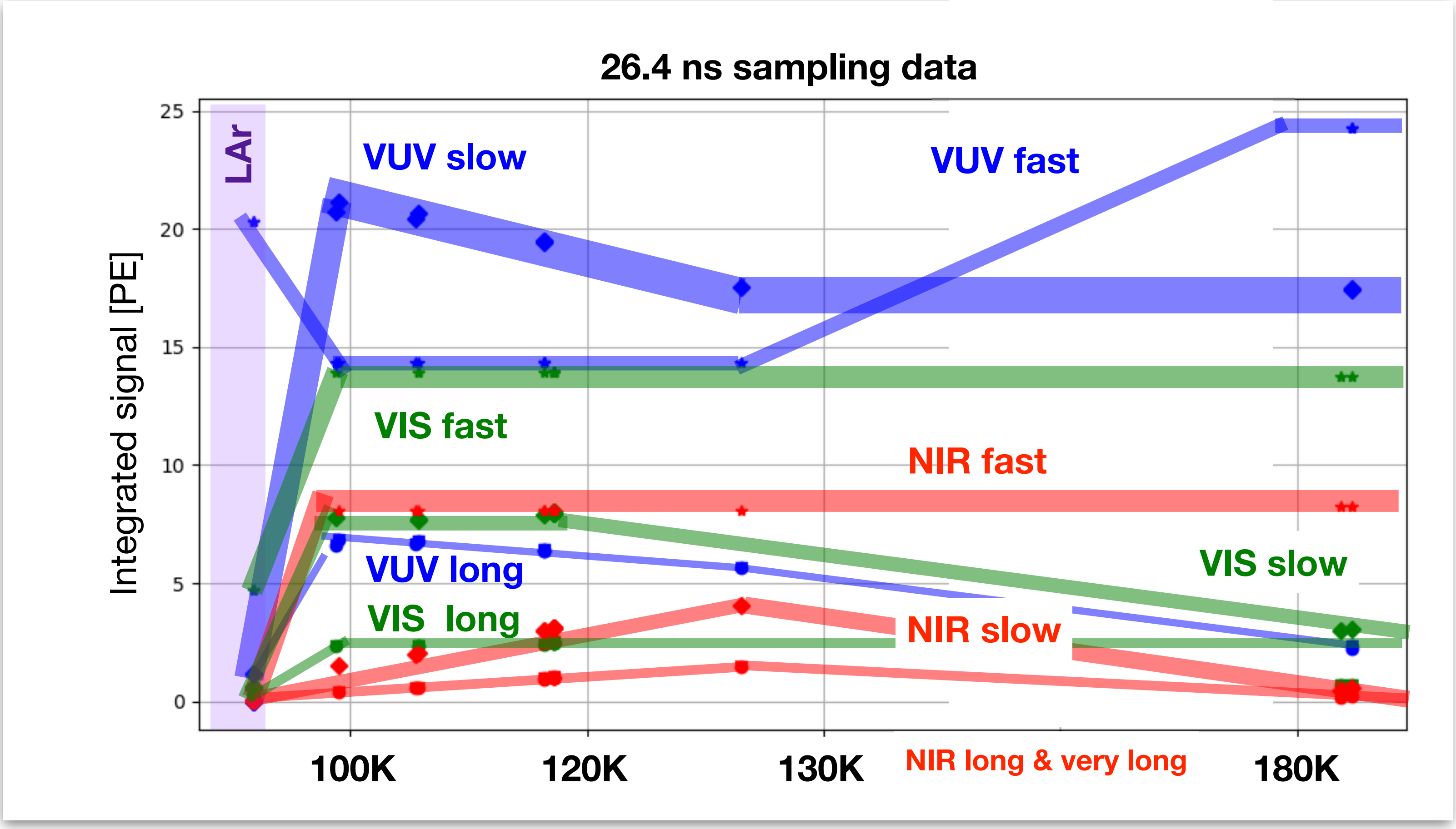


Experimental results

The results here are based on in-situ temperature-dependent SPE calibration,and shown as integrated signal (averaged trace) in the 4 time ranges:

Fast component: < 1.5 μs
Slow component: 1.5–8 μs
Long component: 8–12 μs
Very long: 12-24 μs

NIR signal is absent in liquid argon, and appears in cold argon gas. Slow component is significant in cold gas, disappearing in warm gas



There are slow and long NIR components that increase with the temperature of cold gas

Signal is present in the visible VIS range, consisting of fast, slow, long and very long components in cold gas, and only fast and slow in warm gas

Integrated signal [PE]												
SiPM:	VUV				VIS				NIR			
Integration time:	<1.5 μs	1.5–8 μs	8–12 μs	12–24 μs	<1.5 μs	1.5–8 μs	8–12 μs	12–24 μs	<1.5 μs	1.5–8 μs	8–12 μs	12–24 μs
liquid	20	0	0	0	5	0	0	0	0	0	0	0
cold gas	15	20	7	6	14	8	2.5	2.5	8	4	1.5	1.5
warm gas	24	18	2	2	14	3	0	0	8	0	0	0

Summary and conclusions

An experiment was performed at Fermilab in 2022, with an ^{241}Am α-source and three photosensors with different (but overlapping) spectral ranges, with the data acquired in liquid and gaseous argon without electric field varying the temperature

<u>The results presented are preliminary</u>:

In liquid argon, we detect the well known VUV signal, and a significant amount of signal in the visible part of the emission spectrum

It is not possible to compare absolute light yields due to not yet calculated photon acceptance of the three photosensors, which depends on the detector geometry, their size and spectral sensitivity
An additional uncertainty arises from the length of the α-track, which is point-like in liquid argon, and on the order of a few cm in argon gas

<u>VUV emission</u> (its fast component) is reduced in cold gas (90–130K), but increased again in warm gas (185K). Signal in cold gas is dominated by the slow component extending up to ~25μs

In cold gas, while VUV light is reduced, we observe factor ~3 increase of the <u>visible signal</u>

Significant signal is measured in the <u>near-infrared</u> sensitive SiPM in cold gas. Slow (1.5–8μs) and long (8-12, up to 25 μs) components are identified in this emission, with the amount of detected light increasing with temperature in cold gas independently from the other two photosensors