

Study of Light Production with a Fifty Liter Liquid Argon TPC



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The Fifty Liter LAr TPC Details

- Three wire planes:
 - 128 collection + 128 induction wires:
 - 325 mm length; 2.54 mm pitch;
 - 4 mm plane separation
 - Screen grid wires parallel to induction wires
- Drift distance: 52 cm
 - 25 squared rings made of uncoated extruded 10 x 10 mm² aluminum bars, spaced by 10 mm
 - Vetronite bars to hold the rings
 - Field cage voltage divider: 50 M Ω ceramic resistors (3 in parallel) on metallized kapton strips

Excellent chamber for quick tests!

Vacuum and cooldown (2 days)

Filling (1/2 day)

Can be operated for several weeks in a row

Dedicated recirculation system → purity improves gradually



The Fifty Liter LAr TPC Test Campaigns

Several test were done with the fifty liter LAr TPC so far including:

- Study of TPB (tetraphenyl butadiene) and PEN (polyethylene naphthalate) as wavelength shifter (WLS) as
 - Coating/lamination on a reflector foil on the cathode
 - Coating/attachment on the PMTs
- Investigation of N₂ contamination and/or Xe doping
 - With PMTs
 - With various setups with SiPMs
 - With PMTs in dual phase setup

Only a fraction will be mentioned here.

Tests with the WLS + Reflector Foil on Cathode

- Run 1: Resistive kapton cathode + reflective foil + TPB coating
- Run 2: Resistive kapton cathode + reflective foil + PEN
- Run 3: Resistive kapton cathode

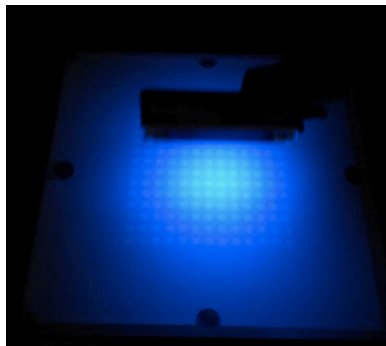
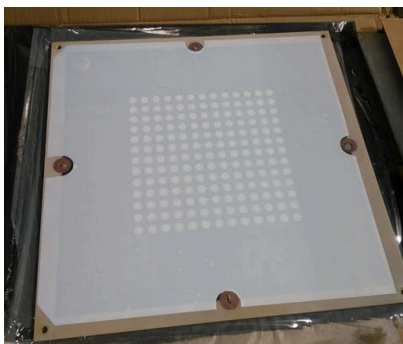
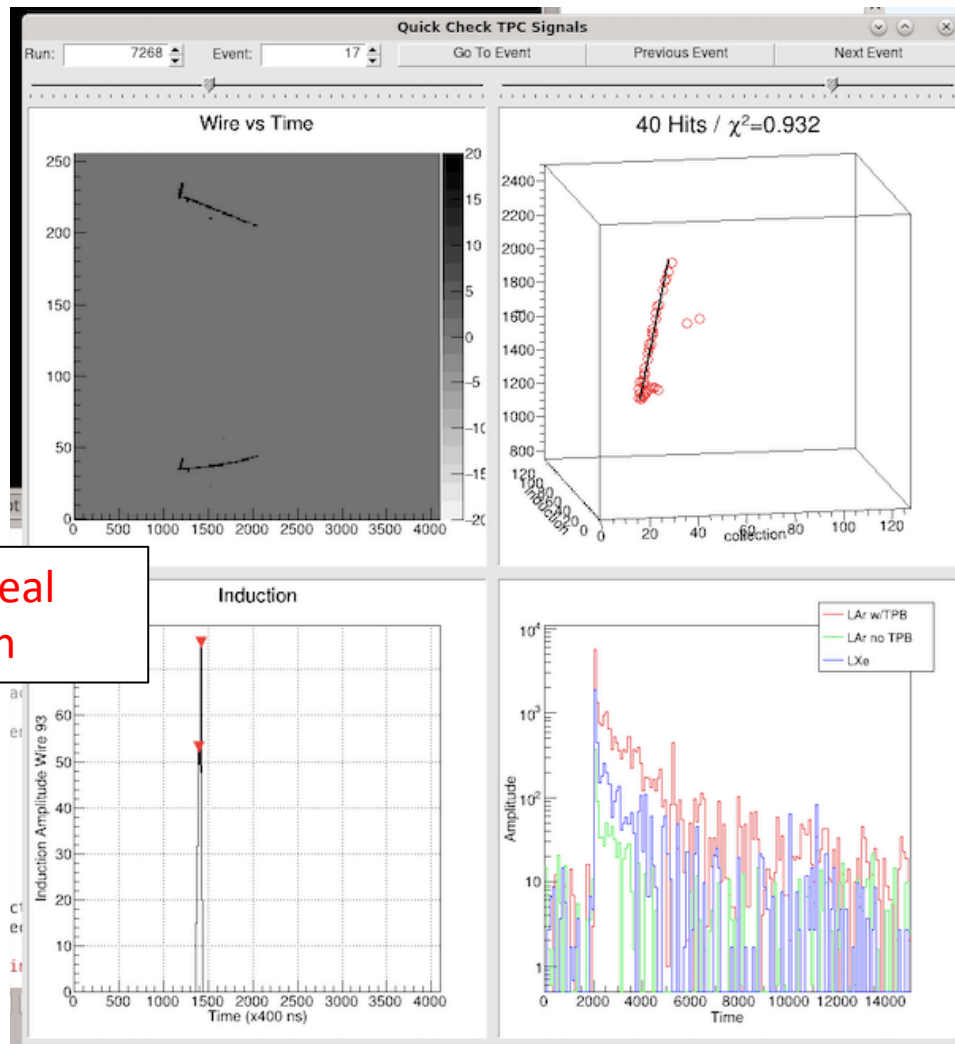
Two Hamamatsu photomultiplier tubes:

- R11065 with TPB coating (LAr w/TPB)
- R11410 (LXe)

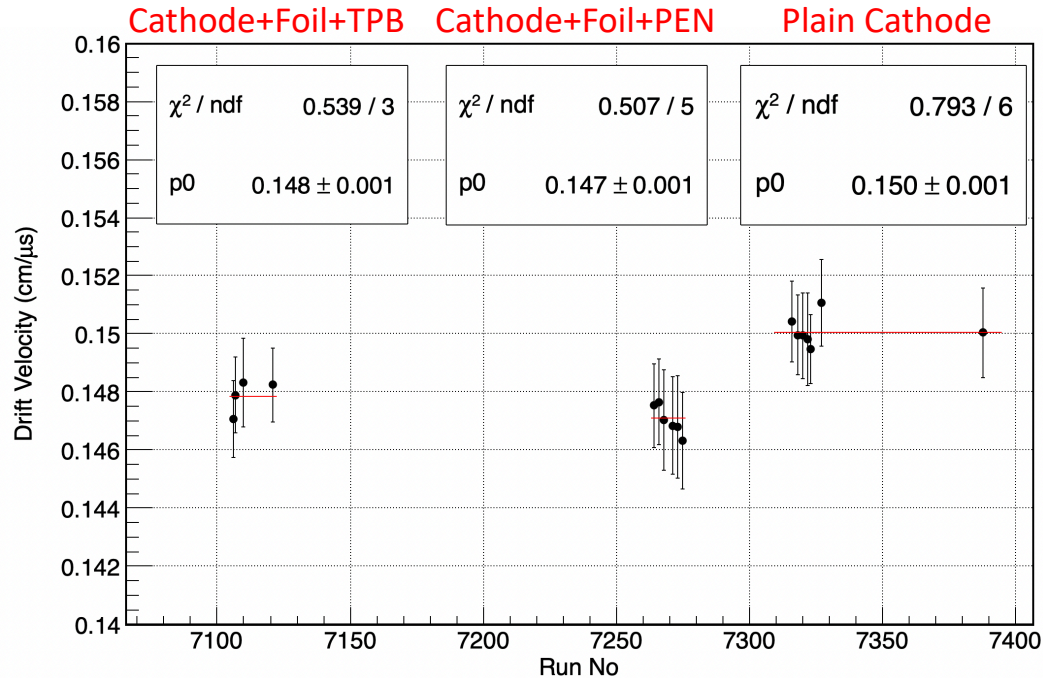
TPC readout with CAEN a2795

PMT readout with CAEN v1751

Running sum on induction signals and real time/offline hit and track reconstruction

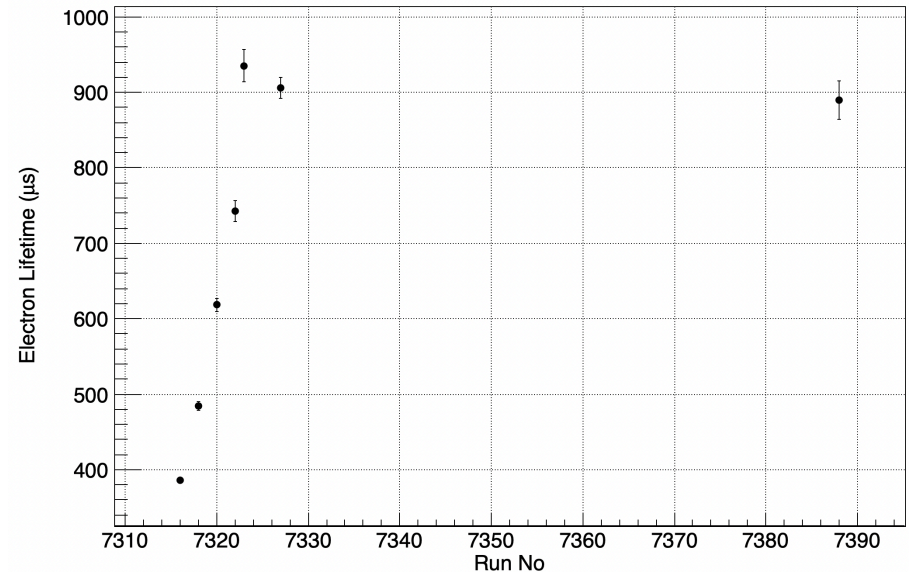


TPC Performance



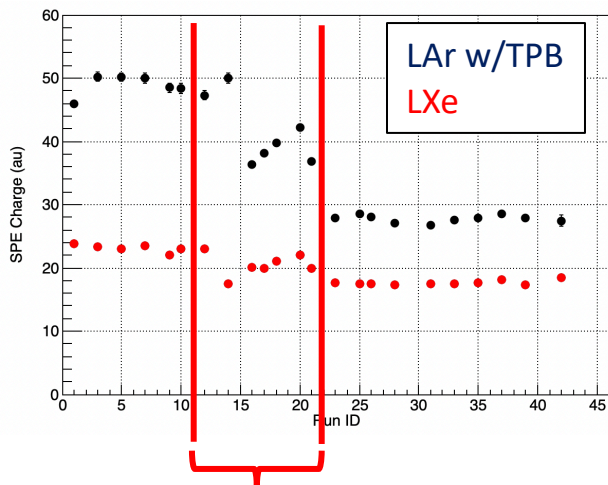
The effect of the reflective foil and the wavelength shifters on the drift speed is minimal (~2 %). The effective HV is ~ 5 % less than nominal HV.

The electron lifetime starts ~ 0.5 ms and reaches ~1 ms in a few days with recirculation.

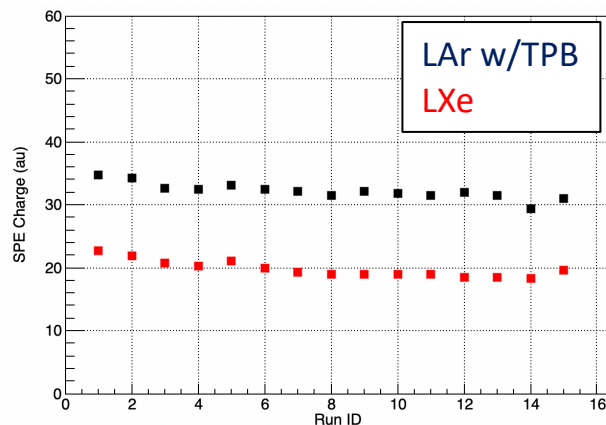


Light Readout

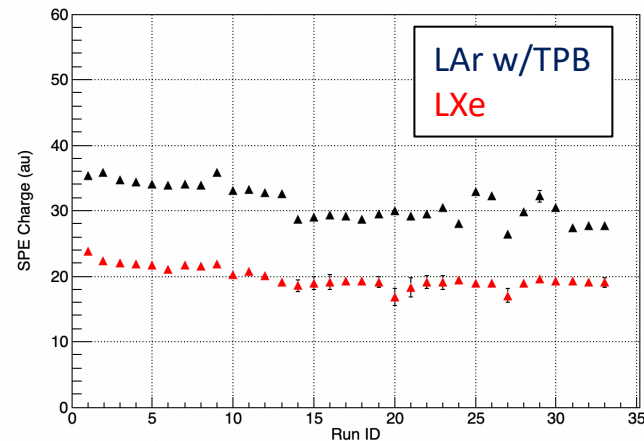
Cathode+Foil+TPB



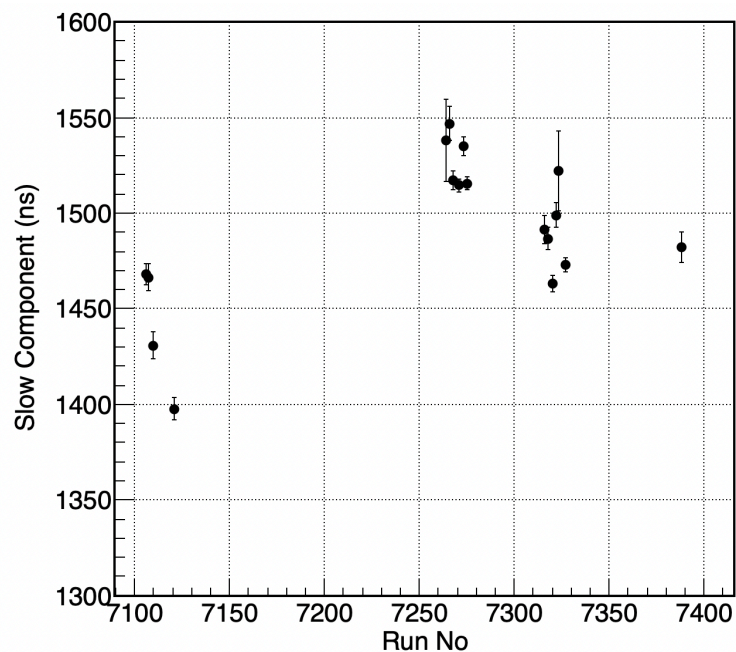
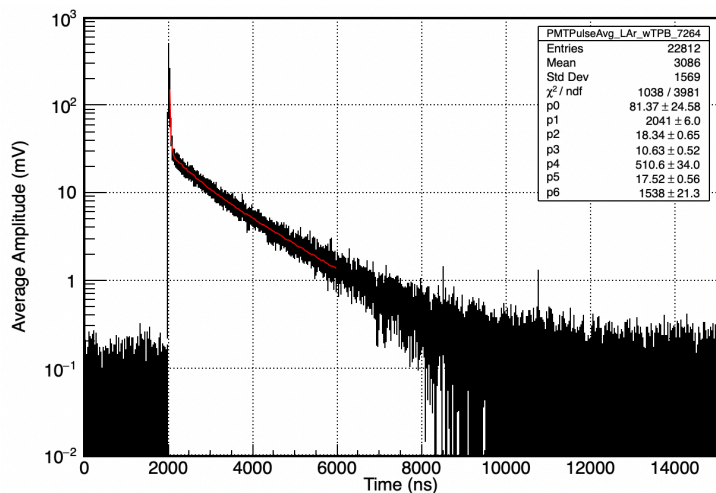
Cathode+Foil+PEN



Plain Cathode

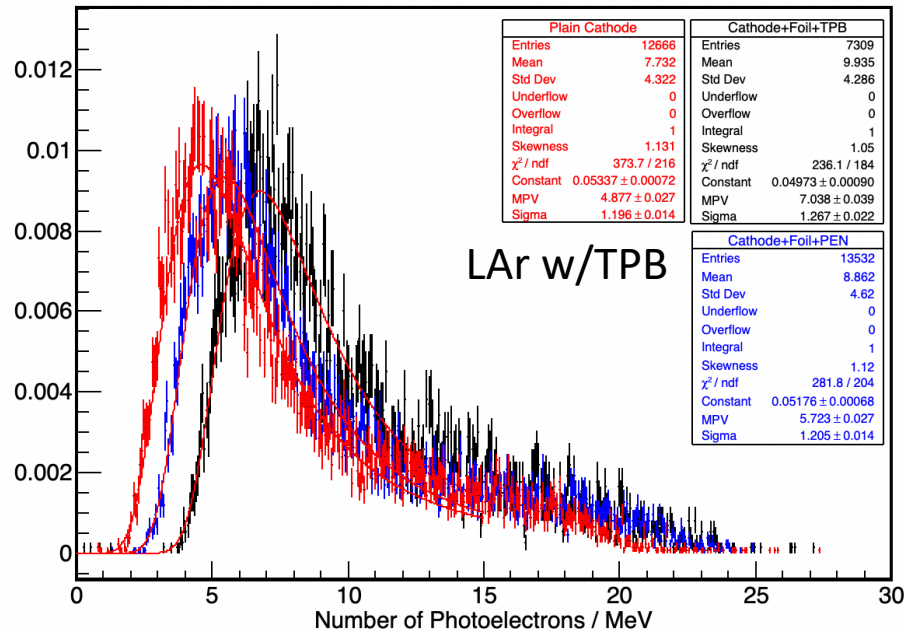


HV modifications



Stable calibration following a cooldown period.
The slow components were around 1.4-1.5 μs .

Light Yield

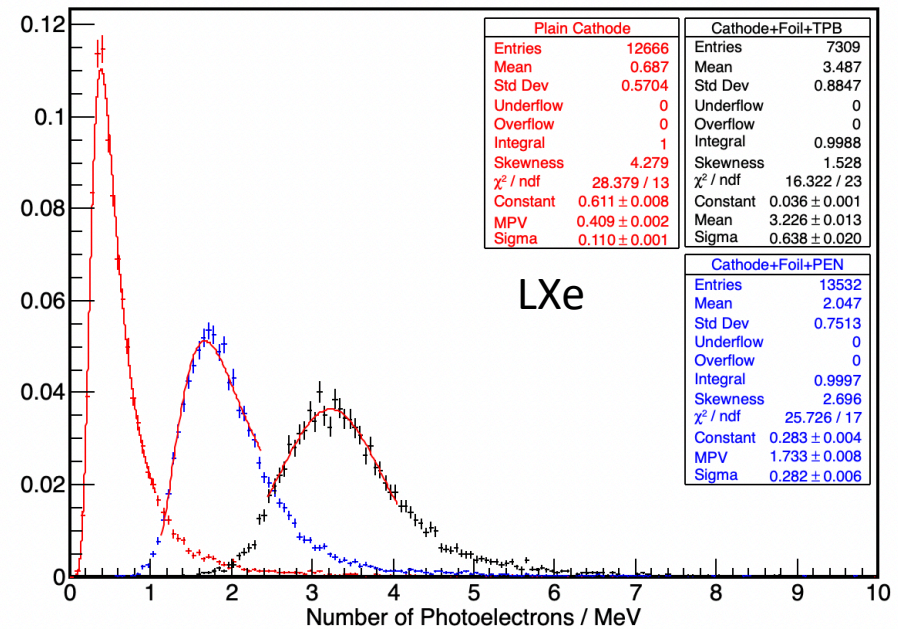


R11065 with TPB coating (LAr w/TPB)

Increase in light yield is 17 % with PEN and 45 % with TPB.

Relative WLS efficiency of PEN/TPB \sim 38 %

Number of photoelectrons / cm calculated with tracks traversing the full drift distance.
Take 2.1 MeV / cm.



R11410 (LXe)

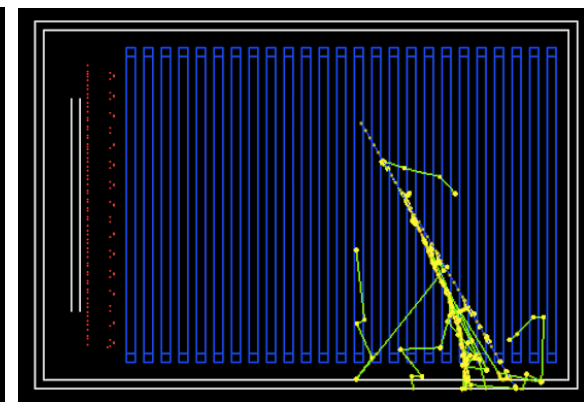
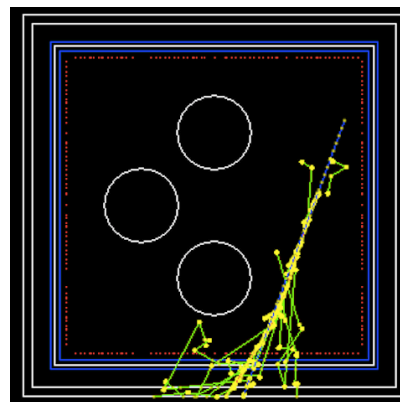
Relative increase in light yield with TPB compared to PEN is 86 %.

The plain cathode yield is not reproduced with Geant4 simulations.

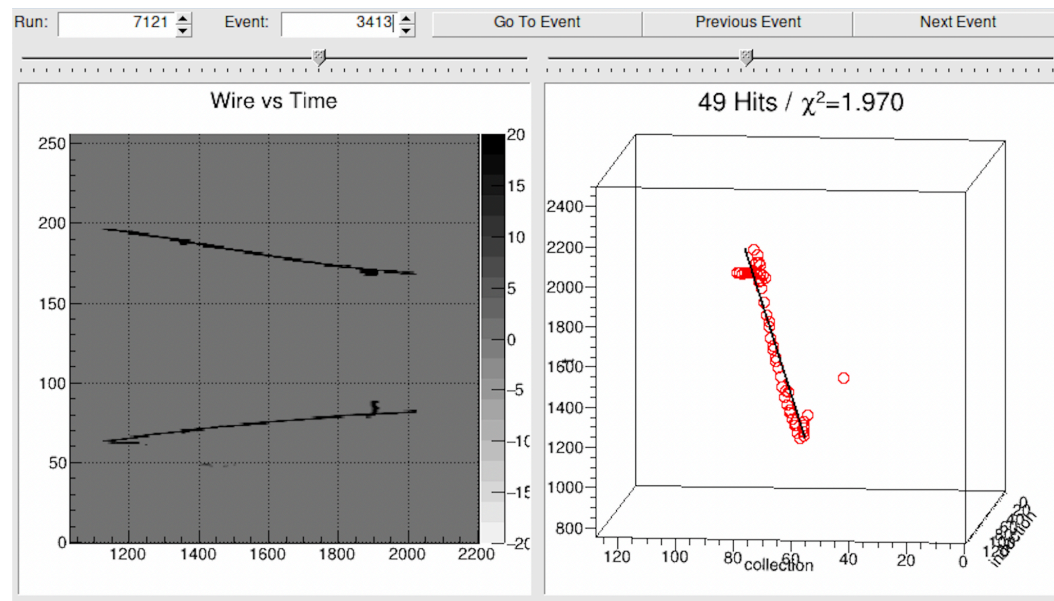
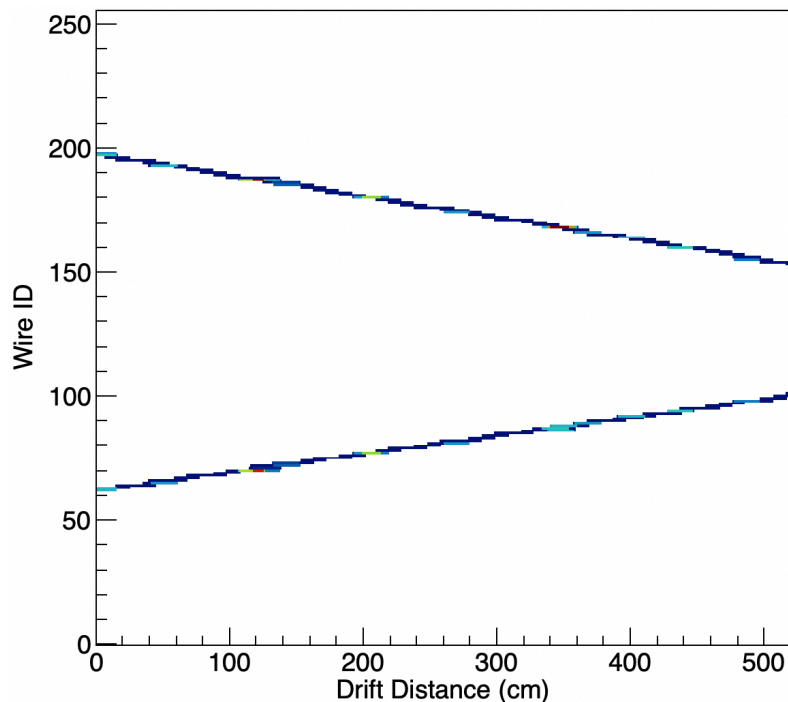
Geant4 Simulations

Full simulation with Geant4
Exact track parameters as data
Muon energy sampled from pdg cosmic muon spectrum
QE sampled from Hamamatsu generic plots

Tune MC only for Run3 (plain cathode) with a single factor.

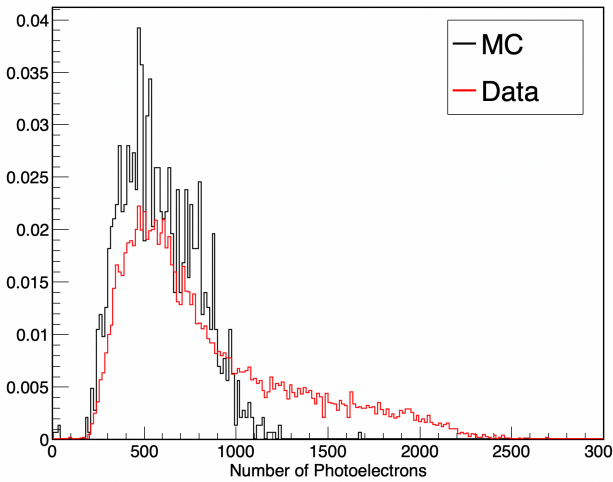


TPC response simulated using the measured track parameters.

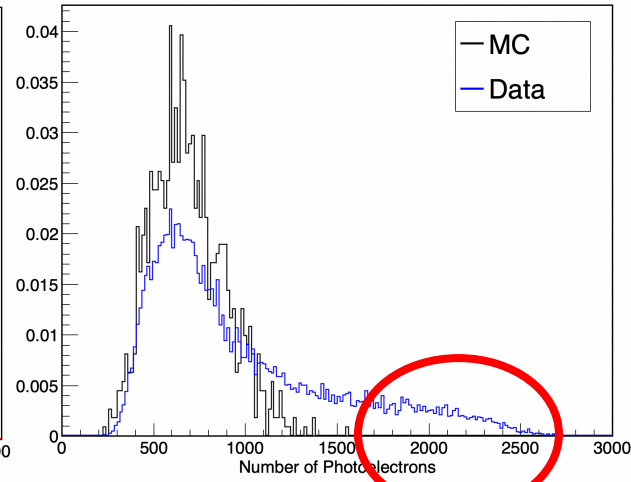


Data – MC Comparison

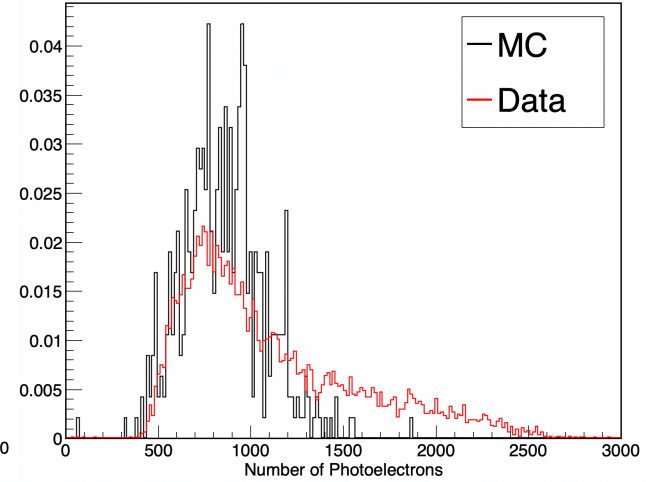
Plain Cathode – MC tuning sample



Cathode+Foil+PEN

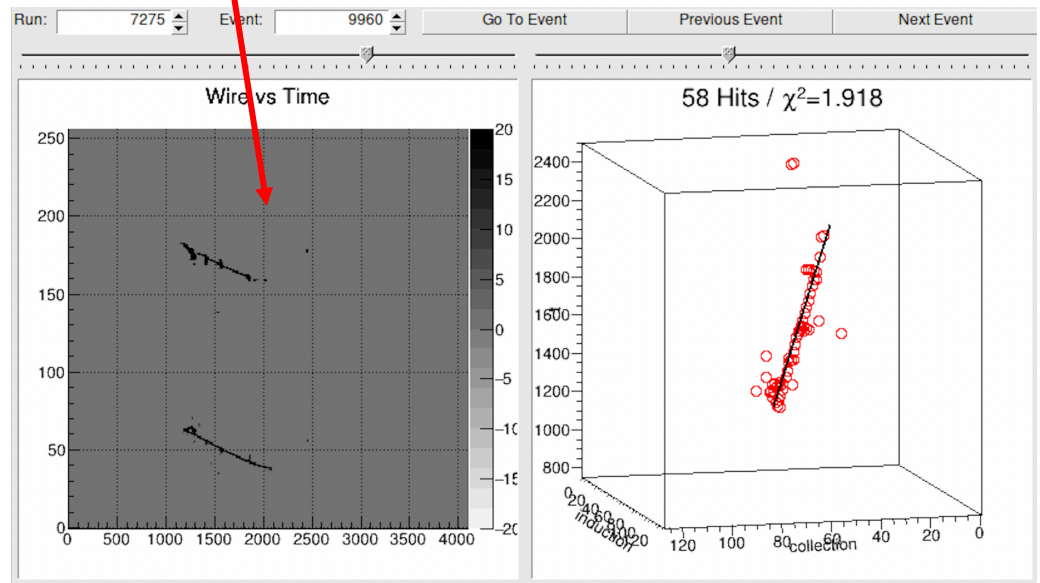


Cathode+Foil+TPB

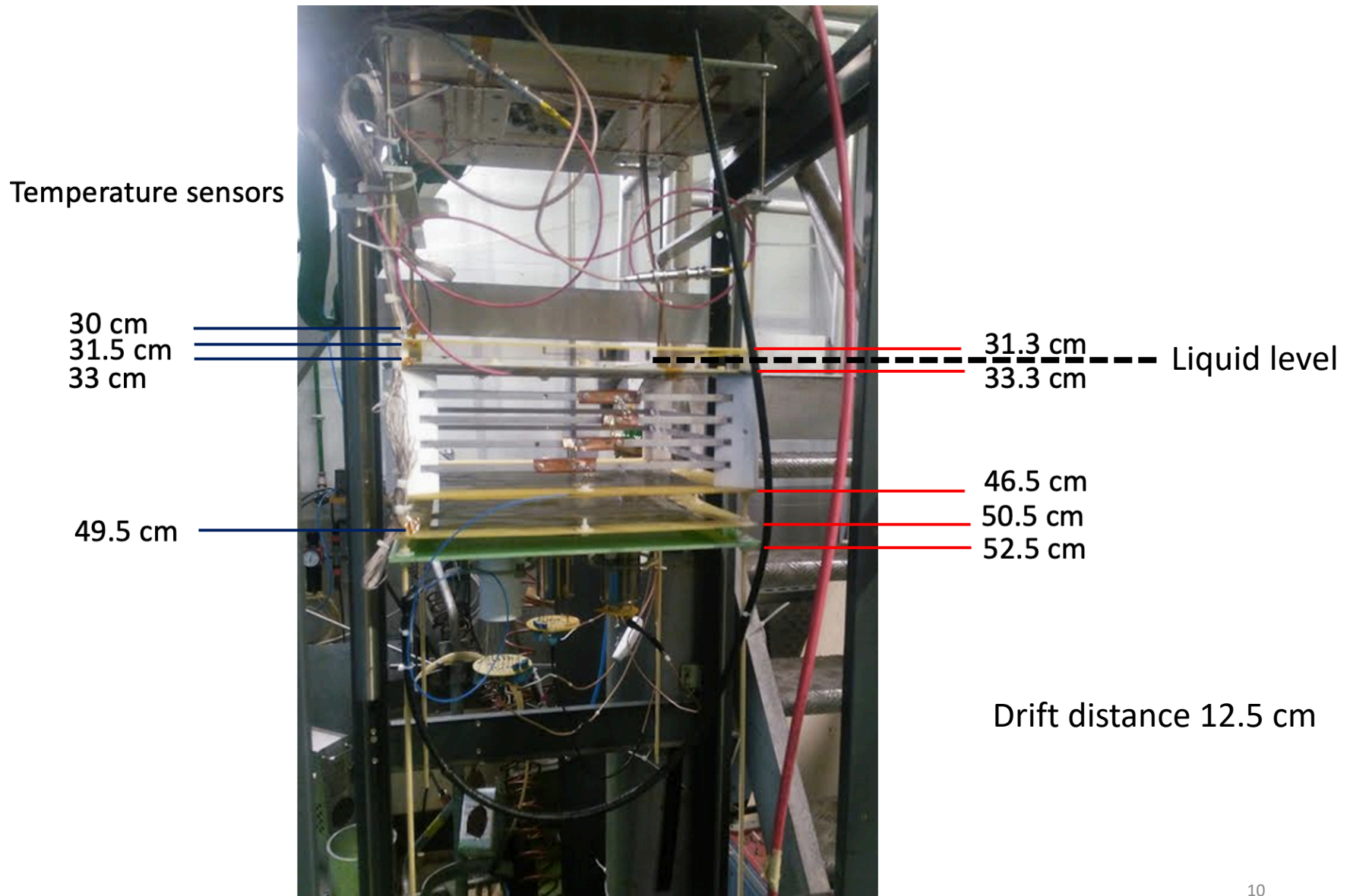


Tail is mostly due to excessive delta rays along the tracks and is not reproduced well in MC.

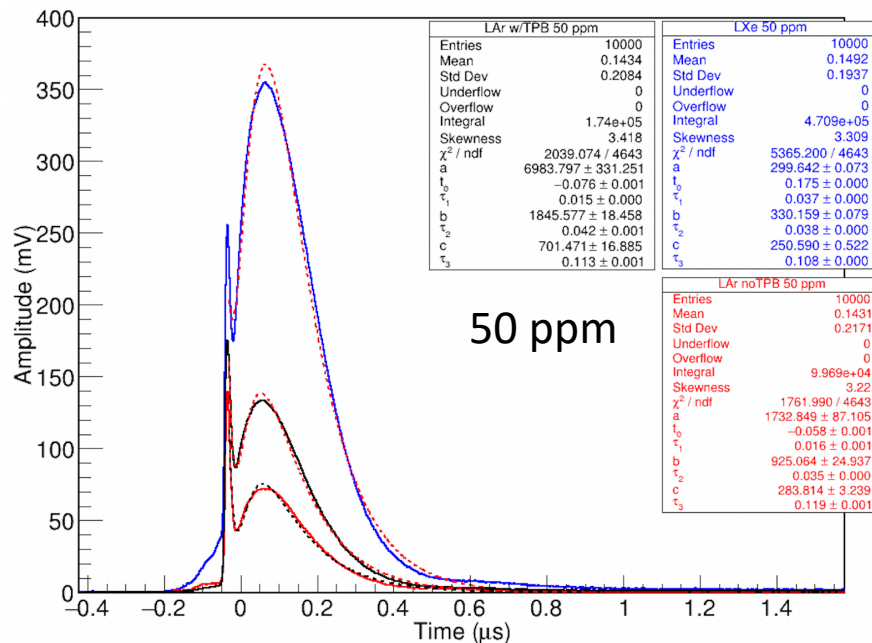
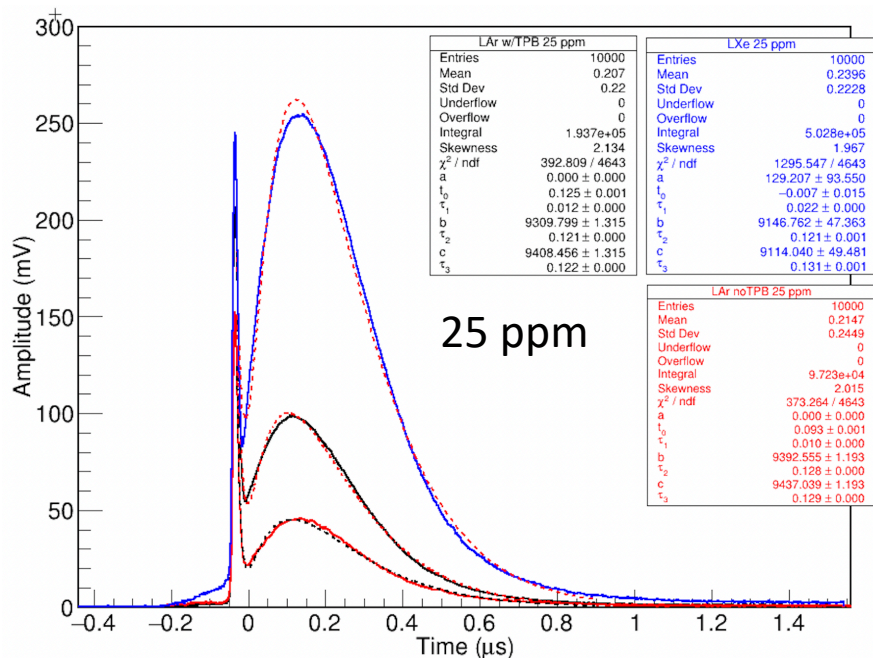
MC tuning done with the plain cathode setup works relatively well with the WLS configurations. Investigations of other EM physics packages is underway.



Dual Phase Xe Doping



Dual Phase Xe Doping – S1 light



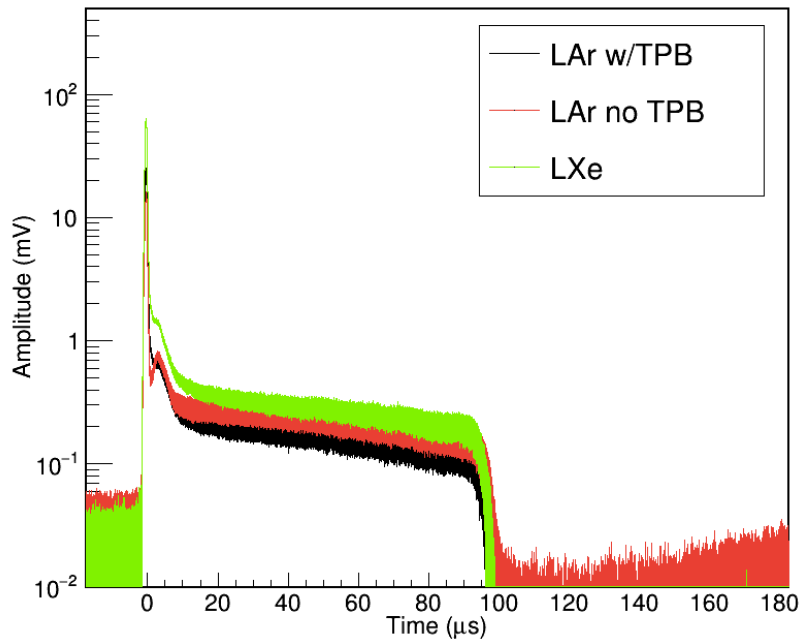
Average waveforms fit to: $f(t) = ae^{-(t-t_0)/\tau_1} - be^{-(t-t_0)/\tau_2} + ce^{-(t-t_0)/\tau_3}$

LAr w/TPB	25 ppm	50 ppm
τ ₁ (ns)	12	15
τ ₂ (ns)	121	42
τ ₃ (ns)	122	113

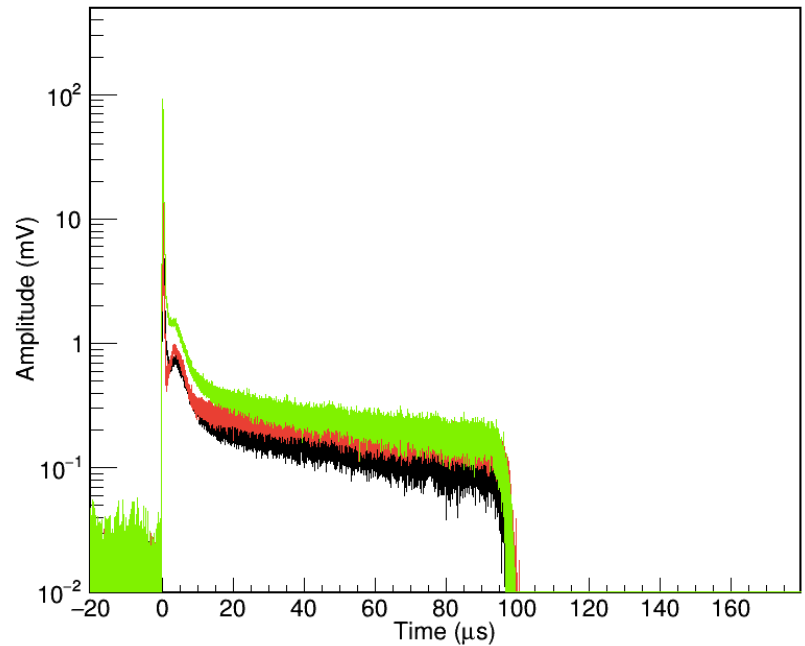
LAr noTPB	25 ppm	50 ppm
τ ₁ (ns)	10	16
τ ₂ (ns)	128	35
τ ₃ (ns)	129	119

LXe	25 ppm	50 ppm
τ ₁ (ns)	22	37
τ ₂ (ns)	121	38
τ ₃ (ns)	131	108

Dual Phase Xe Doping – S2 light



25 ppm Xe



50 ppm Xe

Successfully operated the detector in the dual phase mode for an extended period of time!

N₂ Injection + Xe Doping

The purpose was to obtain the N₂ contamination level in ProtoDUNE-SP by controlled doping of N₂ and investigate the level of Xe that should be doped in order to compensate for the light loss due to N₂ contamination.

PMTs

- R11065 with TPB coating (LAr w/TPB) x2
- R11065 without TPB coating (LAr no TPB)
- R11410 (LXe)

anode grid

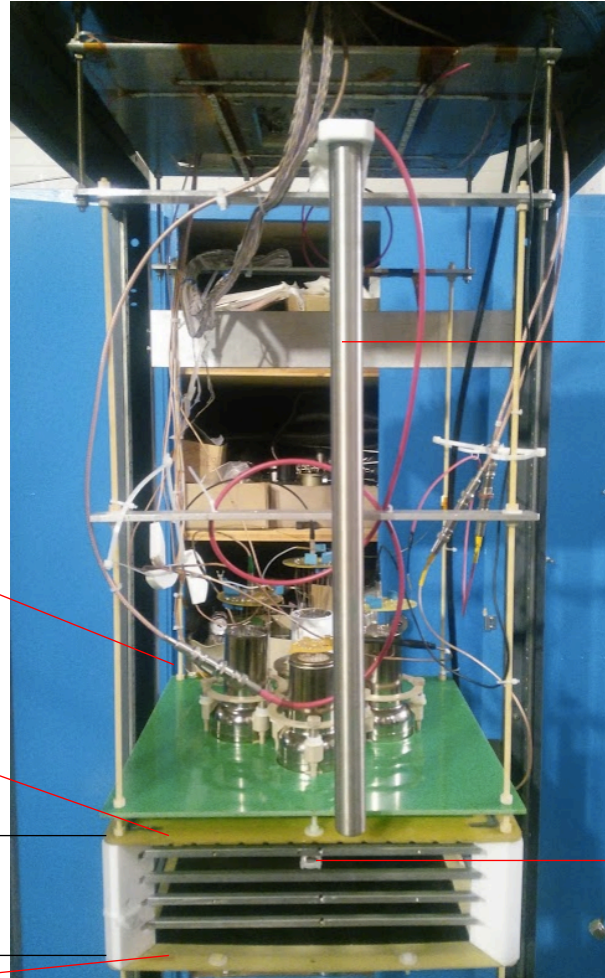
12.5 cm drift distance (~ 26 MeV)

cathode

Level meter

Temperature sensors
LED + fiber
Camera

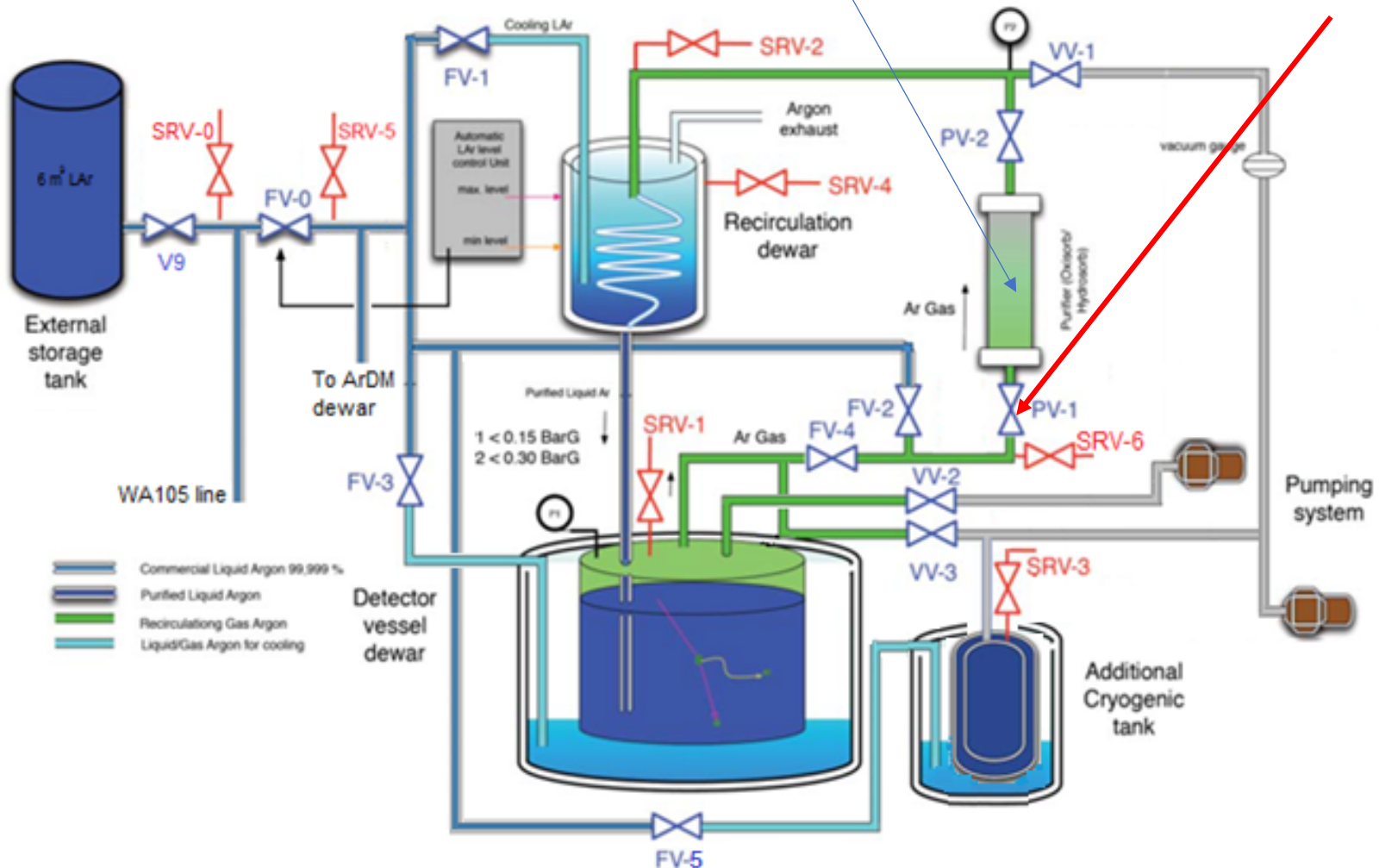
Am-241
alpha source
(40 kBq) – 5 MeV



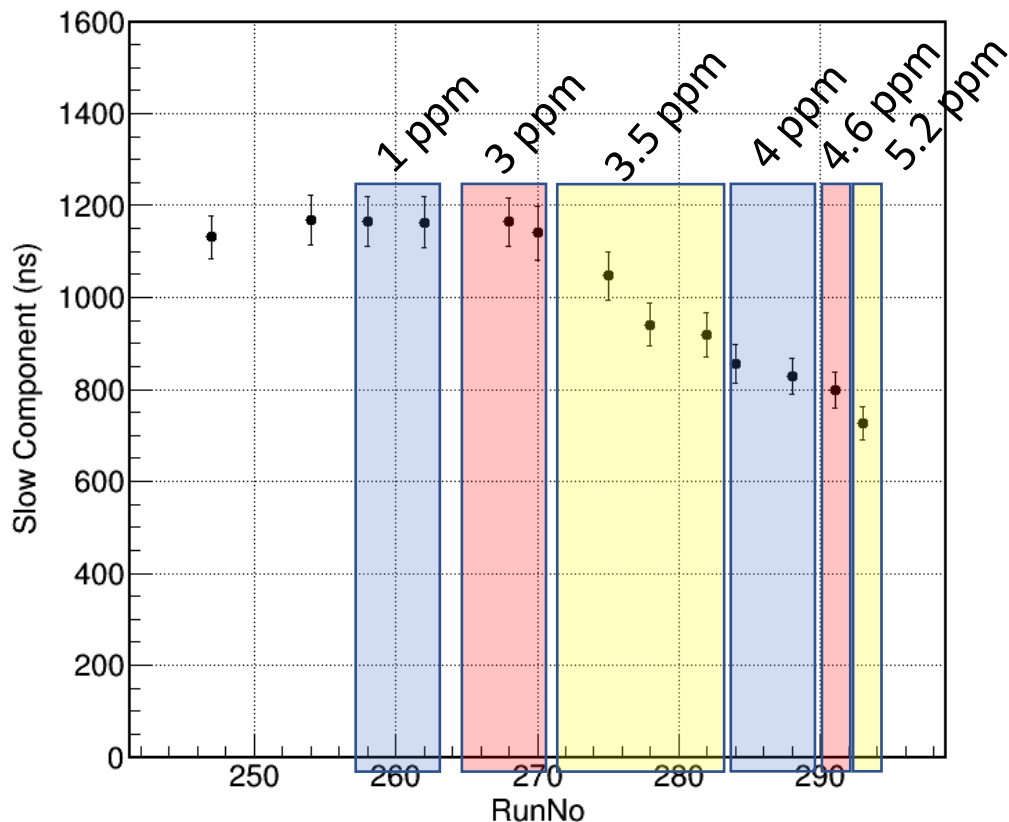
Injection/Doping Setup

1 g/s of Ar gas

Xe and N₂ injection area
(gas mixing)



N₂ Injection



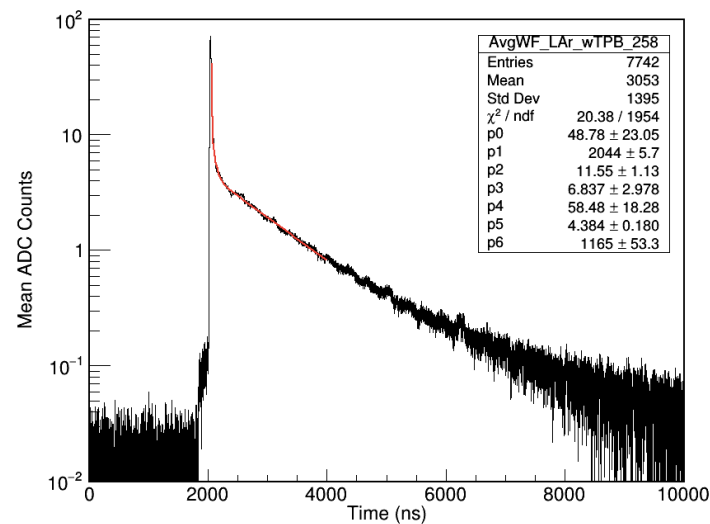
0 ppm $\sim 1.15 \mu\text{s}$

5.2 ppm $\sim 0.75 \mu\text{s}$

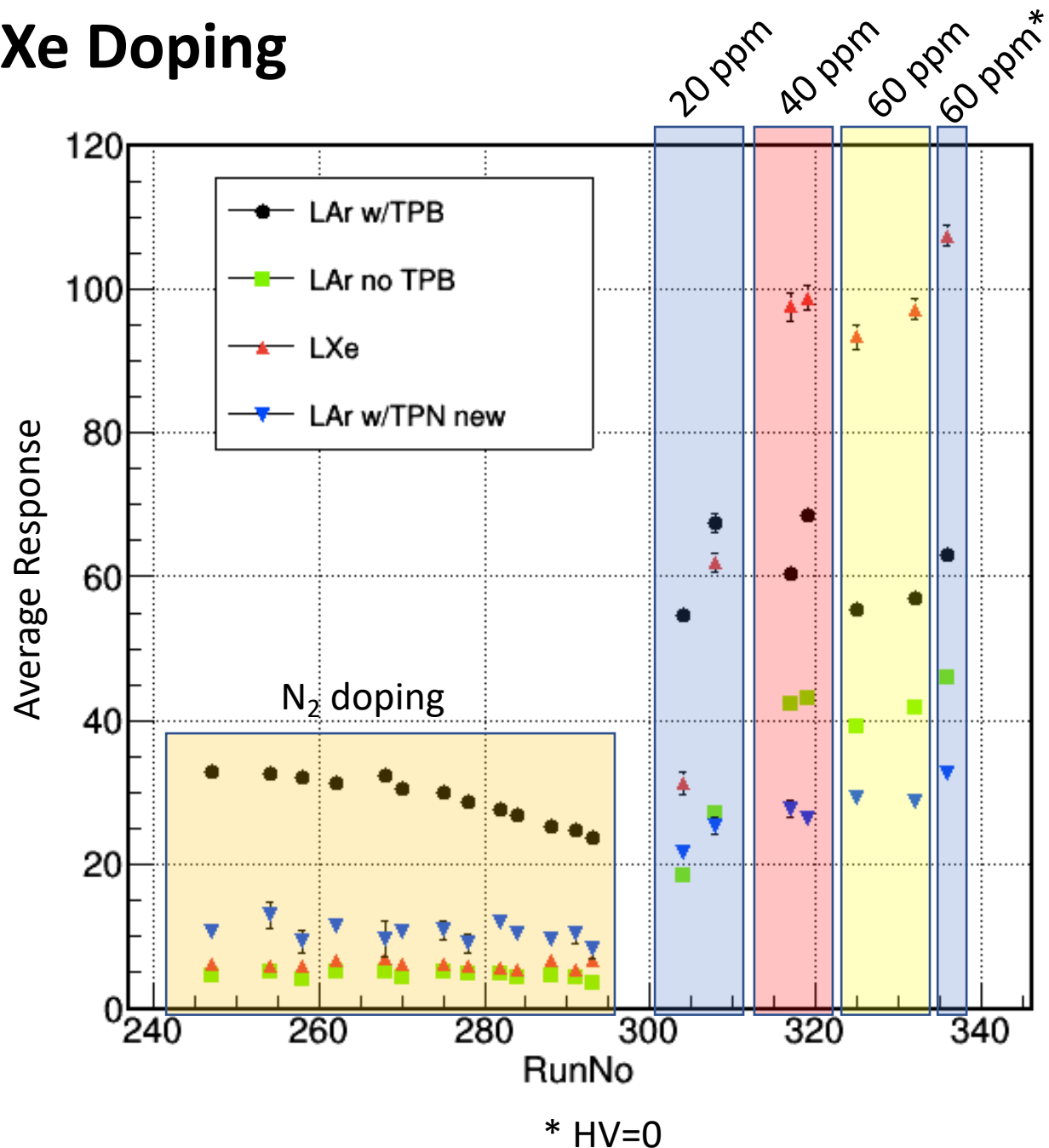
➔ $\sim 65\%$ reduction in the slow component

The injection was performed in four days at several sessions. The outcome was inspected carefully after each injection.

Slow component obtained with a three-component exponential fit to the falling edge of the average waveforms.



Xe Doping



LAr w/TPB response drops to ~ 70 % with N₂ doping to 5.2 ppm

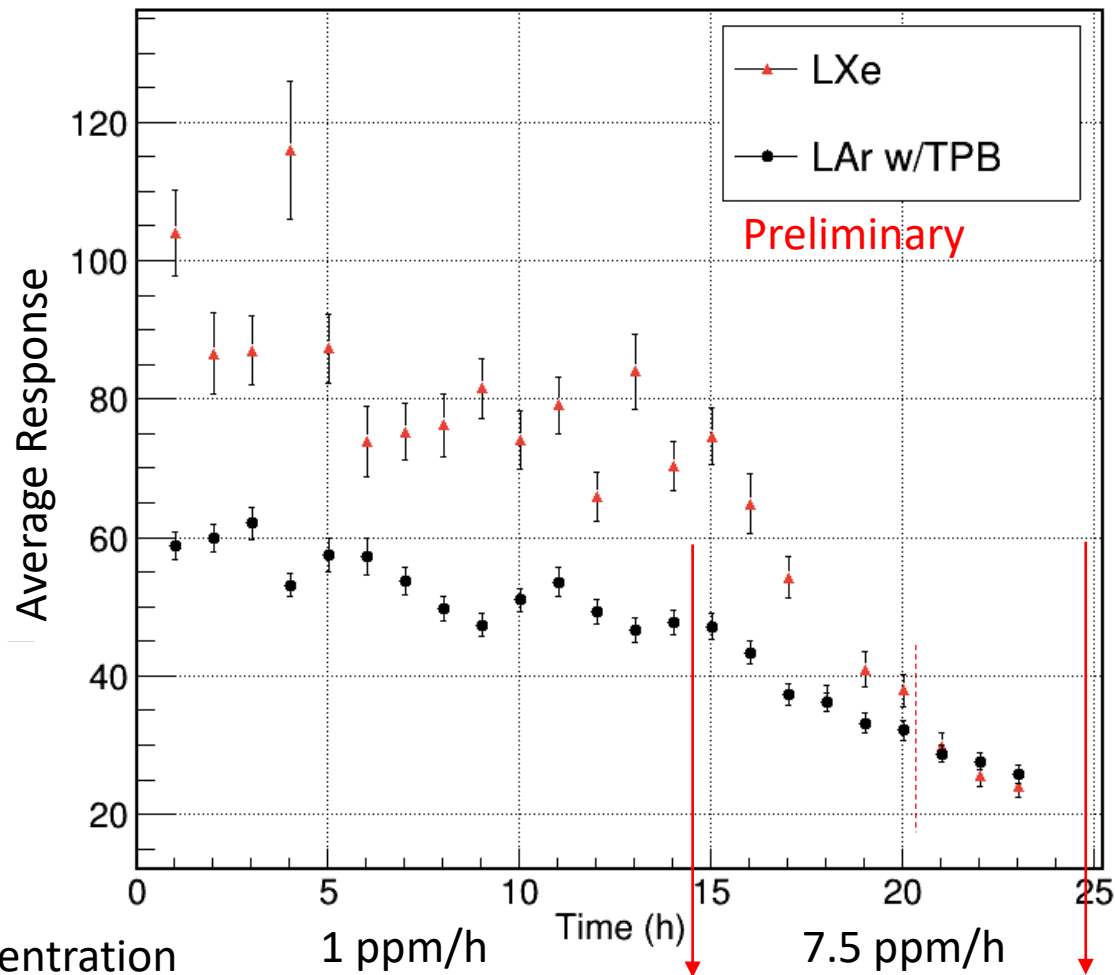
All PMTs see an increase in the level of light

The amount of light seen is larger than the pure LAr response with the first Xe doping

LAr w/TPB new is newly coated for this campaign. Needs more testing before its response can be compared with LAr w/TPB.

Continuous N₂ Injection

At the end of the test program, we continuously injected N₂ at a rate of 1 ppm/h for 14 h and 7.5 ppm/h for 9 h



Due to present Xe concentration, the effect is minimal up to very high N₂ fractions.

Starting concentration
5 ppm

1 ppm/h

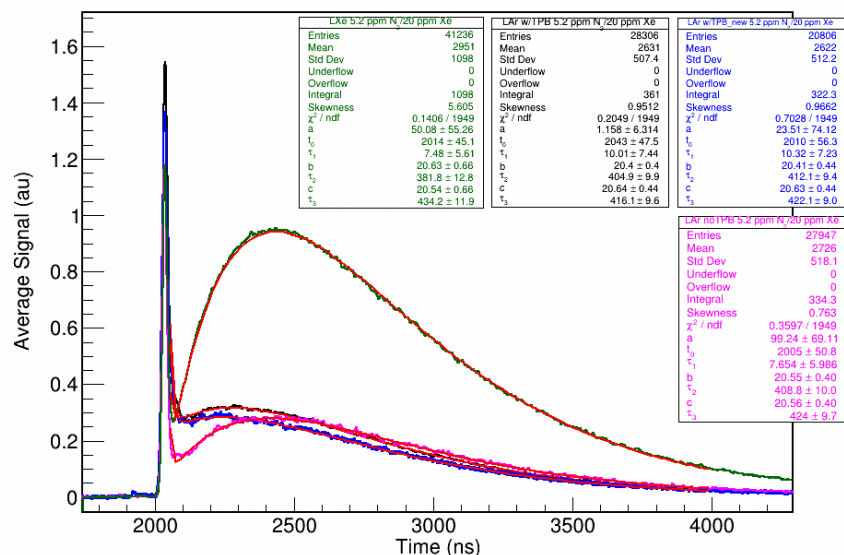
Time (h)

7.5 ppm/h

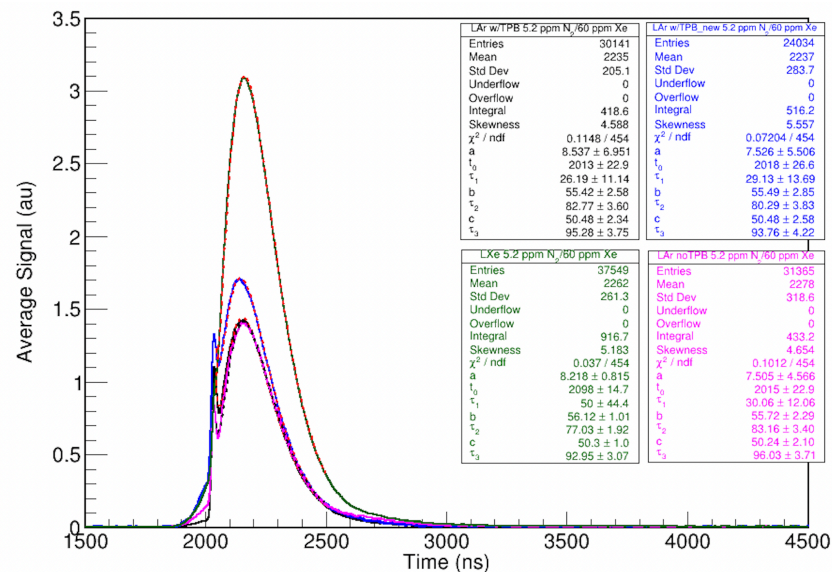
19 ppm

86.5 ppm

N₂ Injection + Xe Doping – Signal Timing



5.2 ppm N₂ / 20 ppm Xe



5.2 ppm N₂ / 60 ppm Xe

Average waveforms fit to: $f(t) = ae^{-(t-t_0)/\tau_1} - be^{-(t-t_0)/\tau_2} + ce^{-(t-t_0)/\tau_3}$

5.2 ppm N ₂ / 20 ppm Xe	LAr w/TPB	LAr w/TPB new	LAr noTPB	LXe
τ_1 (ns)	10	10	7	7
τ_2 (ns)	405	412	409	382
τ_3 (ns)	416	422	424	434

5.2 ppm N ₂ / 60 ppm Xe	LAr w/TPB	LAr w/TPB new	LAr noTPB	LXe
τ_1 (ns)	26	29	30	50
τ_2 (ns)	83	80	83	77
τ_3 (ns)	95	94	96	93

Summary

- The fifty liter liquid argon TPC at CERN is a valuable R&D equipment!
- We tested the performance of reflective foils coated (laminated) with TPB (PEN). The effective voltage was measured to be reduced around 5 %. The light yield increase compared to the plain cathode is 45 % (17 %) with TPB (PEN).
- We did several N_2 injection and Xe doping tests. The quenching effect of N_2 is eliminated by Xe doping starting from very small concentrations.
- A three component exponential fit to the average waveforms of light signals seem to represent the data well.
- The chamber was operated at the dual phase mode for several days.
- Data analysis to combine the results of various tests are underway.

