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 MΩ 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 N\textsubscript{2} 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
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

LAr w/TPB

LXe

LAr w/TPB

LXe

LAr

LXe

LAr

LXe

HV modifications

Stable calibration following a cooldown period.
The slow components were around 1.4-1.5 $\mu$s.
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 ~ 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.
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

Temperature sensors

30 cm
31.5 cm
33 cm

49.5 cm

31.3 cm
33.3 cm

46.5 cm
50.5 cm
52.5 cm

Liquid level

Drift distance 12.5 cm
Dual Phase Xe Doping – S1 light

Average waveforms fit to: 

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

<table>
<thead>
<tr>
<th>LAr w/TPB</th>
<th>25 ppm</th>
<th>50 ppm</th>
<th>LAr noTPB</th>
<th>25 ppm</th>
<th>50 ppm</th>
<th>LXe</th>
<th>25 ppm</th>
<th>50 ppm</th>
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</thead>
<tbody>
<tr>
<td>$\tau_1$ (ns)</td>
<td>12</td>
<td>15</td>
<td>$\tau_1$ (ns)</td>
<td>10</td>
<td>16</td>
<td>$\tau_1$ (ns)</td>
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<td>37</td>
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<tr>
<td>$\tau_2$ (ns)</td>
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<td>42</td>
<td>$\tau_2$ (ns)</td>
<td>128</td>
<td>35</td>
<td>$\tau_2$ (ns)</td>
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<td>$\tau_3$ (ns)</td>
<td>122</td>
<td>113</td>
<td>$\tau_3$ (ns)</td>
<td>129</td>
<td>119</td>
<td>$\tau_3$ (ns)</td>
<td>131</td>
<td>108</td>
</tr>
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</table>
Successfully operated the detector in the dual phase mode for an extended period of time!
N$_2$ Injection + Xe Doping

The purpose was to obtain the N$_2$ contamination level in ProtoDUNE-SP by controlled doping of N$_2$ and investigate the level of Xe that should be doped in order to compensate for the light loss due to N$_2$ contamination.

![Diagram of experimental setup]

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

Level meter
Temperature sensors
LED + fiber
Camera
Am-241 alpha source (40 kBq) – 5 MeV

12.5 cm drift distance (~26 MeV)

anode grid
cathode
Injection/Doping Setup

1 g/s of Ar gas

Xe and N\textsubscript{2} injection area (gas mixing)
N$_2$ Injection

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.

0 ppm ~ 1.15 $\mu$s
5.2 ppm ~ 0.75 $\mu$s

$\Rightarrow$ ~ 65% reduction in the slow component
LAr w/TPB response drops to ~ 70% with N\textsubscript{2} 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 $N_2$ Injection

At the end of the test program, we continuously injected $N_2$ 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 $N_2$ fractions.

Starting concentration 5 ppm

Average Response

1 ppm/h $\rightarrow$ 15 Time (h) $\rightarrow$ 7.5 ppm/h $\rightarrow$ 25

LXe
LAr w/TPB

Preliminary
N₂ Injection + Xe Doping – Signal Timing

5.2 ppm N₂ / 20 ppm Xe

5.2 ppm N₂ / 60 ppm Xe

Average waveforms fit to:

$$f(t) = a e^{-(t-t_0)/\tau_1} - b e^{-(t-t_0)/\tau_2} + c e^{-(t-t_0)/\tau_3}$$

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<tr>
<td>(\tau_1) (ns)</td>
<td>10</td>
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<td>(\tau_2) (ns)</td>
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<td>(\tau_3) (ns)</td>
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<td>(\tau_1) (ns)</td>
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<td>30</td>
<td>50</td>
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<tr>
<td>(\tau_2) (ns)</td>
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<tr>
<td>(\tau_3) (ns)</td>
<td>95</td>
<td>94</td>
<td>96</td>
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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 N₂ injection and Xe doping tests. The quenching effect of N₂ 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.