Light detection in Large scale cryogenic liquid detectors

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on behalf of the Ciemat Neutrinos Group
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Dual-phase LAr TPC

Ionizing particle in LAr (2.12 MeV/cm for mip)

Two measurements:

1. **Charge from ionization**: tracking and calorimetry

   Double-phase: multiplication in gas to increase gain and allow for long drift distances (> 5m) and low energy thresholds

2. **Scintillation light**: primary scintillation (trigger and t0) & secondary scintillation in gas

Large surface instrumented with PMTs in LAr
Dual-phase LAr R&D

- **Fundamental step**: realization and operation of large-scale detector prototyping before going to kton scale.

CERN Neutrino Platform

- **WA105 3x1x1 m³ proto (~4.2 ton) under installation @CERN**
- **WA105 6x6x6 m³ (~300 ton) in charged-particle test beam**

DUNE Far Detector: 10 kton dual-phase LAr detector (12x12x60 m³)

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**WA105/ProtoDUNE-dual phase photon system**

- **6x6x6 m³ (fid.) DLAr TPC @CERN** to test technical solutions and perform physics studies

**Basic configuration:**
- 36 cryogenic photomultipliers
- Wavelength-shifter: TPB coating on the PMT (or on external plates)
- Voltage divider base + single HV-signal cable + splitter (external)
- DAQ system (external)

**Goals:**
- Trigger for non-beam events
- $t_0$ for both beam and non-beam events (cosmic background rejection)
- Possibility to perform calorimetric measurements and particle identification

Some detector parameters:
- 8.3x8.3x8.1 m³ total volume
- Total mass: 705 tons
- Active mass: 300 tons
- 7680 charge readout channels

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WA105/ProtoDUNE-dual phase PMTs

- Hamamatsu R5912-02mod 8” PMTs
- Suitable for LAr and proven technology in LAr
- Excellent timing resolution
- Dynode stages: 10/14
- Gain: 10^7/10^9
- Dark counts: 4000 cps
- Diameter: 8”
- Cathode coverage: ~3%

3x1x1 will be perfect test bench to understand light detection for double phase.
2 possibilities are considered for the wavelength shifter
- TPB on the PMT
- TPB on external plates

Mechanical structure designed accordingly

2 possibilities for power supply and cabling:
- Negative HV
- Positive HV
A) Current design:
- Negative power supply
- 2 Wires per PMT

Proposed design pros:
- One cable and one feed-through per PMT in the vessel
- Photo-cathode grounded
Cons:
- External decoupling (splitter) needed

B) Ciemat Proposed design:
- Positive power supply
- 1 Wire per PMT

Same PMT behavior expected (gain, signal shape.. etc) in both options
Each single splitter is enclosed into an aluminum box to reduce EM noise and crosstalk between channels.

The cables are directly connected to the board by screws and clamps. This reduces costs, the space required inside and outside the splitter boxes is reduced and the cable connections are keep inside the box which is good for noise and humidity.
Performed Tests for the 3x1x1 m3 detector PMTs
TPB coating and QE measurements at CERN

- TPB is coated in PMT glass and acrylic plates by vacuum evaporation (0.05 – 0.2 mg/cm²)
- TPB uniformity was checked
First cryogenic tests at CIEMAT

- PMT test in LN2:
  - Test of the PD system **up to 2 bars** (equivalent to ~7m LAr)
  - Test of PMT response **in cold** with single wire base:
    - Dark current
    - Pulse shape
    - Gain
  - Response of the system for **different light conditions** (in preparation)

Gain evolution with time

Before immersion 16 h after immersion
Pre-installation PMT tests at CERN

- Tests Performed for the **five** 3x1x1 PMTs
- Assembly of the whole photodetection system
- Gain tests with LED scanning the PMT voltage from 1000 V to 1600 V
- Test in GAr with alpha source for checking **128 nm light detection**

**Ar scintillation response**

**FA094 HV = 1500 V**

**FA090 HV = 1500 V**

**FA094 + Coated plate + CIEMAT base**

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Plans for the PD system for the 6x6x6 m³ detector

- **Tests and setups at CIEMAT**
  - **Test 1:** Design validation tests (with a few PMTs)
    - Study the variation of the PMT response with the light intensity and frequency + optimization of the PMT base
    - Setup ready (~60 l vessel)
  - **Test 2:** Characterization tests (with all PMTs)
    - Characterization of all PMTs being installed at WA105 at room and cryogenic temperature (dark current, gain vs HV, ...)
    - Setup in preparation (~300 l vessel)

- **TPB coating at CERN or Univ. Barcelona/IFAE**
  - Uniformity and spectral response to be tested
  - Stability measurements foreseen

- **Light calibration system being designed**
- **The complete PD system should be operational in 2018**
Details:
- Filters of the Filter Box are to control the test global light intensity.
- A diffuser at the end of each fiber provide a homogeneous illumination of the photo-cathode.
- The function of the monitor #1 is to compensate possible variations over time in the lighting system.
- The function of monitor #2 is to get simultaneous outputs of the same PMT type at room temperature and in LN2 for being compared receiving the same amount of light.

The three PMTs are single cable with + HV and signal splitter.
Preliminary linearity results at room T

Cryogenic tests will be performed this Summer
Test 2 - 6x6x6 m³ Production tests

Fast tests to characterize and validate each single PMT+base before installation:
- Gain vs HV
- Dark current frequency

These tests will also be performed at room and cryogenic temperatures.

We have bought a vessel with capacity for 4 PMTs in LN2 to be able to test 4 PMTs/week.

On 2017 All 40 PMTS of the 6x6x6 will be tested at Ciemat.
TPB Coating for WA105. IFAE

- **Thin Films Deposition system:**
  - Chamber: high 45 cm, Ø: 30 cm.
  - Mechanical pump
  - Diffusion pump (High vacuum)
  - Vacuum meters:
    - Pirani
    - Penning
  - High intensity source
  - In situ thickness measurement (quartz crystal microbalance)

- **TPB Deposition parameters:**
  - Technique: Thermal evaporation
  - Base pressure: < 5·10^{-7} mbar
  - Substrates: glass and Acrylic (5 x 5 cm).
Linux based DAQ developed by PSI and TRIUMF.

The DAQ software was used at T2K and at the IFAE electroluminescence setup for DAQ and Slow Control.

- Web interface.
- Plenty of experience at IFAE.
- Easy to setup
- Tools available for decoding and monitoring.
- Easy to integrate commercial hardware with C library interfaces.
Light Readout Electronics

- Development of **cost-effective electronics** for light readout
- LRO electronics based on the same technology as charge readout = \( \mu \text{TCA} \) for easy integration in the global DAQ system
  - MicroTCA = Micro Telecommunications Computing Architecture
- Easy to scale for large detectors
- LRO FEB at room temperature (reliability, maintenance, upgradability)
- WA105 LRO FEB developed by APC-LAPP-OMEGA-IPNL collaboration

Diagram:
- \( \mu \text{TCA} \) rack DAQ + FEB
- 9 PMTs

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**PARISROC2 ASIC**

(Photomultiplier ARray Integrated in Sige ReadOut Chip)
- 16 inputs for negative signals
- Time stamping (1 ns precision)

**ADC AD9249** for charge measurement:
- 16 channels
- 14 bits at 40 MHz (\(T_s = 25\) ns). Up to 65 MHz (\(T_s = 15.4\) ns) if needed
Light calibration system

- Measure the gain inside the detector.
- Intercalibrate the optical units.
- Monitor the performances and the stability of the light detection system (QE, TPB conversion...)
- Monitor the detector behavior in “real time” (event rate, purity...)

It will be necessary to produce light inside the detector in a controlled way.
Light calibration system.

Software

Automatic procedure

Calibration analysis → Extract PV, Gain, Dark counts ....etc

Automatic procedure:

\text{FIT} → \text{Calibration Map} → \text{Gain file} → (DB to store / access the data)
DUNE Far Detector dual-phase light readout system

- Hamamatsu R5912-02mod PMTs + coating, at the bottom of the tank below the transparent cathode (same as WA105)
  - Minimal: 1 PMT/4m² (180 PMTs)
- Mechanical supports implemented for different TPB coating options
- Single cable for HV + signal
- Development prototype of uTCA light readout digitization boards based on Bittware S4AM, 9 channels/card, 36 PMTs in 6x6x6
- Trigger from PARISROC2 ASIC

Input from WA105 will be crucial for final configuration of a 10 kton dual-phase DUNE Far Detector
R&D
VUV SiPM Prototype. Performed Tests

- New SiPMs from Hamamatsu (3x3mm – 100um VUV3) sensitive to VUV light without wavelength shifter

![Graph showing PDE of VUV3-MPPC](image)

<table>
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<tr>
<th>Serial No.</th>
<th>Vop [V]</th>
<th>dark counts (kcps)</th>
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<tbody>
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<td>671</td>
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<tr>
<td>A0020</td>
<td>53.63</td>
<td>607</td>
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</table>

Vop : Operating Voltage at Gain = 5.5x10^6
VUV SiPM Prototype. Performed Tests

Setup

-光学纤维
-260nm LED
-SiPM
- Fiber
-SiPM
- 阴暗LN2容器
- Gali S66放大器 (x6)
- Thorlabs 260 nm LED
- CAEN V965A QDC
- Tek AFG3252信号发生器
VUV SiPM Prototype. Performed Tests

The aim of this first tests is to check how the devices behave at cryogenic temperatures and low wavelengths.

<table>
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<th>Serial N.</th>
<th>Vop (V)</th>
<th>Dark Counts (cps)</th>
<th>Gain</th>
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<td>675k</td>
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<th>Vop * (V)</th>
<th>Dark Counts (cps)</th>
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<td>6.93E6</td>
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<tr>
<td>A0020</td>
<td>44.1</td>
<td>~20</td>
<td>6.71E6</td>
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*The Temperature coefficient provided by Hamamatsu doesn’t work at 77K. Vop for LN2 is an estimation so we have a similar gain than the one we have at room temperature.
VUV SiPM Prototype. New Setup in Progress

- New dewar construction in progress.
- Lid just arrived ➔ Ready to start the Tests!

- Replace QDC with fast ADC ➔ Readout Software and post processing already developed.

- The aim of this setup:
  1. Measure the PDE in Liquid Argon @ 128nm
  2. Systematic measurement of dark counts and Operating Voltage

First results will be available for the end of this summer
ITO + TPB as Cathode. ETH Zurich

- Idea: Replace grid cathode Transparent cathode built from PMMA plates coated with conductive ITO (Indium Tin Oxide) coating
- TPB coating for VUV shifting

### Advantages:
- Uncoated PMTs will not be sensitive to light produced below cathode
- Protection against discharges due to possible bubbles from bottom of the tank

Bit it is....
- Expensive
- Many plates of $\leq 1 \text{ m}^2$ → gluing them together and align them
- Effect of ions on TPB?

Principle to be tested in the ArDM experiment
ITO + TPB as Cathode. ETH Zurich

A first proof of principle operation in 3L LAr TPC

Mechanical and resistive tests of the coating
- Contacts seem also be reliable at low temperature

Gluing Tests:
Excellent mechanical and optical properties

1m open cryostat @ CERN - half filled with LAr
We are working on the light readout for double phase LAR TPC with PMTs as baselines and other alternatives.

WA105 will allow us to test all proposed solutions for large scale detectors.

We will follow closely the evolution of the single-phase proposals and the results DUNE Single Phase light readout.

From these studies an optimized proposal for 10 KT detector light readout system will emerge.
Thank you for your attention
BACKUP
Negative & Positive PMTs base circuits

A) Current design (-HV)
2 cables are needed: HV & Signal

B) Proposed design (+HV)
Only one cable is needed for HV & Signal.
Circuit changes:
1- Input RC filter is moved from cathode to anode and cathode is directly connected to GND
2- The 50Ω termination resistor is connected to GND by a capacitor
Preliminary Tests – Positive base with/without the 50Ω termination

Single waveform

Average of 128

Without the 50Ω

With the 50Ω

No reflections observed removing the 50 termination at the PMT base, so, it’s not needed and we save the extra capacitor on the base.
Preliminary Tests - Conclusions

- Dual cable base pick-up more low frequency noise (base line oscillation) which can easily removed by SW.
- Single cable base removes the low freq. noise but pick-up a bit more high freq. noise.
- Same gain for same absolute voltage
- SPE with similar resolution for both bases
- The 50Ω termination is not needed and no extra capacitors are needed in the positive base vs the negative base.
HV to Signal-Output noise transference in the DC splitter

A1535 Voltage ripple specification: 30mV max from 10Hz to 15MHz

A1535 Voltage ripple measurements: ~ 250mV up to 100MHz (worst channel)

With the splitter attenuation (>50dB) Vripple ≤ 1mV
Some issues for WA105

- Cosmics are normally great for detector characterization but in for WA105 also a challenge
  
  ~10 kHz of cosmics
  $\Rightarrow$ ~40 cosmics overlapping in 4 ms readout window
  $\Rightarrow$ reconstruction of beam event a challenge.

- $dE/dx$ (MIP): ~2 MeV/cm
  $\Rightarrow$ 50,000 e/ions, 50,000 $\gamma$ per cm
  $\Rightarrow$ 30 million e/ions and $\gamma$ per MIP in 600 cm

- Electroluminescence (EL) in gas phase
  - Each e- will produce some hundreds $\gamma$s
  - “constant” background

- Primary light has 2 components:
  - fast component, singlet: $6 < \tau < 18$ ns
  - slow component, triplet: ~1.6 $\mu$s
  - 30 million photons for straight cosmic
  - Most of light for MIPs in fast component $\Rightarrow$ perfect for triggering
  
  But we have light background ...

- 2 mm, 5 kV/cm
- 5 mm, 3 kV/cm
- 1 mm LEM, 35 kV/cm