Liquid Argon TPCs for future neutrino oscillation experiments

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Happy birthday, Bruno!

Dubna, 1984
Arbitrary choice for a 25’ talk

• describe a part of the intense R&D work in progress worldwide on LAr TPCs in view of future neutrino oscillation projects

• example: Bern group activities since several years aimed at LBL future projects such as LAGUNA, LAGUNA/LBNO (see next talk)

• this work that can also be useful for short time-scale experiments (SBL configuration) according to a graded strategy

• notable example: MicroBooNE at Fermilab

• another long-term LBL applications, LBNE, is the subject of the next-to-next talk
R&D issues for LAr TPCs

- realize XXL observatories: long drift distance is an issue (according to the specific approach)
- readout: double phase, wire planes with cold electronics (low noise), ...
- purity (recirculation), diffusion, recombination
- high voltage (how to supply and limitations)
- insulation, evacuation, mechanics,...
- calibration
- event reconstruction: exploit the rich information from the raw data
Evolution of LAr TPCs at LHEP Bern

0.5 cm  25 cm  57 cm

JINST 4, P07011 (2009)
JINST 5, P10009 (2010)
The Bern ARGONTUBE (5 m long drift)
Up to 4.76 m drift distance
About 200 l active volume (total 1200 l), 280 kg LAr
HV generated inside by a Greinacher circuit (up to 500 kV, 1 kV/cm design values)
2 wire planes, 20x20 cm$^2$, 3 mm wire pitch, 64x64 channels
PMT’s, scintillator planes and UV-laser beams for triggering
LAr purity: better than 0.1 ppb contaminant
S/N ratio >10
- Greinacher circuit: 125 stages, input 4 kV AC
- COMSOL finite element analysis software to optimize the geometry of the field-shaping rings
- Goal: drift field of 1 kV/cm
- Reached 170 kV (0.34 kV/cm)

The use of Greinacher for LAr detectors was originally proposed by the ETHZ group: J.Phys.Conf.Ser. 308 (2011) 012027
R/O electronics

ARGONTUBE operation: 100-1000 ns sampling time

e⁻ speed: 2mm/µs → max drift time: 2500 µs (@ 1 kV/cm)
Cryogenics & purity

LAr recirculation system:
• first cleaning stage at filling, continuous liquid recirculation through filters with bellow pumps
• standard purification cartridges: active copper

Cryo-cooler to run 24/7 long term without refilling
Long drift tracks (cosmic-rays) routinely detected

(compressed aspect ratio!)
Cold electronics tests

• Preamplifiers immersed in LAr at 87 K

• Advantages:
  
  – Directly on the wire planes, close to signal source. Avoids long cables between wires and preamps (reduce noise from pickup on the way, cable capacitance,...)
  – @at 87K: CMOS technology gives lower thermal noise, higher gain and higher speed
  – Easier design of cryostat and cable feedthroughs

• Configurable (gain, timing, ...) CMOS ASIC chip (LARASIC) designed by BNL: V. Radeka et al, BNL and FNAL
  
iopscience.iop.org/1742-6596/308/1/012021/pdf/1742-6596_308_1_012021.pdf

• ARGONTUBE: test chips in a real environment with long tracks and make comparison with warm electronics
Warm, for impedance matching (gain 1)

(Warm electronics running in parallel for comparison)
Cold electronics
Cold electronics
Cold electronics
Cold electronics
UV-laser calibration

LHEP Bern pioneered the use UV laser-beams to ionize LAr by a multi-photon process

Exploit the technology to generate calibration “tracks” to correct for:
- space charge effects,
- local accumulation of ions leading to field distortions

2009 JINST 4 P07011
NJP 12 (2010) 113024
Example of track correction for E-field disuniformities
Moving UV-laser beam in LAr
(for the needs of the MicroBooNE experiment, see later)
Application: measurement of purity by UV-laser tracks

$E_{\text{drift}} = 200 \text{ V/cm}$

Recirculation system running for 6 h. at ~50l/h. e- life time increased by a factor 10

Night stop and morning measurement

Re-fill with argon

Recirculation system running again

ARGONTUBE routine operation: 2.5 ms lifetime (0.12 ppb Oxygen equivalent)
Physics result from ARGONTUBE:
measurement of transverse charge diffusion (by laser beams)

\[ D = \frac{\sigma^2 - \sigma_0^2}{2t} \]

\[ D = 4.21 \pm 0.42 \text{ cm}^2/\text{s} \]
we entered the era of precision measurements of neutrino oscillations

- liquid argon TPCs also perfectly suited for X-section studies (particle ID) and SBL accelerator experiments

- physics goal: assess the completeness of the 3-flavor mixing scenario vs additional sterile neutrinos (LSND and MiniBooNE signal/indications)

- long standing issue with anomalies in:

  \[ \nu_\mu - \nu_e \text{ and } \bar{\nu}_\mu - \bar{\nu}_e \text{ oscillations} \]

- is it a real signal of new physics or an unknown background?
MiniBooNE electron-like event excess

muon  electron  neutral pion
The excess translates into allowed oscillation parameters
Another mass splitting parameter?  
Then (at least) another (sterile) neutrino
Address the LSND/MiniBooNE signal with an advanced detection technique

**MiniBooNE**

Electron, Photon  
Muon  
Proton  
\( \pi^0 \rightarrow \gamma + \gamma \)  
(Cherenkov Detector)

**MicroBooNE**

Electron, Photon  
Muon  
Proton  
\( \pi^0 \rightarrow \gamma + \gamma \)  
(LArTPC)
LAr TPC technology (ArgoNeuT neutrino-induced event)

Pixel size: 4mm x 0.3mm

Color is proportional to amount of charge collected

~96cm
• ArgoNeuT: 175 l of liquid Argon
• Placed in the NUMI neutrino beam at Fermilab
• 3 wire planes oriented at 60° relative to each other
• Each plane: 240 wires with 4 mm pitch
• Electric field of 500 V/cm
• 2048 samples in 400 µs

• Large samples of low-energy neutrino interactions (0.1-10 GeV) collected and analyzed:
  
  JINST 7 (2012) P10019
  JINST 7 (2012) P10020
  JINST 8 (2013) P08005
The experiment will measure low energy neutrino cross-sections, and investigate the excess of events observed by the LSND/MiniBooNE experiments.

The collaboration includes groups from:

MicroBooNE: a “classical” SBL oscillation experiment

Start data taking 2014: in 3 years expect $6.6 \times 10^{20}$ pot and ~140 k events (BNB)
$e/\gamma$ separation performance ($dE/dx +$ topology)

PRELIMINARY MC

2.4 cm
if assume an electron signal and have analyzed for an e⁻
(>5σ)

unlike MiniBooNE, MicroBooNE can distinguish e⁻’s from γ’s.

if assume a photon background and have analyzed for a γ
(tell if part of the MiniBooNE signal is due to γ’s)
(>4σ)

(projections for 6.6x10²⁰ POT)
The MicroBooNE detector

Dimensions: 10 m x 2.3 m x 2.5 m
125 kV high voltage, 2.5 m drift length
3 wire planes (3 mm pitch) Y, U, V
32 8” PMT’s
Y: vertical plane (2.5 meter long wires), U,V planes: +/- 60 degrees from vertical (5 meters long)
The experimental hall

The realization of the various sub-systems is on schedule
One example: the UV-laser calibration system

Two independent laser lines on either side of the cryostat
Remote controlled steered beam (mirrors) with easy slow control
The laser source has to be in a box, due to its UV radiation.
Full scale test of the MicroBooNE laser system
Спасибо за ваше внимание!