R&D on LAr TPCs for neutrino, proton decay and DM experiments

Presented by A. Marchionni, ETH Zurich
CHIPP Annual Plenary Meeting, Sept. 2008

- **GLACIER:** a concept for a scalable LAr detector up to ~ 100 kton
  - a precision detector for proton decay searches & neutrino oscillation measurements
- **Same technique suitable for dark matter searches**
- **Necessary R&D and plans**
  - dewar design, safety, underground operation
  - novel readout techniques, electronics (performance, reliability, cost reduction,...)
- **LAr LEM-TPC:** a novel scalable detector for cryogenic operation
  - 0.1 x 0.1 m² test setup
  - low-noise preamplifiers and DAQ developments
- **ArDM:** a ton-scale LAr detector with a 1 x 1 m² LEM readout
  - status of the inner detector
  - cryogenics and first cool down

- **Conclusions**
Processes induced by charged particles in liquid argon

When a charged particle traverses medium:

- **Ionization** process
- **Scintillation** (luminescence)
  - UV spectrum (λ=128 nm)
  - Not energetic enough to further ionize, hence, argon is transparent
  - Rayleigh-scattering
- **Cerenkov light** (if fast particle)

\[ \tau_1 = 6 \text{ ns} \]
\[ \tau_2 = 1.6 \mu\text{s} \]

\[ \Rightarrow \text{UV light} \]
\[ \Rightarrow \text{Charge} \]
\[ \Rightarrow \text{Cerenkov light (if } \beta > 1/n) \]

M. Suzuki et al., NIM 192 (1982) 565
GLACIER

A scalable detector with a non-evacuable dewar and ionization charge detection with amplification

Giant Liquid Argon Charge Imaging ExpeRiment

Electronic crates possibly up to 100 kton

Drift length

h = 20 m max

Passive perlite insulation

Single module cryo-tank based on industrial LNG technology

Size dictated by neutrino and proton decay experiments
GLACIER concepts for a scalable design

- **LAr storage based on LNG tank technology**
  - Certified LNG tank with standard aspect ratio
  - Smaller than largest existing tanks for methane, but underground
  - Vertical electron drift for full active volume

- **A new method of readout (Double-phase with LEM)**
  - to allow for very long drift paths and cheaper electronics
  - to allow for low detection threshold (≈50 keV)
  - to avoid use of readout wires
  - A path towards pixelized readout for 3D images

- **Cockroft-Walton (Greinacher) Voltage Multiplier** to extend drift distance
  - High drift field of 1 kV/cm by increasing number of stages, w/o VHV feed-through

- **Very long drift path**
  - Minimize channels by increasing active volume with longer drift path

- **Light readout** on surface of tank
  - Possibly immersed superconducting solenoid for B-field

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<table>
<thead>
<tr>
<th>Scalable detector</th>
<th>Size (kton)</th>
<th>Diameter (m)</th>
<th>Height (m)</th>
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<tr>
<td></td>
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Steps towards GLACIER

Small prototypes ➞ ton-scale detectors ➞ 1 kton ➞ ?

- B-field test
  - proof of principle double-phase LAr LEM-TPC on 0.1x0.1 m² scale

- LEM test
  - LEM readout on 1x1 m² scale
  - UHV, cryogenic system at ton scale, cryogenic pump for recirculation, PMT operation in cold, light reflector and collection, very high-voltage systems, feed-throughs, industrial readout electronics, safety (in Collab. with CERN)

- Test beam 1 to 10 ton-scale
  - Application of LAr LEM TPC to neutrino physics: particle identification (200-1000 MeV electrons), optimization of readout and electronics, cold ASIC electronics, possibility of neutrino beam exposure

- ArDM ton-scale
  - direct proof of long drift path up to 5 m

- Argon Tube: long drift, ton-scale
  - we are here

- 1 kton
  - full engineering demonstrator for larger detectors, acting as near detector for neutrino fluxes and cross-sections measurements, ...
LAr LEM-TPC

A novel kind of LAr TPC based on a Large Electron Multiplier (LEM)

Operated in double phase: liquid-vapor

A. Badertscher et al., ‘Construction and operation of a double phase LAr Large Electron Multiplier TPC’, accepted contribution at the 2008 IEEE Nuclear Science Symposium, Dresden, Germany
Double stage LEM with Anode readout

- Produced by standard Printed Circuit Board methods
- Double-sided copper-clad (18 μm layer) FR4 plates
- Precision holes by drilling
- Gold deposition on Cu (<~ 1 μm layer) to avoid oxidization
- Single LEM Thickness: 1.55 mm
- Amplification hole diameter = 500 μm
- Distance between centers of neighboring holes = 800 μm

Bottom LEM

Top LEM

Signal collection plane

10 x 10 cm²
16 strips 6 mm wide
LAr LEM-TPC: principle of operation

Electric field in the LEM region
~ 25 kV/cm

\[ \text{Gain} = G_{\text{LEM1}} \cdot G_{\text{LEM2}} = G^2 = e^{2\alpha x} \]
\[ \alpha: \text{effective LEM hole length (~0.8 mm)} \]
\[ 1^{\text{st}} \text{ Townsend coefficient} \approx A_p e^{-B_p/E} \]

Typical Electric Fields for double-phase operation
Preamplifier development

Inspired from C. Boiano et al.

Custom-made front-end charge preamp + shaper

2 channels on one hybrid

4 different shaping constants

<table>
<thead>
<tr>
<th>Version</th>
<th>FET integrator decay time constant (µs)</th>
<th>Shaper integration time constant (µs)</th>
<th>Shaper differentiation time constant (µs)</th>
<th>Sensitivity (mV/fC)</th>
<th>Noise (e⁻)</th>
<th>S/N @ 1 fC</th>
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<td>3.6</td>
<td>13</td>
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<td>485</td>
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<td>10</td>
</tr>
</tbody>
</table>

ICARUS electronics
($T_f=1.6$ µs)

- $S/N=10 @ 2$ fC, $C_i=350$ pF
- equivalent to $S/N=7 @ 1$ fC, $C_i=200$ pF
Data Acquisition System development

- In collaboration with CAEN, developed A/D conversion and DAQ system
  - 12 bit 2.5 MS/s flash ADCs + programmable FPGA with trigger logic
  - Global trigger and channel-by-channel trigger, switch to 'low threshold' when a 'trigger alert' is present
  - 1 MB circular buffer, zero suppression capability, 80 MB/s chainable optical link to PC

Tests in progress
LEM-TPC operation in pure GAr at 300K

Radioactive sources

- $^{55}$Fe: 6.9 kBq
- $^{109}$Cd: 0.5 kBq

Gain vs LEM electric field

- LEM: red
- Anode: green

Typical cosmic ray events

Diploma Work by A. Behrens, ETHZ

F. Resnati, PhD ETHZ in progress
Typical cosmic ray events

LEM-TPC operation in double phase Ar

Proof of principle of a LAr LEM-TPC

F. Resnati, PhD ETHZ in progress
ArDM: a ton-scale LAr detector with a 1 x 1 m² LEM readout

Cockroft-Walton (Greinacher) chain: supplies the right voltages to the field shaper rings and the cathode up to 500 kV (E=1-4kV/cm)


ETHZ, Zurich, Granada, CIEMAT, Soltan, Sheffield

Assembly @ CERN
ArDM Inner Detector

- Field shaping rings and support pillars
- Cockroft-Walton (Greinacher) chain
- Cathode grid
- Shielding grid
- PMTs

Light measurements vs. position of $^{241}$Am source

$^{241}$Am source GAr @ 88K

Light vs. Position of the source

$P=1.1\text{bar}$

$\tau_2 \sim 3.2\mu s$
ArDM
Cryogenics and LAr purification

Recirculation and CuO purification cartridge

Bellow pump

In collaboration with BIERI engineering Winterthur, Switzerland
Cryogenic Tests

In collaboration with BIERI engineering Winterthur, Switzerland

First ArDM cooldown with automatic refill of LAr cooling bath

LAr Pump test

Measured LAr flux ~ 20 l/hr
The next short-term steps …

- Engineering design of an underground 100 kton LAr tank
  - Part of LAGUNA package by Technodyne
- Small LAr LEM-TPC
  - implementation of a recirculation system for LAr purification
  - test of cold electronics
  - investigation of efficiency, stability and energy resolution of the LEM readout system
- Filling of ArDM inner detector with LAr
  - address safety issues of ArDM: handling of one ton of LAr, in situ-regeneration of the LAr purification cartridge
  - operation of the LAr pump and purification cartridge
  - tests of light readout in LAr
  - test of the HV system
  - stability of cryogenic operation of the device: installation of a cryocooler
- Design and construction of a 1 × 1 m² LEM readout system for ArDM
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- **1 kton**

  12m 10m
ARGONTUBE

Bern, ETHZ, Granada

- Full scale measurement of long drift (5 m), signal attenuation and multiplication, effect of charge diffusion
- Simulate ‘very long’ drift (10-20 m) by reduced E field & LAr purity
- High voltage test (up to 500 kV)
- Measurement Rayleigh scatt. length and attenuation length vs purity
- Infrastructure ready
- External dewar delivered
- Detector vessel, inner detector, readout system, ... in design/procurement phase
R&D on electronics integrated on the detector

IPNL Lyon in collaboration with ETHZ

- R&D on an analog ASIC preamplifier working at cryogenic temperature
  - very large scale integration
  - low cost
  - reduction of cable capacitances

- R&D on a Gigabit Ethernet readout chain + network time distribution system PTP
  - further development of the OPERA DAQ, with larger integration, gigabit ethernet, reduced costs
  - implementation in just one inexpensive FPGA of the capabilities provided by the OPERA 'mezzanine' card
  - continuous and auto-triggerable readout
  - synchronization and event time stamp on each sensor with an accuracy of 1 ns

0.35μm CMOS charge amplifier delivered on July 2008, presently under test in Lyon

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Conclusions

- The synergy between precise detectors for long neutrino baseline experiments and proton decay (and astrophysical neutrinos) detectors is essential for a realistic proposal of a 100 kton LAr detector
  - discovery physics, not only precision measurements
- GLACIER is a concept for a scalable LAr detector up to 100 kton demanding concrete R&D
- ArDM is a real 1-ton prototype of the GLACIER concepts
- ArgonTube will be a dedicated measurement of long drifts (5m)
- Aggressive R&D on readout electronics ongoing (warm/cold options, detector integration…)
- After a successful completion of this R&D (ArDM, test beams, …) we want to proceed to a proposal for a 100 kton scale underground device
  - discussion of a 1 kton full engineering prototype
Comparison Water - liquid Argon

<table>
<thead>
<tr>
<th>Particle</th>
<th>Cerenkov Threshold in H\textsubscript{2}O (MeV/c)</th>
<th>Corresponding Range in LAr (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>e</td>
<td>0.6</td>
<td>0.07</td>
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<tr>
<td>(\mu)</td>
<td>120</td>
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<tr>
<td>(\pi)</td>
<td>159</td>
<td>16</td>
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<tr>
<td>K</td>
<td>568</td>
<td>59</td>
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<tr>
<td>p</td>
<td>1070</td>
<td>105</td>
</tr>
</tbody>
</table>

- LAr allows lower thresholds than Water Cerenkov for most particles
- Comparable performance for low energy electrons
Can we drift over over long distances?

- HV feedthrough tested by ICARUS up to 150 kV (E=1kV/cm in T600)
- \( v_{\text{drift}} = 2 \text{ mm/\mu s} @ 1 \text{kV/cm} \)
- Diffusion of electrons:
  \[
  \sigma_d = \sqrt{2 \times D \times t}, D = 4.8 \pm 0.2 \text{ cm}^2\text{s}^{-1}
  \]
  \( \sigma_d = 1.4 \text{ mm for } t = 2 \text{ ms (4 m @ 1 kV/cm)} \)
  \( \sigma_d = 3.1 \text{ mm for } t = 10 \text{ ms (20 m @ 1 kV/cm)} \)

- to drift over macroscopic distances, LAr must be very pure
  - a concentration of 0.1 ppb Oxygen equivalent gives an electron lifetime of 3 ms

- for a 20 m drift and >30% collected signal, an electron lifetime of at least 10 ms is needed
LNG storage tanks

- Many large LNG tanks in service
  - Vessel volumes up to 200000 m³
- Excellent safety record
  - Last serious accident in 1944, Cleveland, Ohio, due to tank with low nickel content (3.5%)

LAr vs LNG (≥ 95% Methane)

- Boiling points of LAr and CH₄ are 87.3 and 111.6 °K
- Latent heat of vaporization per unit volume is the same for both liquids within 5%

Main differences:

- LNG flammable when present in air within 5 - 15% by volume, LAr not flammable
- ρ_{LAr} = 3.3 ρ_{CH₄}, tank needs to withstand 3.3 times higher hydrostatic pressure