STATUS of ArDM at CERN

Group of Andre Rubbia ETHZ - CERN
Invited talk at GLA2010 workshop given by
A. Marchionni ETHZ

Hefei April 2010
J. Ulbricht
ArDM

A. Marchionni, ETHZ
GLA2010, KEK, March 29, 2010

- **ArDM**: Argon Dark Matter
  - a 1 ton double-phase LAr TPC for direct searches of dark matter particles
  - exploring the low energy frontier in LAr with an imaging device, to help in background rejection
- **Lessons for a large LAr TPC** for neutrino oscillation, proton decay and astrophysical neutrinos searches
ArDM (CERN RE18)

- a 1 ton LAr detector presently installed on surface at CERN to fully test all functionalities
- to be later moved to an underground location

Collaboration


CIEMAT, Spain: M. Daniel, M. de Prado, L. Romero.

Soltan Institute for Nuclear Studies, Poland: P. Mijakowski, P. Przewlocki, E. Rondio.


H. Niewodniczanski Institute of Nuclear Physics Krakow, Poland: M. Haranczyk, P. Karbowicz.

Institute of Physics, University of Silesia, Katowice, Poland: S. Mania

CERN: N. Bourgeois, G. Mare, S. Ravat
Principle and sensitivity of WIMP detection

Event rate above recoil energy threshold per day and per 1000 kg target of Xe/Kr/Ar/Ne

Event Rate for 100 GeV WIMPs Engel FF

$\sigma_{\text{WIMP-proton}} = 10^{-42}$ cm$^2 = 10^{-6}$ pb
$M_{\text{WIMP}} = 100$ GeV

"Canonical" halo model

-1 event/ton/day

0.01 event/ton/day

expected signal for a threshold of 30 KeVr
LAr as target and detector medium

- Only sensitive to spin-independent interaction with a favorable form factor
- Extensive experience as detector medium
- Can operate as a TPC, providing both imaging and energy measurements
- Possibility of assembling large masses
- Provides self-shielding → reduce external backgrounds
- High yields → keV thresholds achievable (≈ 1 collected phc/kC)
- Scintillation via atomic excimer states → nuclear recoil discrimination achieved
- Possibility to use underground Ar with low level of radioactive $^{39}$Ar

<table>
<thead>
<tr>
<th>Medium Property</th>
<th>Boiling point @ 1 atm</th>
<th>Liquid density g/cm³</th>
<th>W (eV) $Q_0=E/W$</th>
<th>Electron mobility (cm²/Vs)</th>
<th>$W_f$ (eV)</th>
<th>Scintillation wavelength (nm)</th>
<th>Scintillation lifetime (fast component)</th>
<th>Scintillation lifetime (slow component)</th>
<th>Long-lived metastable isotope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ar</td>
<td>87.3K</td>
<td>1.40</td>
<td>23.8</td>
<td>400</td>
<td>25.0</td>
<td>128 need WLS or MgF₂</td>
<td>6 ns</td>
<td>1.6μs</td>
<td>$^{39}$Ar, $^{42}$Ar</td>
</tr>
</tbody>
</table>
Experimental strategy

- ton-scale LAr detector providing self-shielding
- direct detection of ionization charge and primary scintillation light
- LAr volume operated as TPC (3D event imaging)
  - charge readout with fine spatial granularity (transverse coordinate)
  - longitudinal coordinate from drift time (time difference between primary scintillation light and charge collection time)
- charge readout \(\rightarrow\) an imaging and calorimetric device
- light readout \(\rightarrow\) discrimination of nuclear recoils against background by pulse shape analysis of the primary scintillation light and by the measurement of the collected charge/primary light ratio
- efficient rejection of external γ background
  - Compton processes are a source of low energy deposits within the fiducial volume, however often producing multiple scatters in the active volume
- efficient rejection of neutron background
  - irreducible genuine nuclear recoils are produced by fast neutrons elastically scattering off target nuclei, however high probability of multiple scatters within active volume
Pulse shape discrimination

Radioactive source: $^{210}\text{Pb}$
$^{210}\text{Pb} \rightarrow ^{210}\text{Bi} \rightarrow ^{210}\text{Po} \rightarrow ^{206}\text{Pb}$
$\alpha$ 5.3 MeV, $\beta$ 1.16 MeV
The ArDM concept


Charge drifts in the E-field, is extracted from the LAr surface into GAr and amplified in the Large Electron Multiplier (LEM)

LEM has good spatial resolution (orthogonal strips readout)

The scintillation light (128 nm) is converted by a wavelength shifter on the lateral reflector and on the surface of the PMTs

Field shaping rings, cathode and immersed HV multiplier provide a uniform E-field
**Thick Large Electron Multiplier (LEM)**

Thick-LEM (vetronite Cu coated + holes)

Sort of macroscopic GEM. Easier to operate at cryogenic temperature.

On application of a difference of potential between the two electrodes, electrons on one side of the structure drift into the holes, multiply and transfer to a collection region.

- Three thicknesses: 1, 1.6 and 2.4 mm
- Amplification hole diameter = 500 μm

Metallization (thickness 17 microns)

Area without metallization at the edge of the hole (17 microns)
High gain operation of LEM in pure Ar at high pressure

- Fe-55 & Cd-109 sources, Argon 100%
- Varying pressures (from 1 bar up to 3.5 bar)
- Room temperature
- Drift field $\approx 100\text{V/cm}$ (100% transparency)

pedestal 5.7 keV
High gain operation of LEM in pure Ar at high pressure

Gain up to ~800 possible even at high pressure (good prospects for operation in cold)
Resolution $\approx 28\%$ FWHM for Fe-55 source
Good agreement with GARFIELD simulations (confirm shower confinement)
Concept of LEM multistage system. Simulations performed with GARFIELD software indicate an expected single electron gain $\approx 10^4$. Will be tested in the coming weeks.

- Thickness: 1.5 mm
- Amplification hole diameter = 500 $\mu$m
- Distance between centers of neighboring holes = 800 $\mu$m
Overview of the detector

- LEM (80 cm diameter)
- The inner detector
- Reflecter foils
- PMTs
- HV system
- Field shapers
- 14 cryogenic PMTs
- Support pillars
- Cathode
- Input/output recirculation system
## ArDM baseline parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector Max. drift length</td>
<td>120 cm</td>
</tr>
<tr>
<td>Target mass</td>
<td>850 kg</td>
</tr>
<tr>
<td>High voltage Drift field</td>
<td>1÷3 kV/cm</td>
</tr>
<tr>
<td>Charge readout LEM gain</td>
<td>$10^3$ per e\textsuperscript{-}</td>
</tr>
<tr>
<td>Light readout Global collection efficiency</td>
<td>2%</td>
</tr>
</tbody>
</table>
Lessons ...

... from ArDM

- Cryogenics and safety
  - argon purification, monitoring of argon purity, cryogenic pumps, cryogenic safety
- Charge collection and amplification in a double-phase LAr TPC
- Development of High Voltage systems
- Light readout with cryogenic PMTs and wavelength shifting technique
ArDM Cryogenics

- presently LAr cooling bath open to atmosphere and automatically refilled
- in the near future foreseen the use of two cryocoolers, for a total of ~400 W, with a sealed LAr bath (essential for an underground location)
ArDM Safety

- Reviewed by the CERN Safety group
- because no safety valves available on the market are vacuum tight at $\sim 10^{-9}$ mbar l s$^{-1}$, the pure LAr circuit is protected by two certified burst disks with a burst pressure of 0.7 bar
- presently installing a PLC based control of the vacuum and cryogenic systems
LAr purification

Recirculation and CuO powder purification cartridge
the cartridge is regenerable in situ at about 250°C in a stream of Ar/H₂ gas

Cryogenic bellow pump

Planning to add:
- molecular sieve with zeolite 3A in LAr circuit
- GAr purification circuit

Measured LAr flux ~ 20 l/hr
LAr filling of the detector

1. cool down, detector under vacuum
2. measurements in pure cold Ar gas
3. detector half filled with LAr, PMTs immersed
4. fully filled with LAr
5. warm-up phase

May 2009

Achieved a detector vacuum of $10^{-6}$ mbar before LAr filling

Monitored LAr purity by the measurement of the slow component of the Ar scintillation light
ArDM High Voltage system

210 stages Cockcroft-Walton circuit

- 2.5 kV, 82 nF metallized film polypropylene capacitors
- 2 kV diodes (3 in series)
- 50 Hz AC voltage source

- possibility of HV measurement by the measurement of discharging current
- monitoring of HV through measurement of drift velocity

- 30 field shapers with 4 cm spacing
- 400 kV at cathode \(\rightarrow\) \(\sim\) 3 kV/cm
- good linearity of drift field by properly choosing the connection of one of the Cockcroft-Walton stages to each field shaper

see talk by S. Horikawa
ArDM charge readout

- ArDM is operated like a double phase argon LEM-TPC, with amplification of the ionization charge by Large Electron Multipliers (LEM) in pure Ar gas.
- It provides both tracking and calorimetric information.

![Diagram of ArDM charge readout](image)

- Free $e^-$ drift in LAr towards liquid-vapour interface.
- $e^-$ are extracted to the vapour via extraction grids ($E_{liq} > 2.5$ kV/cm).
- $e^-$ undergo multiplication in double stage LEM.
- Multiplied charge induces signals on the segmented electrodes of top LEM and anode.

A. Badertscher et al., arXiv:0811.3384
Test setup for ArDM charge readout

A novel kind of LAr TPC based on
- operation in double phase Argon
- amplification in pure GAr by 1 or more stages of Large Electron Multipliers (LEM)
- extrapolated from GEM technology

- Produced by standard Printed Circuit Board methods
- Double-sided copper-clad FR4 plates
- Precision holes (500μm) by drilling

Double-stage LEM

A. Badertscher et al., arXiv:0907.2944

Synergy with RD51 @ CERN

see talk by F. Resnati
Argon purification

For a 20 cm drift at 0.5 kV/cm, contaminations ≤2 ppb (O₂ equivalent) are needed:

\[ \tau_e [O_2] = 300 \text{ ppb } \mu s \]

To purify argon we use two purification stages:

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**Input LAr purification:**
- Custom made cartridge for LAr purification at detector input.

**GAr purification circuit:**
- Heating resistors evaporate LAr in the detector.
- A metal bellow pump pushes GAr into a flow meter and SAES getter (~48h to recirculate 1 volume).
- Purified GAr condensates into the detector volume.
- Also used during the cooling phase, essential to obtain good initial purity.
Development of readout electronics

- Preamplifier development

- Development of LAr TPC electronics for small scale devices
  - CAEN, in collaboration with ETHZ, developed A/D and DAQ system
  - 12 bit 2.5 MS/s flash ADCs + FPGA

Inspired from C. Boiano et al.

ETHZ preamps

~11 mV/fC
S/N = 10 @ 1 fC, C_i = 200 pF
MIP ~ 10 fC/cm

see talk by C. Tintori
Performance of a double-phase LEM LAr TPC

**Single stage 1.0 mm LEM, 36 kV/cm**

- Anode signals (event 43)
- LEM signals (event 43)
- Anode signals (event 1256)
- LEM signals (event 1256)
- Anode event display (event 43)
- LEM event display (event 43)
- Anode event display (event 1256)
- LEM event display (event 1256)

**Determination of the electron lifetime using reconstructed muon tracks**

Lifetime fit 24 hours after filling

\[ \tau^{-1} = 0.0023 \pm 0.0001 \mu s^{-1} \]

**Single stage 1.0 mm LEM**

**Double stage 1.6 mm LEM**

**dQ/dx Distribution of the anode (lifetime-corrected)**

- Entries: 4380
- Mean: 24.34
- RMS: 5.31
- \( \chi^2/\text{ndof} \): 154.9/109
- Width: 1.291 \pm 0.054
- MP: 19.13 \pm 0.67
- Area: 1447 \pm 22.0
- S/Sigma: 2.259 \pm 0.990

**Total charge collected on Anode and LEM electrode**

- Electric field in the LEM holes (kV/cm)
- 26 kV/cm
- 16% res.

**26 kV/cm**
Charge amplification system in ArDM

- ArDM requires fine segmentation (few mm, 1024 channels), charge gain of \sim 1000
  \[ \text{Gain} = e^{\alpha x} \]
  \( x \): effective LEM hole length
  \( \alpha \): 1\textsuperscript{st} Townsend coefficient \approx Ape^{-Bpx/V} \)

- edge effects of the holes limit the maximum gain before discharging
- good tolerances in LEM fabrication is essential, in particular the presence of a centered rim around the hole
- new LEMs of 0.5, 1.0, 1.6 mm thickness fabricated at the CERN PCB workshop (good quality!)

- density of LAr at 87K/1 bar is equivalent to that at 300K/3.5 bar
- use of thinner LEMs, compensating the increase in pressure by a decrease of the hole length
- also considering the possibility of working in subcooling conditions, @ 0.7 bar, 84 K

- already constructed a 60x60 cm\(^2\) LEM for Compass, 40x80 cm\(^2\) also possible
Intermediate step towards a charge readout in ArDM

- adjustable hanging system with vertical and tilting movements

- thermal shields

- first test of the charge drift and extraction system

- 32 pads readout

- extraction grids
WLS coated reflector foils

V. Boccone et al. JINST 4 P06001 2009

- LAr emission spectrum peaked at 128 nm
- use reflector foils coated with TPB in order to use standard bialkali PMTs
  - TPB shifts to a mean wavelength of 430 nm
- 15 cylindrically arranged overlapping foils of TTX (120x25 cm²) coated with 1.0 mg/cm² TPB by vacuum evaporation
  - TTX is an aligned polytetrafluoroethylene (PTFE) fibrous cloth
- measured a reflection coefficient close to 97% at 430 nm

coating achieved by evaporation of
TPB is very uniform

see talk by K. Mavrokoridis
Light readout system

14 low radioactivity photomultiplier tubes
Hamamatsu R5912-02MOD
8“ diameter

PMT windows TPB coated by evaporation

cryogenic voltage divider
First light readout in LAr with a PMT test setup

Test with radioactive sources: $^{22}\text{Na}$, $^{137}\text{Cs}$, AmBe (still under study)

**PMT test setup**
- 7 reached a gain of $2.5 \times 10^7$

**Different PMT configurations**
- 5 R5912/02mod, 2 R5912/01mod, 1 ETL9357
- TPB coated (by evaporation, liquid immersion, w and w/o sandblasting)
- TPB uncoated

**Trigger configurations**

- $^{137}\text{Cs}$: $\gamma$ 662 keV
- $^{22}\text{Na}$: $\beta^+$, $\gamma$ 1275 keV
Preliminary results of measurements with the PMT test setup

ArDM self trigger

$^{22}$Na with NaI Xtal trigger (1.8 MeV)

![Graphs and tables showing light yield for different positions and elements.]

<table>
<thead>
<tr>
<th>Position</th>
<th>Distance from cathode [cm]</th>
<th>Light yield 7 PMTs [p.e./keVee]</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>10</td>
<td>$0.502 \pm 0.007$</td>
</tr>
<tr>
<td>D</td>
<td>30</td>
<td>$0.440 \pm 0.005$</td>
</tr>
<tr>
<td>F</td>
<td>50</td>
<td>$0.370 \pm 0.006$</td>
</tr>
<tr>
<td>G</td>
<td>60</td>
<td>$0.319 \pm 0.005$</td>
</tr>
</tbody>
</table>

(Error only statistical)
Measurements in Gas Argon with Final Light Readout (14 PMT)

Light yield as a function of the distance between PMT and an internal $\alpha$-source in pure GAr

better light yield with new PMT's

1...14 Final PMT configuration
1...8 Test PMT configuration
GLACIER Roadmap

3 lt @ CERN, 10 lt @ KEK
small test setups for readout devices, electronics

250 lt @ KEK
detector construction 2009 charged particle beam

ArDM (RE18) @ CERN
1 ton LAr, Cockroft-Walton, LAr recirculation and purification, industrial electronics, safety, optimized for dark matter searches, in operation

ArgonTube @ Bern
5 m drift under procurement

6 m³ @ CERN (?) to be proposed for test beams in NA

full engineering demonstrator for larger detectors + physics construction 2012-2016

1 kton
Conclusions and outlook

- Successful first cool-down run in 2009
  - first data were taken, analysis still ongoing
- A great part of the detector development has been accomplished
  - vacuum, cryogenics and safety OK
  - HV system up to 400 kV directly immersed in LAr fully assembled
  - light readout system optimized and final configuration installed and tested in GAr
  - a first readout system with 32 channels (without amplification) installed, low noise electronics and DAQ working satisfactorily
  - R&D still ongoing for the final charge readout (charge amplification of $\geq 10^3$ with a bi-dimensional readout for a total of 1024 channels)
- These items represent relevant R&D towards large LAr TPCs
- Start of the next run in the coming weeks
  - first run with a drift field and a charge readout system
  - calibration of the 14 newly installed low background PMTs in LAr
  - study response to gamma and neutron sources
- We hope to start to transfer the experiment to an underground location in the end of 2010
  - investigating different sites: Canfranc underground laboratory (Spain), SUNLAB Sieroszowice mine (Poland), Unirea salt mine (Romania)
Conversion and reflection efficiency

[Diagram showing a setup with labels like Gas in, Gas out, WLS, 3" PMT, and a scintillation light (128 nm)].

[Graphs showing light yield vs. time (ns) and light yield vs. TPB layer (ng/cm²)].

[Graphs showing sample intensity relative to NIST reference vs. incident light wavelength (nm)] for TPB on TTX and TPB on 3M foil.

ETH Institute for Particle Physics