The “DarkSide” of Dark Matter

Depleted Argon Cryostat
for Scintillation and Ionization Detection

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**DarkSide Project**

*Null background strategy for direct Dark Matter searches - looking for rare nuclear recoils induced by WIMPs in a specialized low background detector.*

*Multi Step program @ LNGS foreseeing:*

- **G1 experiment: DS-50** - $10^{-45}$ cm$^2$ GOAL
- **G2 experiment: DS-5K** - $10^{-47}$ cm$^2$ GOAL
- Plus few prototypes for technical measurements...
**DArkSide Project**

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**DArkSide Recipe**

- **TARGET:** Underground Argon DEPLETED in its $^{39}$Ar isotope to reduce internal contaminations (light nucleus $A=40$, form factor not too steep).

- **DETECTOR:** two-phase argon time projection chamber (offering excellent particle identification methods).

- **VETO & SHIELD:** a compact liquid scintillator VETO (à la Borexino) relying on $(n,\alpha)$ on $^{10}$B combined with a Water Cherenkov Detector to kill neutron induced background.
Two-Phase Argon TPC

- Photomultiplier array
- GAr
- LAr
- Quartz window
- Diving bell for gas pocket trapping
Two-Phase Argon TPC

- Transparent metal film (ITO) working as Drift Cathode
- Grid for extraction/multiplication
- Racetrack system to provide a uniform drift field (order of 1kV/cm)
- Transparent metal film (ITO) working as Drift Anode
Since you want to detect light produce in the scintillator:

- put reflectors everywhere you do not have photocathodic surfaces
- coat all inner surfaces with a waveshifter (TPB) to make scintillation light visible to PMTs.
Two-Phase Argon TPC

The primary ionizing particle (nuclear recoil or electron recoil) produces ionization and excitation along its track. Excited argon dimers are formed and their de-excitation leads to the emission of scintillation light presenting a fast and slow component (associated Ar$_2^*$ singlet and triplet state) whose average ratio depends on the nature and energy of the ionizing particle.
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- Slow component (1500 ns)
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**Fast component** (6 ns)

**Slow component** (1500 ns)

Electron recoil

Nuclear recoil

$S_1 > 35 \text{ p.e.}$ and recoil acceptance = 50%

Rejection better than $3 \times 10^{-7}$
The ionization electrons surviving the recombination with the produced ions, are drifted towards the liquid-gas interface by means of the electric field.

Fast component (6 ns)

Slow component (1500 ns)

S1 signal
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$\text{S1 signal}$

$\text{Fast component (6 ns)}$

$\text{Slow component (1500 ns)}$
The field applied near the liquid gas interface forces the extraction of the drifted electrons into the gas phase.

A field of the order of 3.0 kV/cm extracts roughly 100% within 0.1 microseconds.

Two-Phase Argon TPC

Slow component (1500 ns)

Fast component (6 ns)

S1 signal
The field applied near the liquid gas interface forces the extraction of the drifted electrons into the gas phase.

A field of the order of 3.0 kV/cm extracts roughly 100% within 0.1 microseconds.
Once in the multiplication region the applied field provides enough kinetic energy to the drifted electrons so that, while traveling in gas phase, they induce ELECTROLUMINESCENCE in a proportional regime (and not charge multiplication). This light is produced all along the multiplication region.

The amount of $S_2$ depends on the nature and energy of the ionizing particle.
Once in the multiplication region the applied field provides enough kinetic energy to the drifted electrons so that, while traveling in gas phase, they induce **electroluminescence** in a proportional regime (and not charge multiplication). This light is produced all along the multiplication region.

The amount of S2 depends on the nature and energy of the ionizing particle. Two-Phase Argon TPC

Electron recoil

Nuclear recoil

\[S_1 > 35 \text{ p.e. and} \]

\[\text{recoil acceptance} = 50\%\]

\[\text{Rejection better than } 10^{-2}\]
Two-Phase Argon TPC

The delay between S1 and S2 corresponds to the e- drift time and is used to estimate the z coordinate of the interaction (few mm uncertainty).
Since $S_2$ production occurs very close to the top PMTs, the signal distribution on the top PMTs will be strongly non-uniform and can be used to locate in the x-y plane the ionization event.

The delay between $S_1$ and $S_2$ corresponds to the $e^-$ drift time and is used to estimate the z coordinate of the interaction (few mm uncertainty).
Two-phase Liquid Argon technology

- Shape of the scintillation signal (PSD)
- Ratio between ionization and scintillation ($S_2/S_1$)
- 3D localization of the ionization event

How to reject the background?
Two-phase Liquid Argon technology

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Electron recoils (induced by gamma and beta natural radioactivity)

How to reject the background?
Two-phase Liquid Argon technology

Shape of the scintillation signal (PSD)

3D localization of the ionization event

Ratio between ionization and scintillation (S2/S1)

How to reject the background?

Electron recoils (induced by gamma and beta natural radioactivity)

Data acquired on surface without shielding

Gamma source

Neutron source
Two-phase Liquid Argon technology

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- Shape of the scintillation signal (PSD)
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Nuclear recoils from surface contamination (surface events).
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How to reject the background?
Two-phase Liquid Argon technology

Shape of the scintillation signal (PSD)

Ratio between ionization and scintillation ($S_2/S_1$)

3D localization of the ionization event

Nuclear recoils induced by elastic scattering of radiogenic and cosmogenic neutrons.

How to reject the background?
DS-10kg detector

Two-phase Argon TPC prototype used to test the effects on the two phase argon technology of new solutions pursued by DarkSide program.

10 kg active mass of Atmospheric Ar

2 PMT (3” Hamamatsu) at the top

2 PMT (3” Hamamatsu) at the bottom

~20cm drift region

~2cm multiplication region

ITO layers for anode and cathode on fused silica windows (instead of conventional grid)

New HTV feedthroughs
DS-10kg detector

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DS-10 @ LNGS

Detector has been installed during last summer on a dedicated platform in Gran Sasso Hall C (near Borexino CTF).

DS-10 runs @ LNGS are mainly focused on the study of the performance of the detector in low background environment.

We are studying dedicated short runs for the technical solutions that will be implemented in DS-50.
DS-10 @ LNGS
Light Yield

$LY = 9.0 \pm 0.1 \text{ p.e.}/\text{keV}_{ee}$

$^{22}\text{Na}$ source
Null field
DS-10 @ LNGS

gamma-like background

The trigger configuration is a majority of 4 PMTs each detecting at least 0.5 p.e.

Total trigger rate in DS-10, once filled with water the shield, is ~ 17 Hz.

Extremely low hardware threshold, corresponding to ~ few keV$_{ee}$.

Currently operating at nominal fields ($E_{\text{drift}}=1$ kV/cm and $E_{\text{ext}}=4$ kV/cm)

It will be an ideal tool for testing at very low energy the performance of the two-phase TPC.
DS-50 two-phase Argon TPC

- 50 kg DAr sensitive volume (cylinder with 36 cm diameter and 38 cm height)
- 19+19 cryogenic high QE Hamamatsu PMTs
- All inner surfaces are coated with a wavelength shifter (TPB) to convert the VUV light into visible (detectable by PMTs)
- Lateral walls made of high reflectivity polycrystalline PTFE.
- Quartz diving bell (top) and window (bottom) in front of the PMT arrays coated with ITO (thin metallic layer highly transparent to visible light).
- Ready by fall 2012.

Designed to provide an extremely high Light Yield, decreasing the detection energy threshold.
Neutron VETO

- The Argon time projection chamber is surrounded by a liquid scintillator spherical veto, 4m diameter, instrumented with 110 low background 8” PMTs.
- Liquid scintillator (PC) loaded with tri-methyl borate (TMB) with natural 20% $^{10}$B.
- Based on (n, alpha) reaction on $^{10}$B so that it can be both relatively compact and highly efficient (99.9% with a 60μs window).
- SS sphere installed and ready by Fall 2012.
- Designed to host a multiton DAr TPC.
CTF Water Tank

- The scintillator vessel will be hosted in the water tank of Borexino Counting Test Facility (CTF), an existing infrastructure @ LNGS.

- It is a 11mx10m stainless steel tank filled with water and working as Cherenkov detector for vetoing muon (and hence muon-induced neutrons) and as neutron passive shielding.

- The CTF has been fully drained and its refurbishing has just started for preparing the assembly of the sphere. It will be instrumented with 80 PMTs.

- Darkside-50 will be integrated with the already existing Borexino water and scintillator plants.
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Darkside-50 will be integrated with the already existing Borexino water and scintillator plants.
The combination of:

- Underground laboratory;
- Material screening for radiopurity;
- Low-background PMT (and QUPIDs);
- Depleted Argon;
- Boron loaded Liquid Scintillator;
- Water tank;
- two-phase Argon TPC;

### Detector Element

<table>
<thead>
<tr>
<th>Detector Element</th>
<th>Electron Recoil Backgrounds</th>
<th>Radiogenic Neutron Recoil Backgrounds</th>
<th>Cosmogenic Neutron Recoil Backgrounds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Raw</td>
<td>After Cuts</td>
<td>Raw</td>
</tr>
<tr>
<td>$^{39}$Ar (&lt;0.01 Bq/kg)</td>
<td>$&lt;6.3 \times 10^6$</td>
<td>$&lt;4 \times 10^{-3}$</td>
<td>0.17</td>
</tr>
<tr>
<td>Fused Silica</td>
<td>3.3 $\times 10^4$</td>
<td>2.0 $\times 10^{-5}$</td>
<td>0.39</td>
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<tr>
<td>PTFE</td>
<td>4,800</td>
<td>3.0 $\times 10^{-6}$</td>
<td>5.0 $\times 10^{-3}$</td>
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<tr>
<td>Copper</td>
<td>4,500</td>
<td>2.8 $\times 10^{-6}$</td>
<td>19.4</td>
</tr>
<tr>
<td>R11065 PMTs</td>
<td>2.6 $\times 10^6$</td>
<td>1.6 $\times 10^{-3}$</td>
<td>0.31</td>
</tr>
<tr>
<td>QUPIDs (1 mBq)</td>
<td>7.0 $\times 10^4$</td>
<td>4.2 $\times 10^{-5}$</td>
<td>2.5</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>5.5 $\times 10^4$</td>
<td>3.4 $\times 10^{-5}$</td>
<td>0.030</td>
</tr>
<tr>
<td>Veto Scintillator</td>
<td>70</td>
<td>4.3 $\times 10^{-8}$</td>
<td>0.030</td>
</tr>
<tr>
<td>Veto PMTs</td>
<td>2.5 $\times 10^6$</td>
<td>1.6 $\times 10^{-3}$</td>
<td>0.023</td>
</tr>
<tr>
<td>Veto tank</td>
<td>1.7 $\times 10^5$</td>
<td>1.1 $\times 10^{-4}$</td>
<td>6.7 $\times 10^{-5}$</td>
</tr>
<tr>
<td>Water</td>
<td>6,100</td>
<td>3.8 $\times 10^{-6}$</td>
<td>6.7 $\times 10^{-4}$</td>
</tr>
<tr>
<td>CTF tank</td>
<td>8,300</td>
<td>5.1 $\times 10^{-6}$</td>
<td>3.5 $\times 10^{-3}$</td>
</tr>
<tr>
<td>LNGS Rock</td>
<td>920</td>
<td>5.7 $\times 10^{-7}$</td>
<td>0.061</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>–</td>
<td>0.007 (0.006)</td>
<td>–</td>
</tr>
</tbody>
</table>

**exp. background events in 0.1 ton-year above threshold**
The unique combination of background rejection techniques coming from Argon technology and the extremely powerful veto system, leads to expected background lower than 0.1 events in 0.1 ton-year.

The projected sensitivity with a threshold of $\sim 20\text{keV}_{\text{rec}}$ is the order of $\sim 1 \times 10^{-45}$ cm$^2$ for a 100GeV WIMP (3 years of background free exposure).
Summary

- Depleted Argon is a reality.
- Argon two-phase technology combined with Borexino liquid scintillator technology looks very promising for future ton scale detectors.

**DarkSide-10**
- Successfully deployed at LNGS;
- Producing results in a low background environment;
- Tested the solutions that we are going to implement on DS-50.
  - Excellent performance in terms of LY has been observed.

**Darkside-50**
- Detectors ready by Fall 2012;
- DAr procurement finished by Fall 2012;
- Commissioning starting Q4 of 2012.