Indirect Dark Matter search in the Sun direction using the data 2007-2008 for the two common theoretical framework (CMSSM, mUED)

Ziad Charif on behalf of the ANTARES collaboration
CPPM - Marseille
19/07/2012
The ANTARES detector

- 885 10inch PMTs
- 12 lines
- 25 storeys / line
- 3 PMTs / storey

40 km to shore

Junction Box

Interlink cables

2500m

450 m

70 m
The ANTARES site & infrastructure

IFREMER Toulon Centre

Shore Station

FOSELEV Marine

ANTARES Site

40 km submarine cable

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Detection principle

- Main detection channel: $\nu_\mu$ interaction giving an ultra-relativistic $\mu$ ($\nu_e$ and $\nu_\tau$ also)
- Energy threshold ~ 10 GeV
- 24hr operation, more than half sky coverage
Example of events

reconstructed up-going neutrino
detected in 6/12 detector lines

reconstructed down-going muon
detected in all 12 detector lines

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Dark Matter Simulation
Independent-model production

- Blennow, Edsjö, Ohlsson (03/2008): “WIMPSIM” model-independent production
- Great statistics with $12 \times 10^6$ WIMPs self-annihilations
- Capture rate and annihilations in equilibrium at the Sun core
- Annihilations in c,b and t quarks, $\tau$ leptons and direct channels
- Interactions taken into account in the Sun medium
- Three flavors oscillations, regeneration of $\tau$ leptons in the Sun medium (Bahcall et al.)
- Available parameters (WIMPs mass, oscillations parameters, ...)

$W$, $I$, $M$, $P$, $s$, $\nu_e$, $\nu_\mu$, $\nu_\tau$, Sun, Earth
Dark Matter Simulation

Independent-model production

\( W^+ W^- \)

\( M_{WIMP} = 350 \text{ GeV} \)

\( b^+ b^- \)

\( \tau^+ \tau^- \)

\( \tau \) leptons regeneration in the Sun

mUED particular case…

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Background in the Sun direction

- Using the scrambled data 2007-2008 (from 5 to 12 lines) in (theta, phi), time (Modified Julian Date) (~294.6 days)
- Using the Sun distribution weighted by its visibility for Antares

Monte-carlo versus 2007-2008 data

Example of Sun tracking in horizontal coordinates
Discriminating variables

χ² (track quality): Separates badly reconstructed down-going muons and up-going neutrinos

Half-Cone angle (centered around the Sun): Separates up-going atmospheric neutrinos and dark matter neutrinos

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Define an Efficiency per channel per WIMP mass

\[ A_{\text{eff}}(M_{\text{WIMP}}) \]
Dark Matter Signal and cuts optimisation

- Neutrino flux at the earth, from the Dark Matter coannihilation, are convoluated with the efficiency of the detector for a cuts parameter space (Q,cone)
- Neutrino background from the scrambled data in the Sun direction is evaluated in the same space
- Minimize this quantity:

\[
\text{Limit} = \frac{\mu_{90}}{A_{\text{eff}} (M_{\text{wimp}}) \times T_{\text{eff}}}
\]

Optimum cone angles around the Sun

Average upper limit (Feldman-Cousins) VS DATA 2007-2008
Dark Matter Signal and Neutrino flux limit

For CMSSM:
Branching ratios = 1
(WW, bb, ττ)

For mUED:
Theoretical branching ratios taken into account

Reason:
High dependence of branching ratios over CMSSM parameter space

\[ \Phi_{\nu,\mu} \times \sigma_v \times R_\mu \times \text{Nucleon density} \times \Phi_{\text{earth}} \rightarrow \Phi_{\mu} \]
Dark Matter Signal and CMSSM Muon flux limit

Flux $\Phi_\mu$

Annihilation rate $\Gamma$

Capture rate $C$

Cross-section $\sigma_{SD}$

$M_{\text{WIMP}}$ (GeV)
Dark Matter Signal and mUED Muon flux limit

Flux $\Phi_\mu$
Annihilation rate $\Gamma$
Capture rate $C$
Cross-section $\sigma_{SD}$

BRs: $0.23(e,\mu,\tau)$, $0.077(u,c, t)$, $0.005(d,s,b)$, $0.014(\nu_e, \nu_\mu, \nu_\tau)$
$0.027$(higgs)
mUED framework
Stable in $(R, \Delta, m_h)$
Dark Matter Signal

CMSSM SD cross-section limit for

ANTARES 2007-2008

Spin-dependent cross-section limit for

ANTARES 2007-2008

Compare SUSY predictions to observables as sparticles masses, collider observables, dark matter relic density, direct detection cross-sections, ...

SuperBayes
(arXiv:1101.3296)
Spin-independent cross-section limit for ANTARES 2007-2008

CDMS 2010
XENON100 2011
IC40/AMANDA 2001-2008 (tτ)
IC40/AMANDA 2001-2008 (WW, τ⁺τ⁻ for m_τ < m_W)
ANTARES 2007-2008 (tτ)
ANTARES 2007-2008 (WW)
ANTARES 2007-2008 (τ⁺τ⁻)

Compare SUSY predictions to observables as sparticles masses, collider observables, dark matter relic density, direct detection cross-sections, ... 

SuperBayes (arXiv:1101.3296)
Dark Matter Signal and mUED SD cross-section limit

Spin-dependent cross-section limit for ANTARES 2007-2008

Compare mUED predictions to observables as KK masses, collider observables, relic density, direct detection cross-sections, …

SuperBayes modified version (Physical Review D 83, 036008 (2011))
Prospect with 2007-2010 Data

Additional improvement of:
10X - 2X between 50 GeV and 200 GeV for the Soft spectrums
2X up to 100 GeV for the Hard spectrums
2X up to 1000 GeV for the hard spectrums

Use of extra variables (energy-like).
Reconstruction strategy optimized for low energy events.
Reconstruction strategy optimized for high energy events.

Factor 3-4 with 2007-2008
Summary & Conclusions

• Reached the limits for the CMSSM, and mUED, in muon flux, and spin-(in)dependent cross-section, with comparisons to the other experiments
• Antares and IceCube gives an opportunity to constraint the dark matter parameter spaces
• Good complement to the direct detection experiments

• Article for the present limits to be submitted for publication (in draft)

• Galactic center first sensitivities waited for the next month
• Enhancement of the present limits for the Sun with the period 2007-2010 of data, passing from a binned to an unbinned method.
• Data for 2011 under preparation, with statistics slightly larger than 2009 and 2010 combined.
Background in the Sun direction

- Interactions $p-p$ give a production of neutrinos through the decay products

Simple parameterization averaged on the oscillations

It doesn’t represent more than $10^{-3}$ events per year in a 12 lines configuration (few events for a km$^3$), 0.4% of the total atmospheric background
From Dark Matter muon flux to the SD cross-section

Convertion factor from muon flux to spin-dependent cross-section

Conservative view on the local region:
- Jupiter Effect
- w/o additional disk in the dark matter halo
- local density 0.3 GeV.cm⁻³

(\text{arxiv:0903.2986v2})
From Dark Matter muon flux
to the SD cross-section

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Conservative view on the local region:
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(arxiv:0903.2986v2)
Prospectives
ANTARES 2007-2010

Muons flux limit for ANTARES 2007-2010 in CMSSM

- Baksan (1978-1995)
- SuperK 2011 (bB)
- SuperK 2011 (W+W)
- IC40/AMANDA 2001-2008 (bB)
- IC40/AMANDA 2001-2008 (W+W; τ+τ− for m_τ < m_W)
- ANTARES 2007-2010 (bB)
- ANTARES 2007-2010 (W+W)
- ANTARES 2007-2010 (τ+τ−)

Factor 3-4 with 2007-2008
Prospectives
ANTARES 2007-2010

Muons flux limit for ANTARES 2007-2010 in mUED

- IceCube 22 2007
- IceCube 40+22 2010
- ANTARES 2007-2010

\[ \Phi_\mu^{90\%} \] (km\(^2\)·yr\(^{-1}\))

\[ M_{\text{WIMP}} \] (GeV)

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Spin-independent cross section limit for ANTARES 2007-2010 in CMSSM.
Prospectives
ANTARES 2007-2010

Spin-dependent cross section limit for ANTARES 2007-2010 in mUED

\[
\log_{10}(\sigma_{H,\text{SD}} \text{ (pb)})
\]

- IceCube 22 2007
- ANTARES 2007-2010
- IceCube 40+22 2007-2008

\(M_{\text{WIMP}} \text{ (GeV)}\)
Region of Sky Observable by Neutrino Telescopes

**IceCube (South Pole)**

**ANTARES/KM3NeT (43° North)**

→ Emphasis on study of galactic sources

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The ANTARES Infrastructure

Connected
30 Oct 2010

100m

Submarine cable to shore

Primary Junction Box

Secondary Junction Box

DeepSeaNeT: optical fibre cable with seismographs

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2006 – 2008: Building phase of the Detector

- Junction box 2001
- Main cable 2002
- Line 1, 2 2006
- Line 3, 4, 5 01 / 2007
- Line 6, 7, 8, 9, 10 12 / 2007
- Line 11, 12 05 / 2008

~70 m

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Secondary Junction Box

Connected 30 Oct 2010

Seismograph

Japan earthquake 2011 March 11 at Antares site

Instrumentation module

Turbidity

BioCam

Currentmeter

O2, CTD, P

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Signal computation method

- Usually, we need:
  - Flux (example: WW) at the surface of the Earth
  - Capture rate into the Sun, dependent on the SD, SI cross-section
  - Annihilation rate $\Gamma \sim 0.5 * C$ (equilibrium condition)

$$\frac{d\phi}{dEd\Omega} = \frac{\Gamma}{4\pi d^2} \sum_i B_i \frac{dN_i}{dE_i}$$

$$C_\odot \simeq 3.35 \times 10^{18} s^{-1} \times \left( \frac{\rho_{\text{local}}}{0.3 \text{ GeV.cm}^{-3}} \right) \times \left( \frac{270 \text{ km.s}^{-1}}{\nu_{\text{local}}} \right) \times \left( \frac{\sigma_{H,SD}}{10^{-6} \text{ pb}} \right) \times \left( \frac{\text{TeV}}{M_{\text{WIMP}}} \right)^2$$

- Flux from WIMPSIM
- Cross-section from Analytic computation, or simulation in the parameter space of the models
- For Kaluza-Klein, Branching ratio not so dependent on the location in the parameter space ($R$, $\Delta$, and SM Higgs mass $m_h$)
- For CMSSM, it's different… Equilibrium in the Sun well/not reached, SD/SI very dependent on the parameter space, branching ratios very dependent, main channel chosen is not so obvious -> large systematic from the sensitivity computed
- Need a simulation, and fast one, to compute the cross-sections, the capture rate, etc, for the allowed parameter space
SuperBayes v1.35

Supersymmetry Parameters Extraction Routines for Bayesian Statistics

• Multidimensional SUSY parameter space scanning
• Compare SUSY predictions to collider observables, dark matter relic density, direct detection cross-sections, …
• Using a new generation Markov Chain Monte Carlo for a full 8-dim scan of CMSSM
• Using PISTOO farm at CC-Lyon to run it

• Well documented (articles, Website), as DarkSUSY package

• Parameter set of CMSSM \((m_0, m_{1/2}, A_0, \tan\beta)\)
• «Nuisance parameters» from SM \((m_t, m_b, \alpha_{em}, \alpha_s)\)