Status of Secluded Dark Matter search in the Sun with ANTARES

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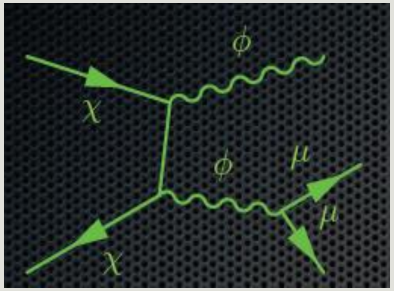
Secluded Dark Matter (SDM)

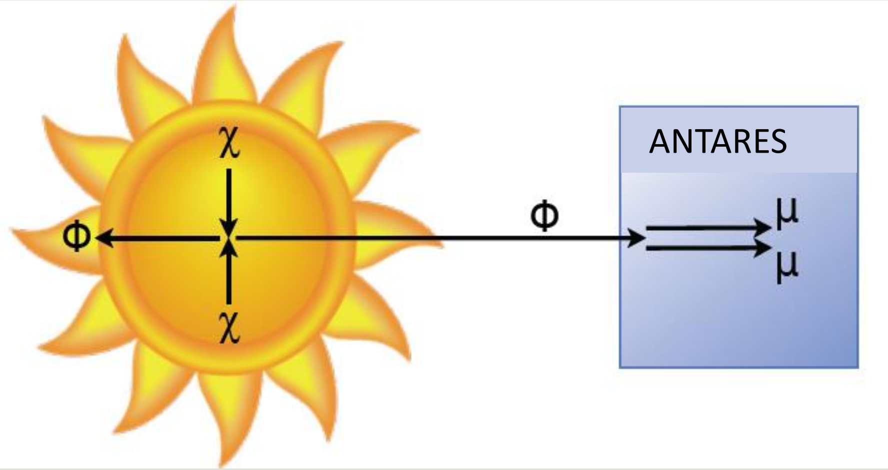
In this model the Dark Matter, χ, is secluded from 'normal' matter by a mediator, Φ.

The mediator could be some new gauge boson from the dark sector, or some other candidate.

In the simplest picture the dark matter annihilates into the mediator. If the mass of the dark matter is greater than the mediator then the dark matter would be leptophilic.

"Typical"
χ → ~1 TeV
ϕ → ~ 1 GeV



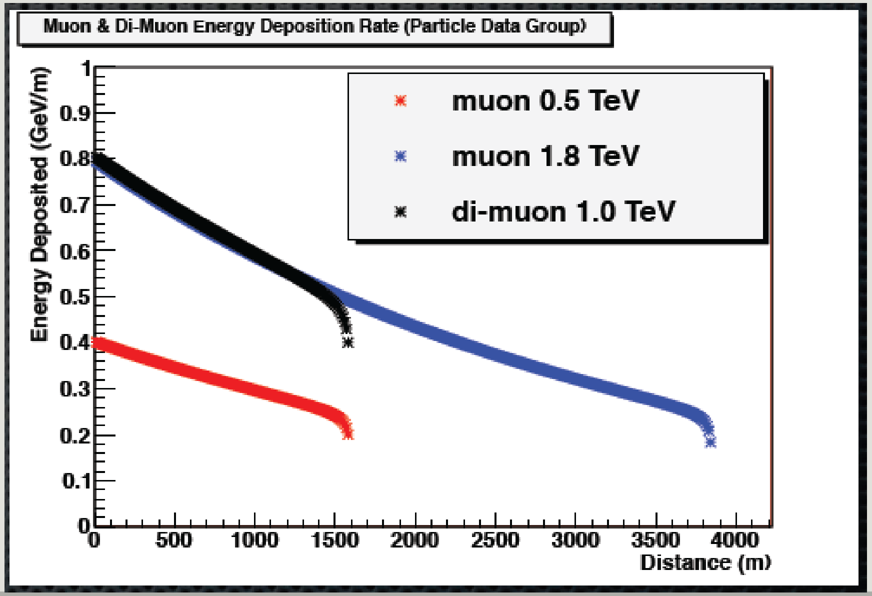


- Leptophilic DM due to interaction with the SM through the kinetic mixing portal
- "Typical" mediator boosted due to DM mass being greater than mediator mass
- Lifetime of mediator could be long, it could decay in the vicinity of the Earth as two co-linear muons

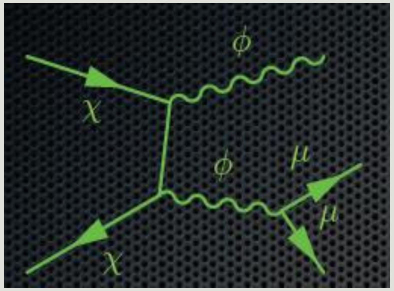
Secluded Dark Matter (SDM)

Di-muon signature

- Di-muon signal traveling through the ice (or water) looks like a much more energetic muon.
- Energy deposited for stopping di-muon event is twice than for a single muon event.



"Typical"
$\chi \rightarrow$ ~1 TeV
$\phi \rightarrow$ ~ 1 GeV



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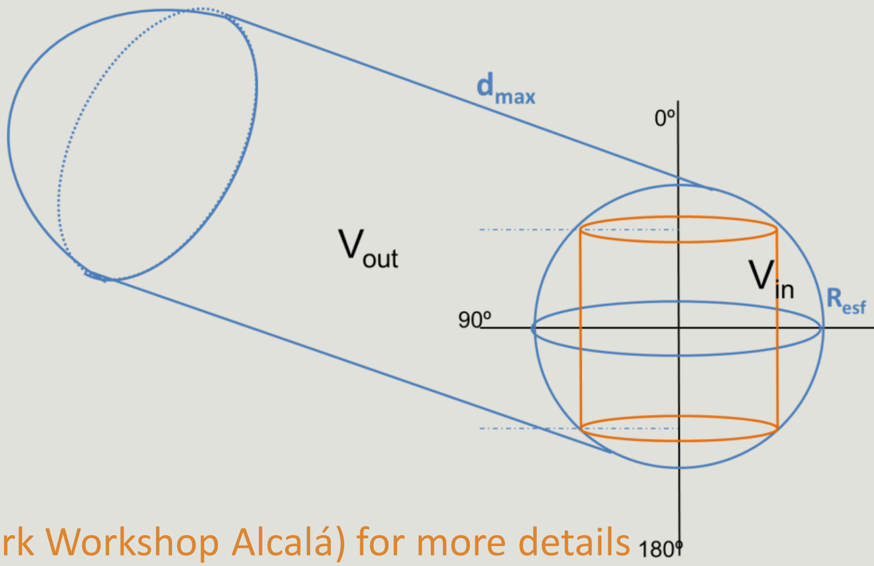
Simulation of Dimuons
Tools: Di-Muon Generator

DiMuGen: Script developed in Matlab© to generate di-muons from SDM.

- Geometry: Sphere containing the cylindrical detection CAN.
- Di-muons from different $m\chi$ and $m\phi$ (distance between tracks ~ 1 m for usual cases, so most probably not very different from single track).
- Muons arriving from Sun direction or Earth Direction or all incoming directions (useful for diverse physics, systematics, etc.).
- Two different cases:
  - i) ϕ Vertex in
  - ii) ϕ Vertex out
- Random position for di-muon production.
- Considering the losses of energy and distance separation of muons before reaching the sphere (distributions parameterised from FLUKA simulations)
- Output used as input for Standard ANTARES MC (.evt)



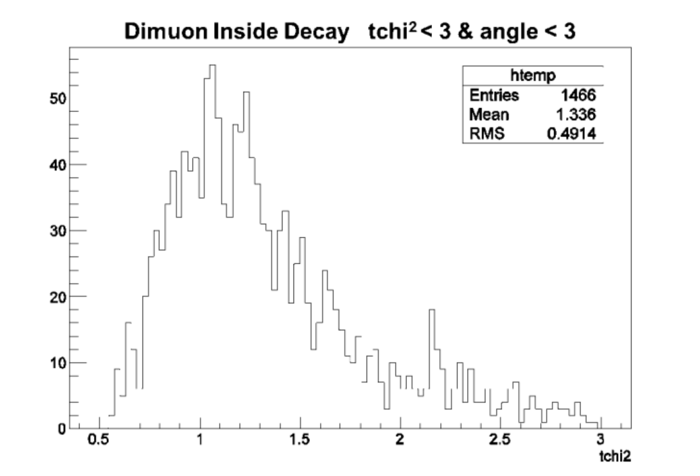
See Ardid's talk (Multidark Workshop Alcalá) for more details

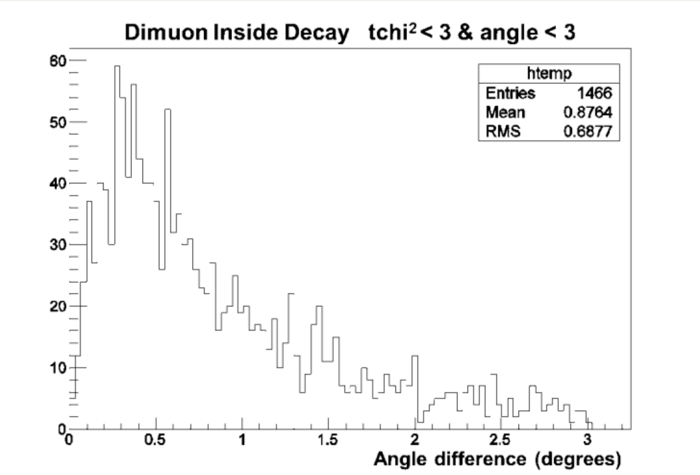
Simulation of Di-muons
Ongoing work

- 1e5 di-muons generated from m_χ= 1 TeV, m_Φ= 1 GeV, with Sun direction for each period during 2007-2012 for both inside and outside decay cases.
  - To compare outside and inside simulations, we should multiply by the considered volumes, (Vout/Vin = 3.33 for m_χ= 1 TeV, m_Φ= 1 GeV)
- 4 cases studied: di-muon, muon1, muon2 and single muon with Energy 1+2
- The output of DiMugen is used as input for standard ANTARES MC tools with different detector configurations and background conditions
- Reconstruction: BBFit
  - Usual cuts and methods for standard DM analysis used
- Other DM masses ongoing, m_χ= 50, 100, 200 and 5000 GeV

Simulation of Dimuons

Multiline Reconstruction





Multi-line strategy is used in the reconstruction of the more energetic events

For the cut optimization, two main parameters are tacking account in the Multi-line strategy:

1. Quality parameter χ^2 (fit quality of the reconstructed event).
2. Angle difference between reconstructed and simulated data (sun direction).

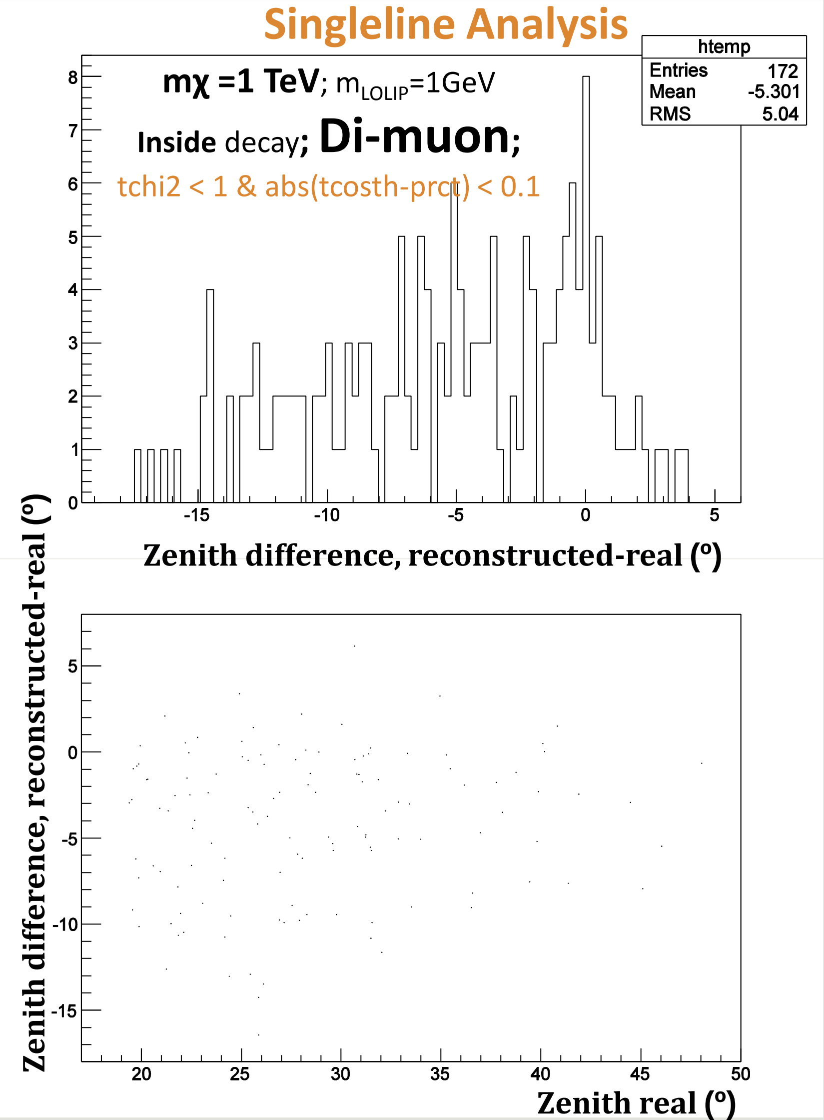
Simulation of Dimuons

Singleline Reconstruction

Single-line strategy is usually used in the reconstruction of events of low energies.

For the cut optimization, two main parameters are tacking account in the Single-line strategy:

1. Quality parameter χ^2 (fit quality of the reconstructed event).
2. Zenith difference between reconstructed and simulated data (sun direction).

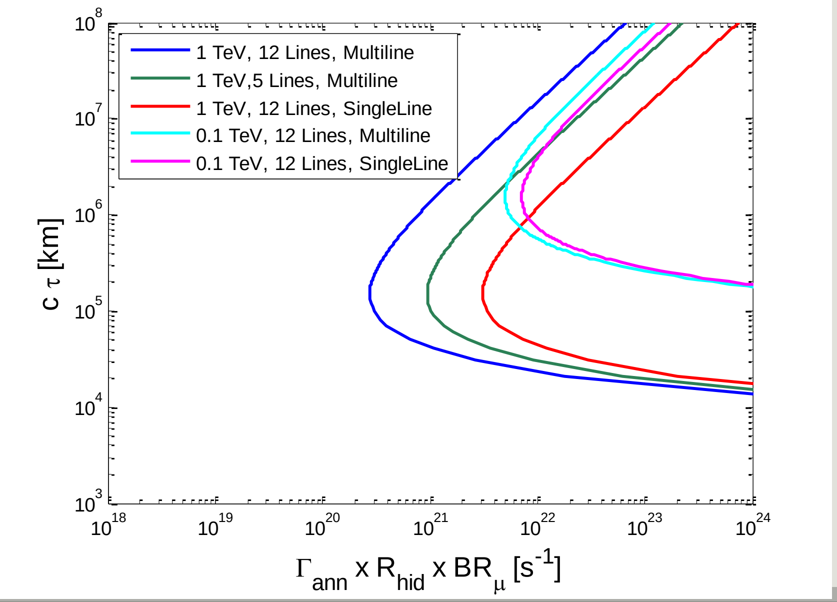


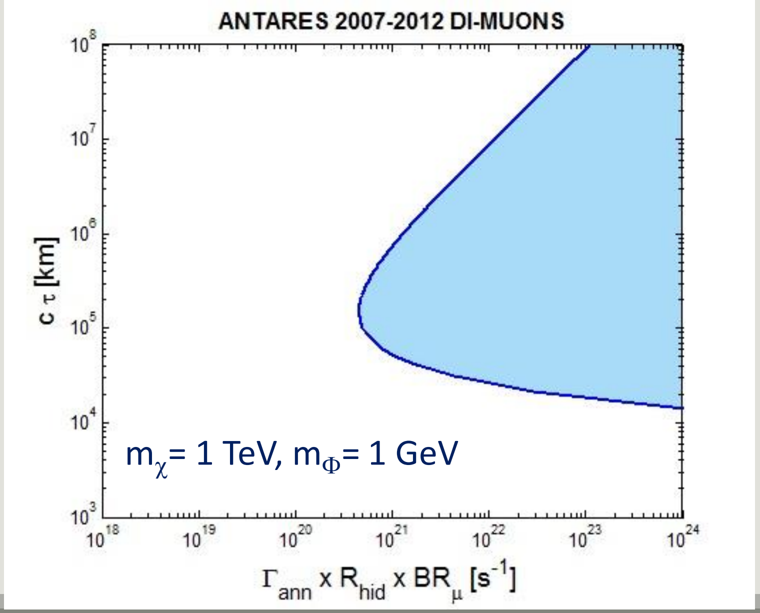
Sensitivities

- 2007-2012 (optimisation using FC Statistics)

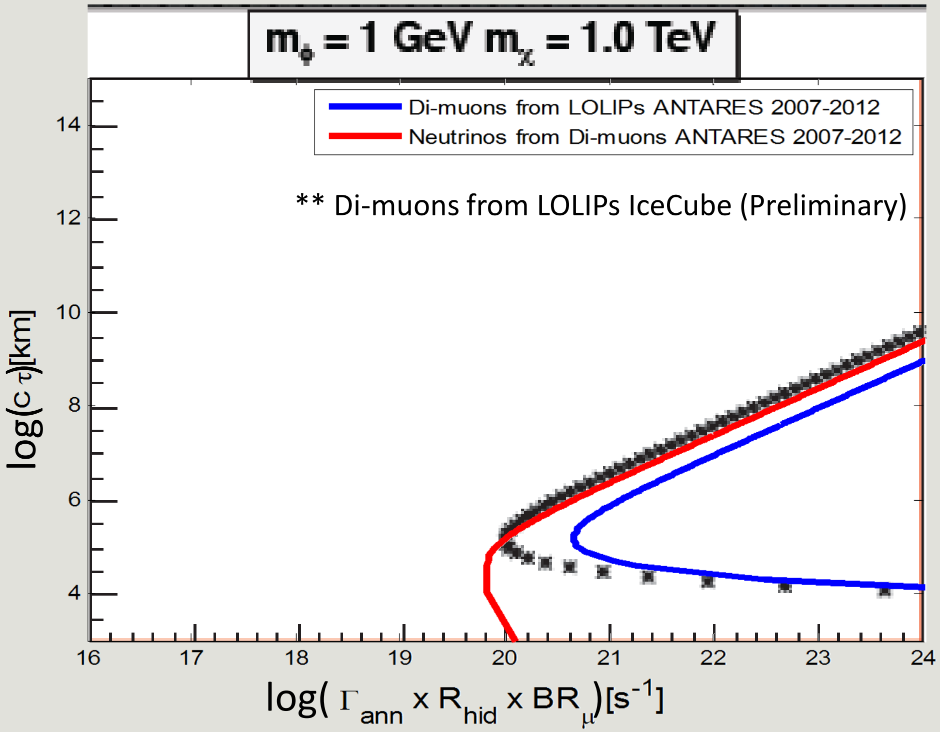
	ML-1TeV-12L	ML_1TeV-5L	SL-1TeV-12L	ML-100GeV-12L	SL-100GeV-12L
mu90bar/ns	0.00232187	0,00478	0,01573	0,02652	0,03629
tchi2	1.6	1.6	1.5	1.5	1.4
cone_angle	1.3	1.5	3.3	2.3	3.6

$$\Gamma_{ann}\ R_{hid}\ BR_{\mu}\ 2\ \left[\frac{d^2}{4\pi D^2}\right] e^{(-D/\gamma c\tau)}\left[1-e^{(-d/\gamma c\tau)}\right] = \frac{N_{sim}[\mu_{90bar}/ns]}{T_{liv}}$$





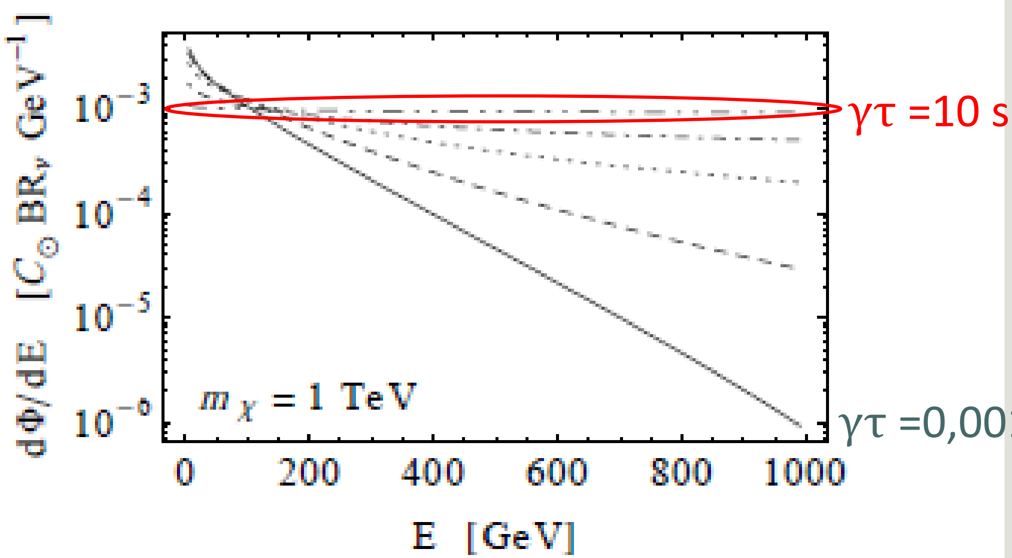
ANTARES vs. Icecube



In this plot is compared the reach for detecting LOLIPs decaying into di-muons with Antares (2007-2012) and Ice cube (Preliminary data)

Also in red the preliminary sensitivity of ANTARES to neutrinos generated from di-muon decay, tacking into account the neutrino flux (a rough estimation)

Other interesting SDM cases to test in neutrino telescopes

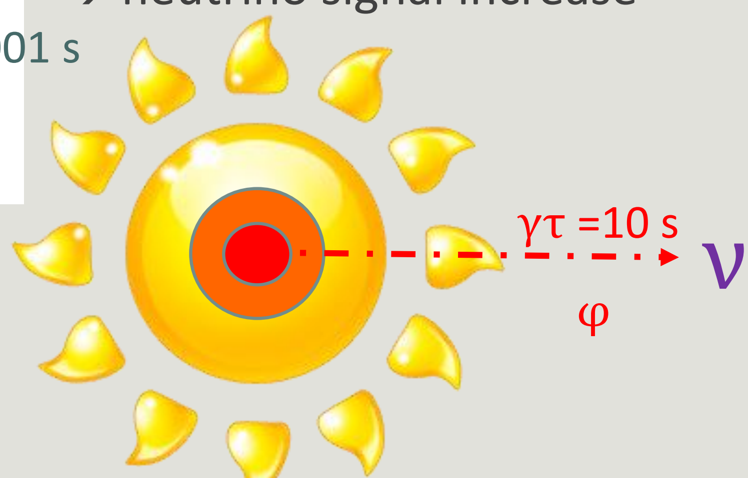


ν_e fluxes for γτ =0.001 s (solid), 0.1 s (dashed), 0.3 s (dotted), 1 s(dot-dashed), 10 s (dot-dashed).

Bell and Petraki, JCAP04(2011)003

Short-lifetime mediators decaying into neutrinos

- In the standard scenario absorption is relevant for energies higher of 100 GeV.
- In secluded scenario the neutrinos are injected away from the Sun core , through the mediator, at lower densities → neutrino signal increase



Longest life-time-> mediators decay outside Sun

Conclusions

- A tool for di-muon generation has been developed.
- We have presented the main ideas and results of the analysis.
- Simulations for di-muons have been done for case m_χ= 1 TeV, m_χ=100 GeV, m_Φ= 1 GeV (other cases will be finished soon).
- First results of sensitivities have been shown.

Next steps:

- Include the neutrino signal coming from di-muons.
  - Optimise strategies, parameters and cuts.
- Evaluate other interesting scenarios for SDM in neutrino telescopes as short-lifetime mediators decaying into neutrinos (not just di-muon case).


Parc Natural de L'Albufera