The indirect search for dark matter with the ANTARES neutrino telescope

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on behalf of the ANTARES Collaboration

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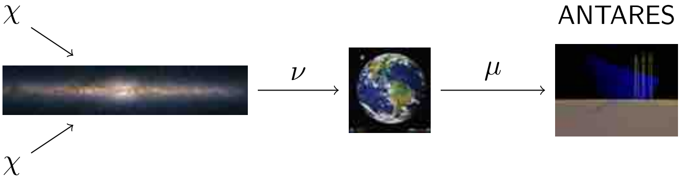
The ANTARES neutrino telescope

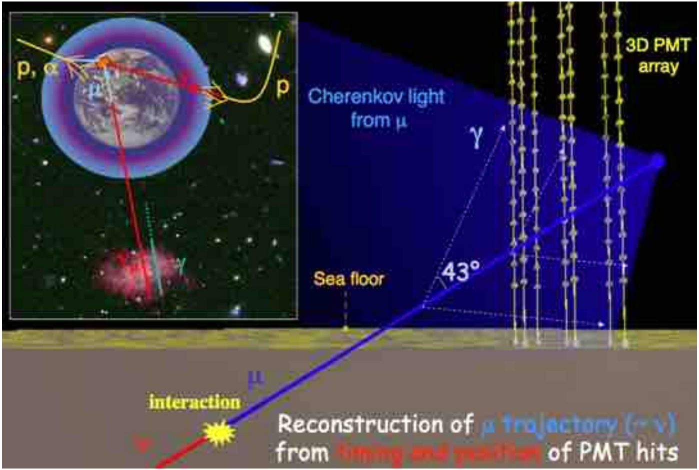
The ANTARES neutrino telescope

Indirect detection of dark matter with neutrino telescopes

- Relic WIMPs accumulate in massive celestial bodies like the Sun, the Galactic Center, the Earth (presented as poster) or galaxy clusters
- The annihilation in $W^{\pm}, Z, H$ bosons, c, b, t quarks and τ leptons can lead to significant neutrino fluxes
- The neutrino signal is less subjected to astrophysical uncertainties than γ-rays or cosmic rays **and a measured signal will be a smoking gun**



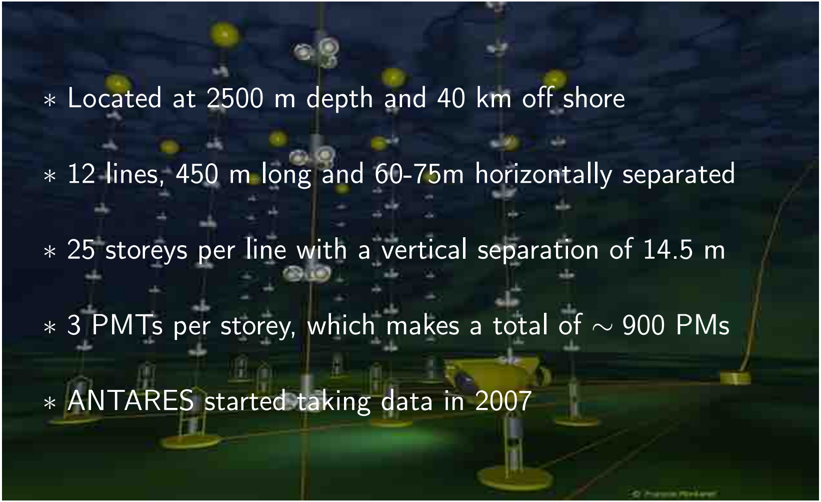
Detection principle



Dark matter neutrino signal

- For the Earth and the Sun analyses the dark matter neutrino spectra have been calculated with the WIMPSIM package (Blennow, Edsjö, Ohlsson, 03/2008)
- For the Galactic Centre and the galaxy cluster analysis the spectra of the Cirelli group are used (M.Cirelli et al., arXiv:1012.4515)
- Annihilations into $b\bar{b}$, $\tau^+\tau^-$, W^+W^-, $\mu^+\mu^-$and $\nu_\mu\bar{\nu}_\mu$ are used as benchmark

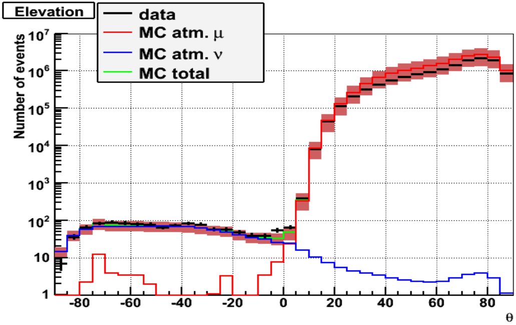
The ANTARES detector



- ∗ Located at 2500 m depth and 40 km off shore
- ∗ 12 lines, 450 m long and 60-75m horizontally separated
- ∗ 25 storeys per line with a vertical separation of 14.5 m
- ∗ 3 PMTs per storey, which makes a total of $\sim$ 900 PMs
- ∗ ANTARES started taking data in 2007

Background rejection

The largest part of the background consists of atmospheric muons



They can be rejected by making a "horizon cut" thereby using the Earth as a shield against these muons

Search towards the Galactic Centre

Galactic Centre

Cone cuts

- In a binned analysis, sensitivities and limits are obtained from a background estimate, that is produced for varying quality cuts and cone cuts around the analyzed source.
- In our analysis this background estimate is generated from time-scrambled data.
- The sensitivities are optimised with respect to the cone and reconstruction quality parameter cut.
- The limits are then generated using the same cone and quality cuts used for the sensitivities.

Flux limits

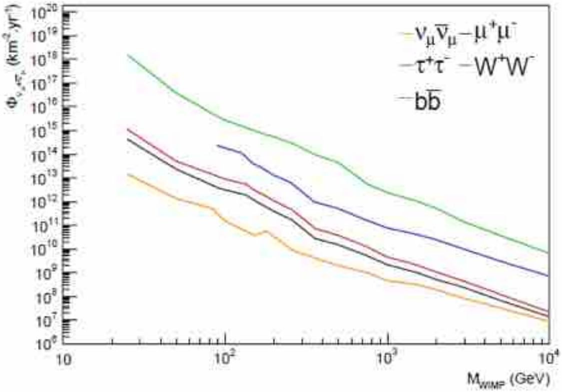


Figure: The neutrino and antineutrino flux limits for the different annihilation channels.

J-Factor

- The J-Factor is the integral along the line of sight of the dark matter density squared.

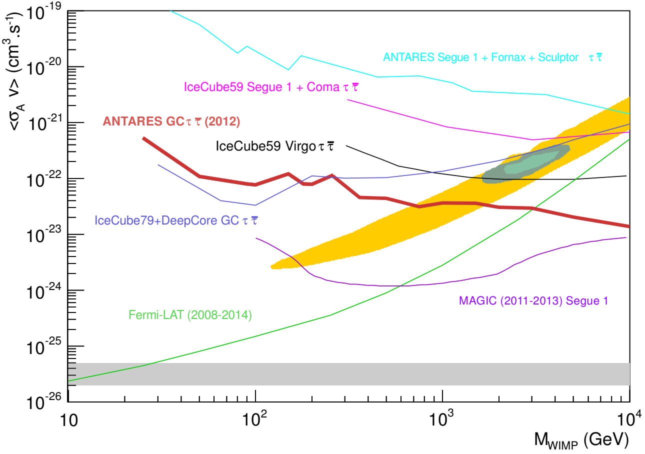
$$J(\theta) = \int_0^{l_{max}} \frac{\rho^2_{DM}\sqrt{R^2_{SC} - 2lR_{SC}\cos(\theta) + l^2}}{R_{SC}\rho^2_{SC,DM}} dl$$

- The J-Factor is necessary to convert a flux into a thermally averaged annihilation cross section $< \sigma v >$

$$\frac{d\phi_\nu}{dE} = \frac{<\sigma v>}{2} J_{\Delta\Omega} \frac{R_{SC}\rho^2_{SC}}{4\pi m^2_\chi} \frac{d\ N_\nu}{dE}$$

- The total J-factor for the binned analysis is calculated by integrating the J-factor over solid angle until the cone cut

Limit comparison



Search towards the Sun

The Sun

Unbinned method

- The used likelihood function is:
  $$\log(L) = \sum_i \log\left(\frac{n_s}{N} S_i(\alpha, N_{hits}, \beta) + \left(1 - \frac{n_s}{N}\right) B_i(dec, N_{hits}, \beta)\right)$$
- N_{hits} is the number of selected hits in the event, β the angular error estimate (χ^2 is used for BBFit)
- The test statistics used is:

$$\log[TS] = \log[L^{max}] - \log[L(n_s = 0)]$$

Flux limits

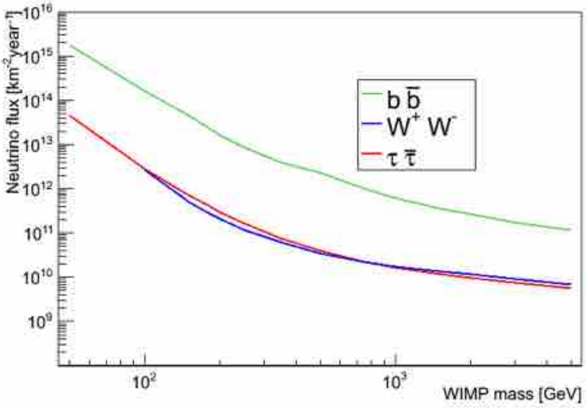


Figure: The neutrino plus antineutrino flux limits for the different annihilation channels.

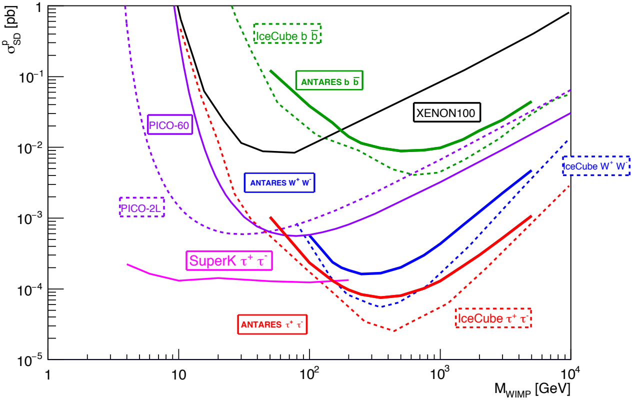
Conversion to cross sections

- The neutrino fluxes are converted to cross sections assuming an equilibrium between annihilation and capture

$$C_{cap} = 2C_{ann}$$

- C_{ann} is the annihilation rate, C_{cap} is the capture rate
- The capture rate is then linked to the cross sections assuming a Maxwellian velocity distribution with a rms velocity of 270 $m \cdot s^{-1}$ and a local dark matter density of 0.4 $GeV \cdot cm^{-3}$

Limits and results



- The data from the 2007-2012 period has been used (1321 days of livetime)

Search for secluded dark matter

Secluded dark matter

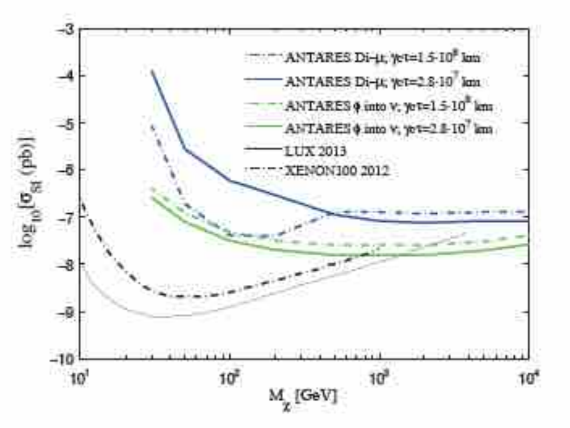
Secluded dark matter

- This type of dark matter is secluded from standard model physics by a mediator called ϕ
- In the analysis presented here three cases were considered:
  - Detection of muon pairs from mediator decays in the source
  - Detection of neutrinos from the decay of these muons
  - Detection of neutrinos directly produced by mediators
- The search was focused on the Sun as a source

Secluded dark matter

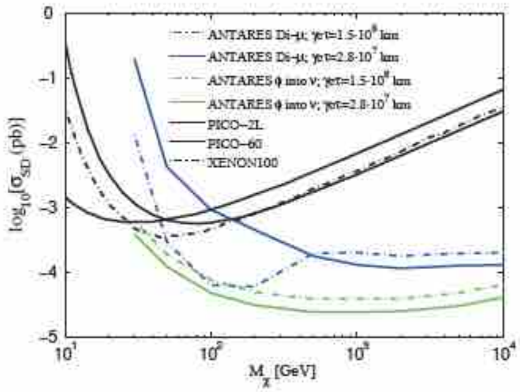
- Limits on secluded dark matter depend on the lifetime of the mediator
- To produce simple limits that only depend on the WIMP mass optimal lifetimes for the mediator were assumed for each considered mass.
- Lifetime dependent limits were produced as well

Limits and results



- The data from the 2007-2012 period has been used with 1321 days of livetime

Limits and results



- The data from the 2007-2012 period has been used with 1321 days of livetime

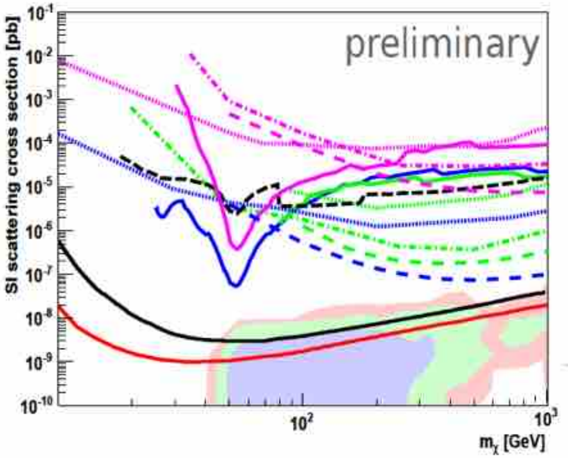
Search towards the Earth

The Earth

Dark matter in the Earth

- In this search no equilibrium between annihilation and capture can be assumed
- Instead different assumptions on the thermally averaged annihilation cross section $<\sigma v>$ have to be tested
- In the example given here $<\sigma v>= 3 \cdot 10^{-26} cm^3 s^{-1}$ was assumed.

Limits and results



- The data from the 2007-2012 period has been used with 1191 days of livetime

Legend

- Blue lines: $\tau^+\tau^-$ channel, Pink lines: $b\bar{b}$ channel, Green lines: W^+W^- channel
- Solid lines: ANTARES (2007-2012), Dotted lines: BAKSAN (1978-2009), Dot-Dashed lines: IceCube (2010-2011)
- Black line: XENON100 (2012), Red line: LUX (2013)

Summary

- The search for dark matter in the Galactic Center analysis show **very competitive** results
- The produced limits begin to constrain the SUSY dark matter models
- ANTARES limits will further improve with new data (and an unbinned GC search is ongoing)

Source selection

- An analysis of the 11 most promising sources is in progress
- For now only the binned method has been applied

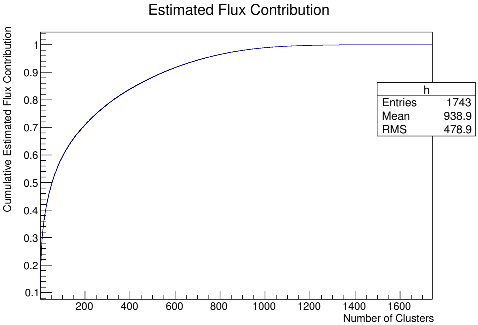


Figure: Cumulative estimated contribution per source sorted by magnitude

First estimation of sensitivity for the Virgo cluster

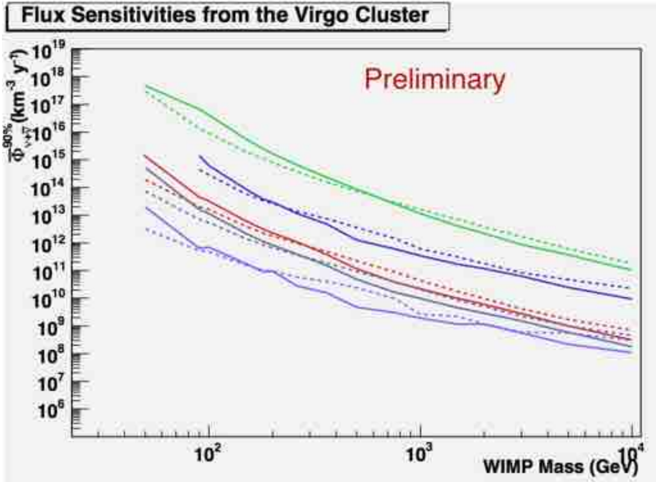
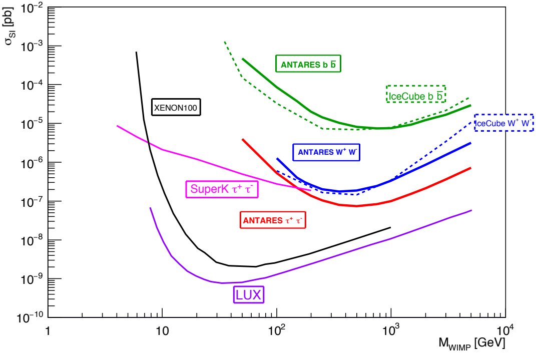


Figure: Solid: AAFit, Dashed: BBFit Colours: b,τ, W, μ,ν_μ

Limits and results



- The data from the 2007-2012 period has been used
- 1321 days of livetime in this period

Dark matter neutrino signal

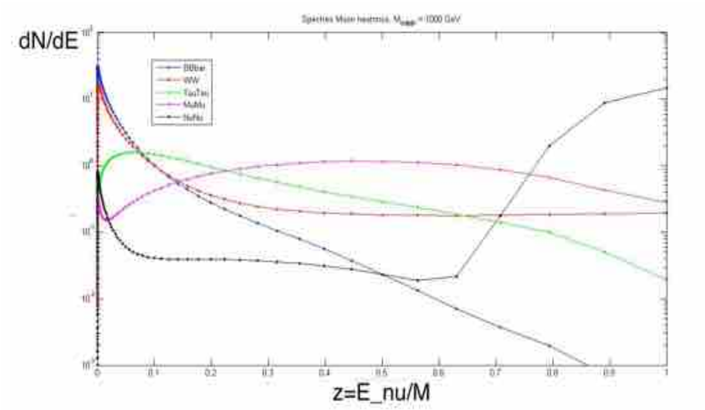


Figure: Neutrino spectra from WIMP annihilations in vacuum, Blue: $b\bar{b}$, Green: $\tau^+\tau^-$,Red: W^+W^-, Black: $\nu\bar{\nu}$, Violet: $\mu^+\mu^-$, used for the Galactic Centre, dwarf galaxies and galaxy clusters

Unblinding

No observed excess.

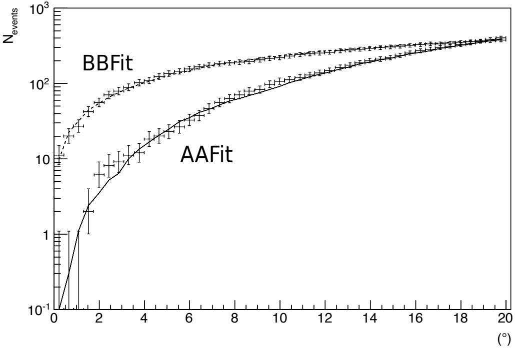


Figure: The cumulative number of events from the 2007-2012 period (crosses) vs. background estimate (line). 1321 days of livetime

Acceptance

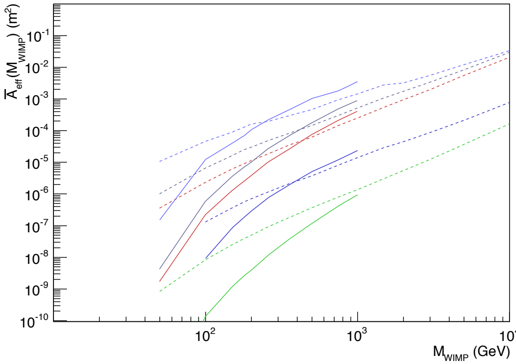
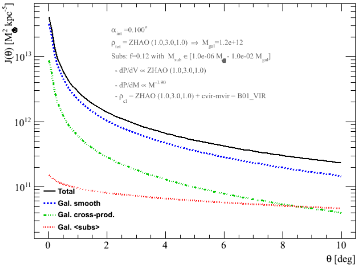
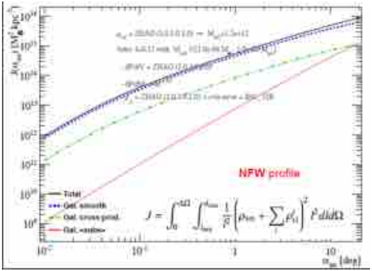


Figure: Acceptance $[m^2]$ per WIMP mass $[GeV]$ for the different channels. Solid lines: AAFit, Dashed lines: BBFit, Green: $b\bar{b}$, Red: $\tau^+\tau^-$,Blue: W^+W^-, Gray: $\mu^+\mu^-$, Light blue: $\nu\bar{\nu}$

Clumpy Output





J factor computed for the NFW profile using CLUMPY version 2011.09_corr2 (A. Chardonnier et al., Comp. Phys. Comm. 183, 656 (2012) (`http://lpsc.in2p3.fr/clumpy`))

Visibility

IceCube visibility
without veto
in galactic coordinates
Resolution in ice $\sim 0.6^\circ$

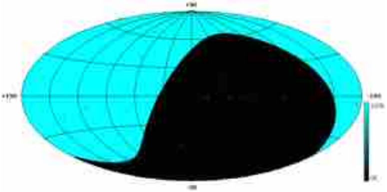
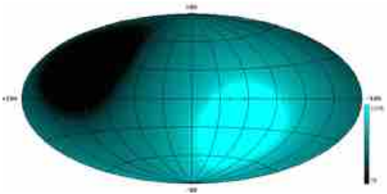
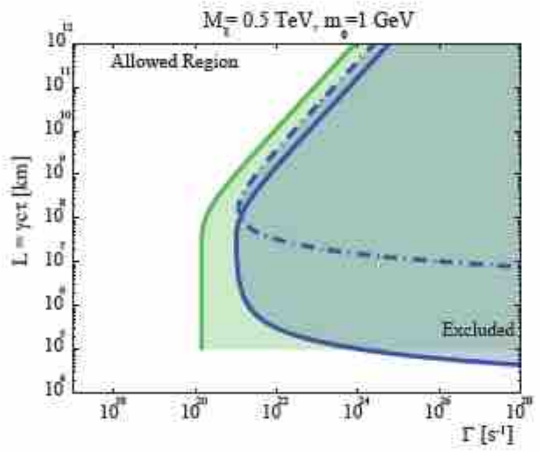


Figure: IceCube visibility increases with the veto at the price effective area

ANTARES visibility
in galactic coordinates
Resolution in water $\sim 0.3^\circ$

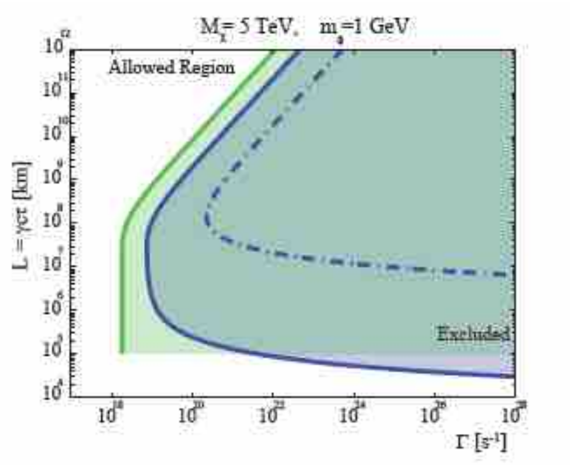


Limits and results



- The data from the 2007-2012 period has been used with 1321 days of livetime

Limits and results



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Spectra and acceptance

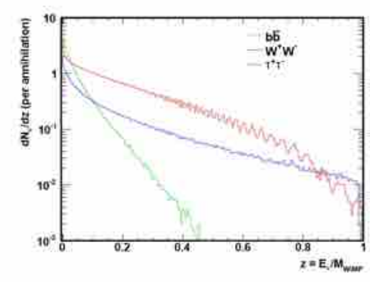

Figure: Neutrino spectra used for the Sun analysis produced with WIMPSIM, taking neutrino oscillations into account.

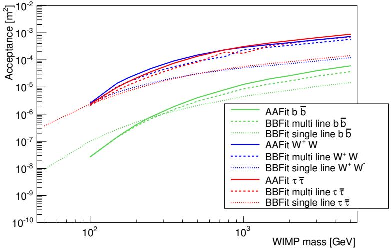

Figure: The acceptance [m^2] as a function of the WIMP mass for the different channels

Reconstruction strategies

- AAFit (likelihood based)
  - Better for high energies (>250 GeV)
  - Event selection parameters are λ (reconstruction quality) and β (angular error estimate)
- BBFit (χ^2 based)
  - Better for low energies (<250 GeV)
  - Can reconstruct single-line events (only zenith angle provided)
  - The main event selection parameter is tchi2 ($\sim \chi^2$)