DM searches with the ANTARES neutrino telescope

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on behalf of the ANTARES collaboration

MultiDark
Multimessenger Approach
for Dark Matter Detection

Scientific scope

- Origin of cosmic rays
- Hadronic vs. leptonic signatures
- Dark matter

Detector size

Limitation at high energies:
Fast decreasing fluxes E^{-2}, E^{-3}

Supernovae

Oscillations

Dark matter (neutralinos, KK)

Astrophysical neutrinos

GZK

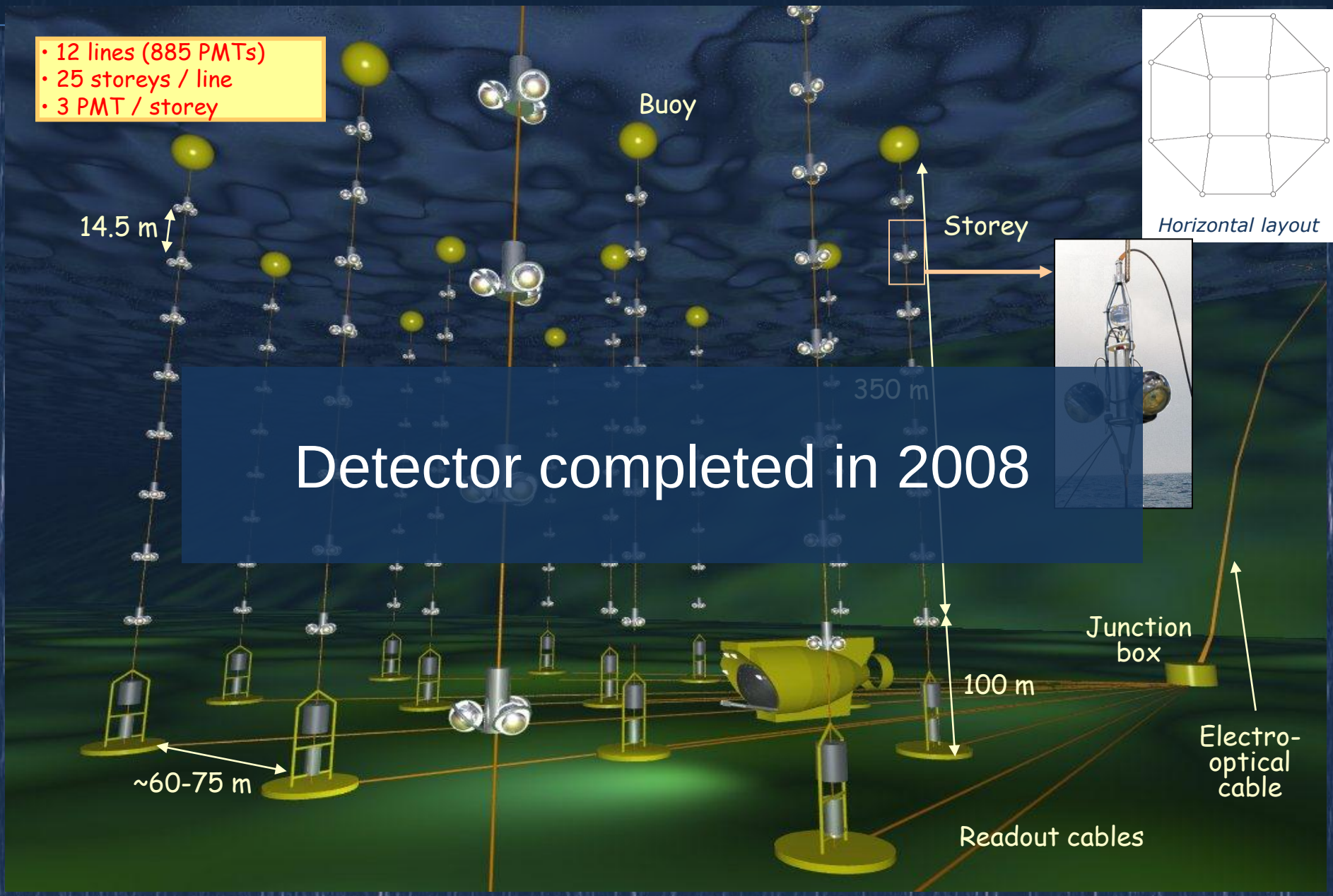
Limitation at low energies:
-Short muon range
-Low light yield
-^{40}K (in water)

MeV GeV TeV PeV EeV

Detector density

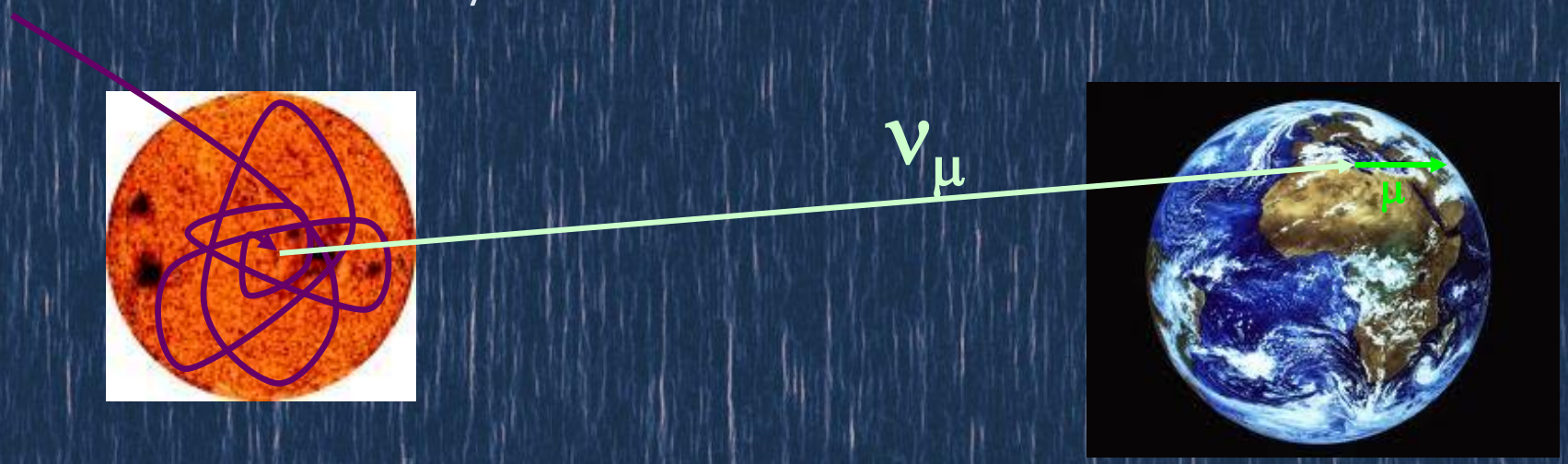
Other physics: monopoles, nuclearites, Lorentz invariance, etc...

The ANTARES detector

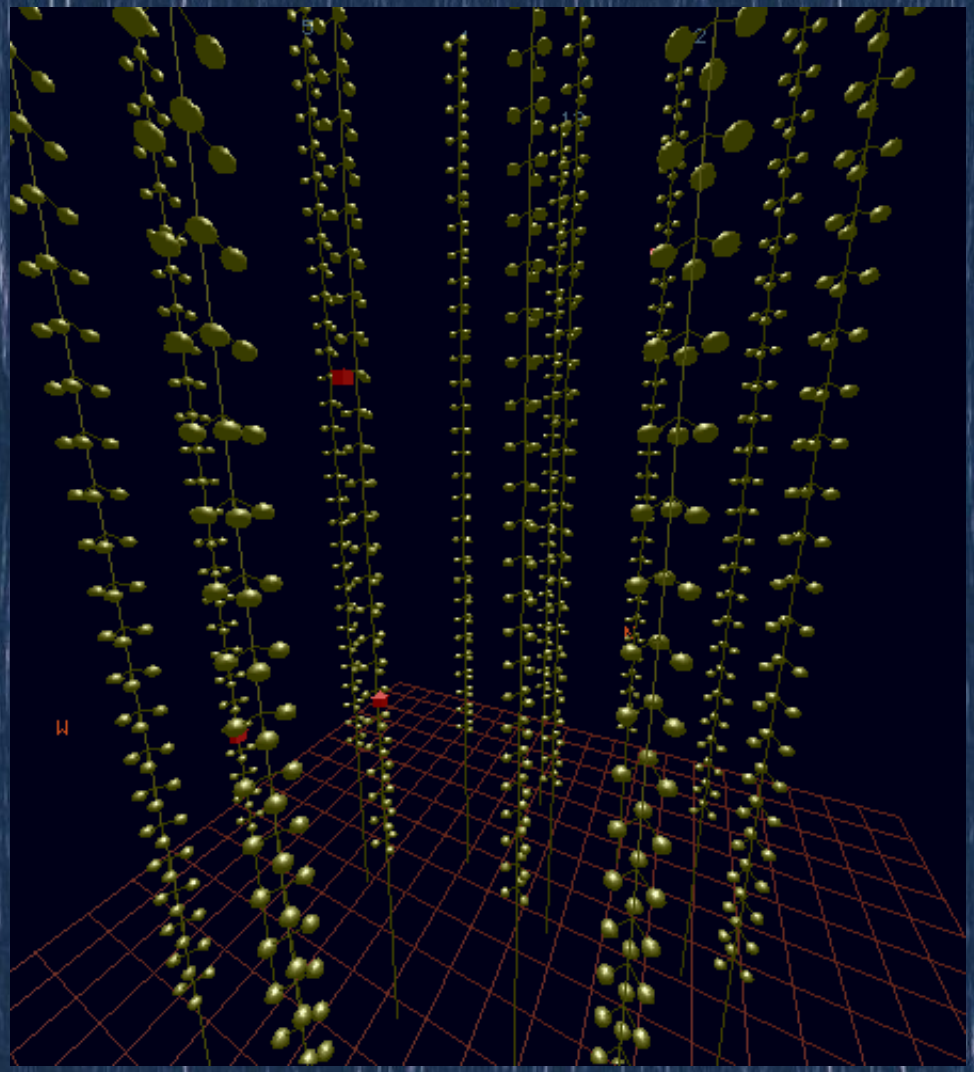


Detection of DM

- WIMPs (neutralinos, KK particles) are among the most popular explanations for dark matter
- They would accumulate in massive objects like the Sun, the Galactic Center, dwarf galaxies…
- The products of such annihilations would yield “high energy” neutrinos, which can be detected by neutrino telescopes
- In the Sun a signal would be very clean (compared with gammas from the GC, for instance)
- Sun travel in the Galaxy makes it less sensitive to non-uniformities

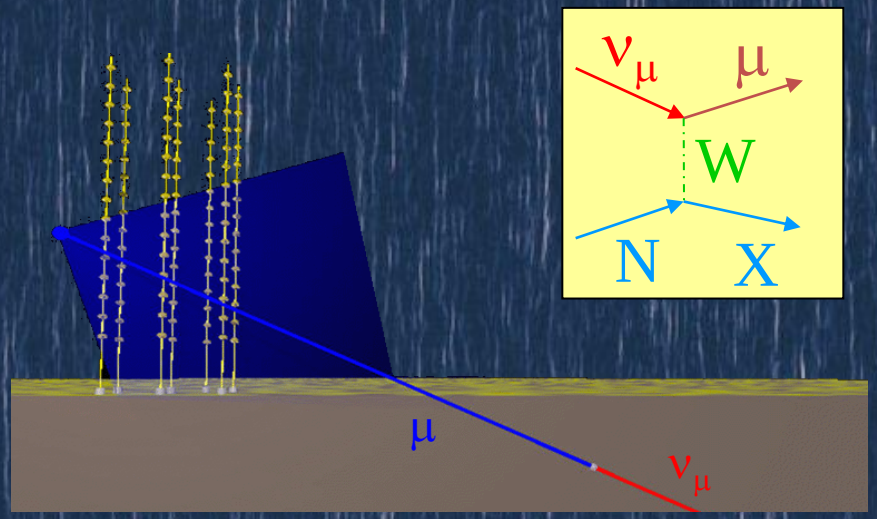


Detection principle

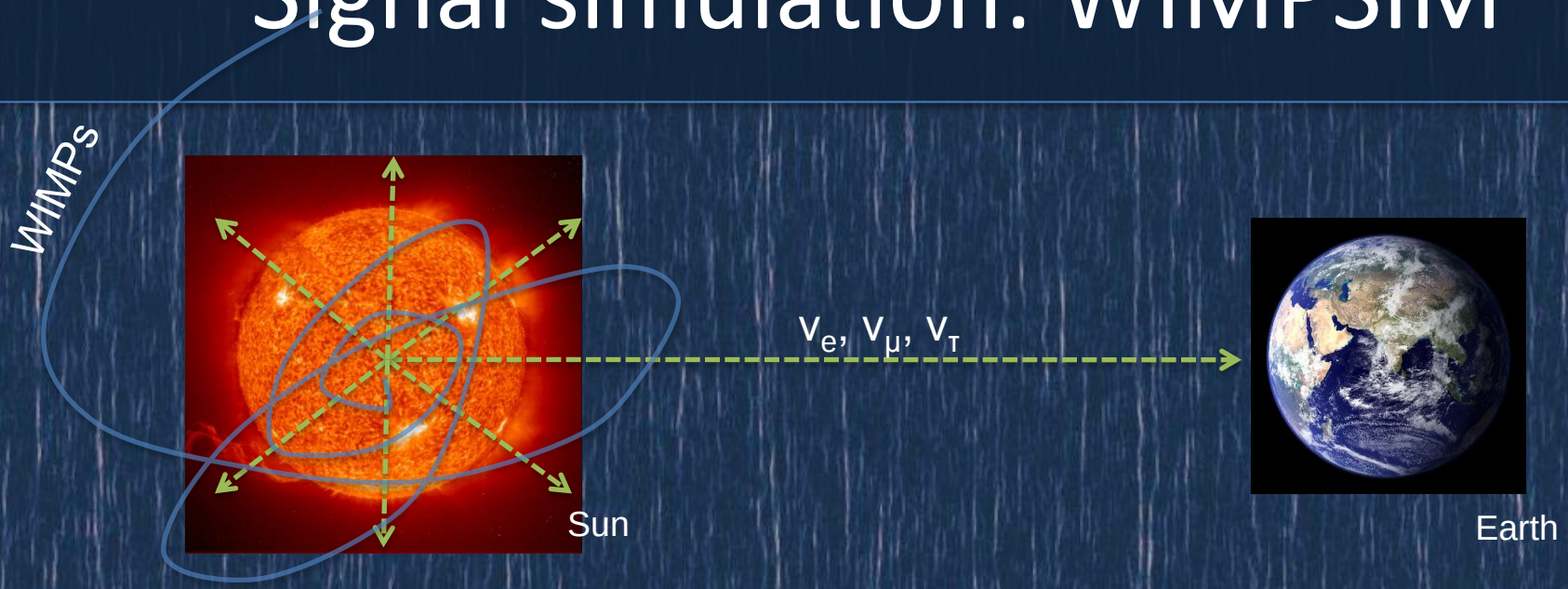


1.2 TeV muon traversing ANTARES

- The neutrino is detected by the Cherenkov light emitted by the muon produced in the CC interaction.

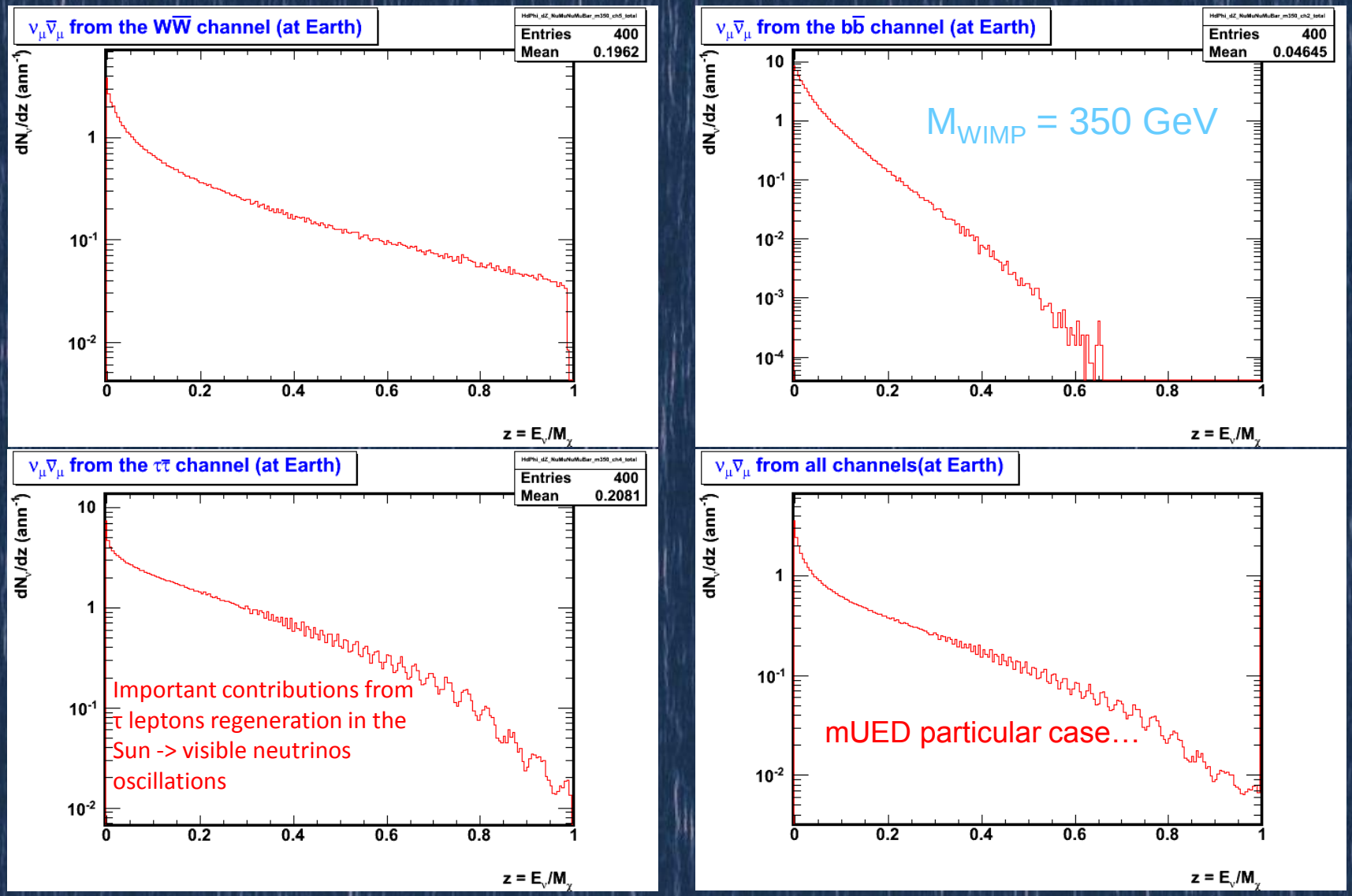


Signal simulation: WIMPSIM



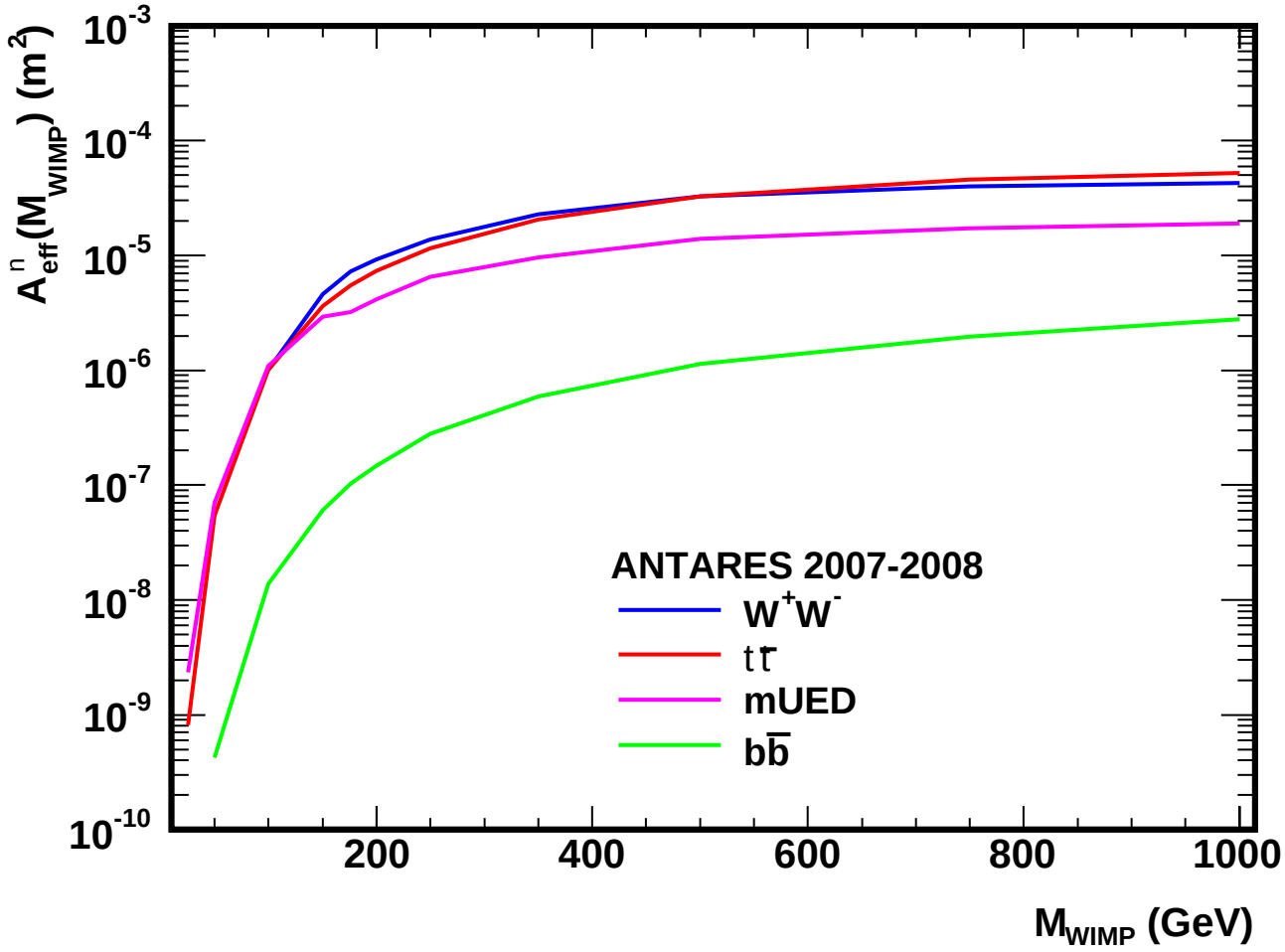
- Blennow, Edsjö, Ohlsson (03/2008): "WIMPSIM" model-independent production
- Great statistics with 12×10^6 WIMPs annihilations
- Capture rate and annihilations in equilibrium at the Sun core
- Annihilations in c,b and t quarks, τ leptons and direct channels
- Interactions taken into account in the Sun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

Main channels



Averaged Effective area

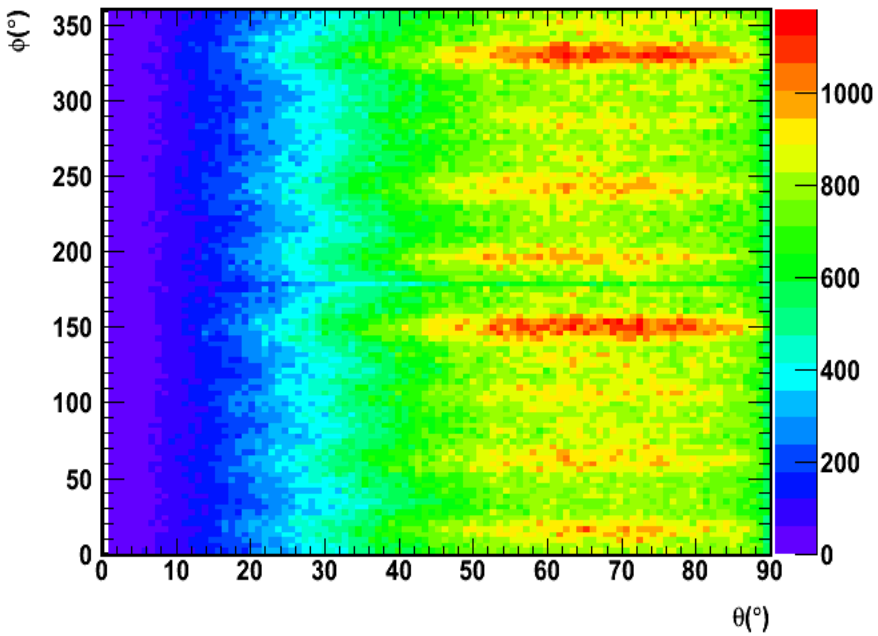
Define an Averaged Effective Area per channel per WIMP mass



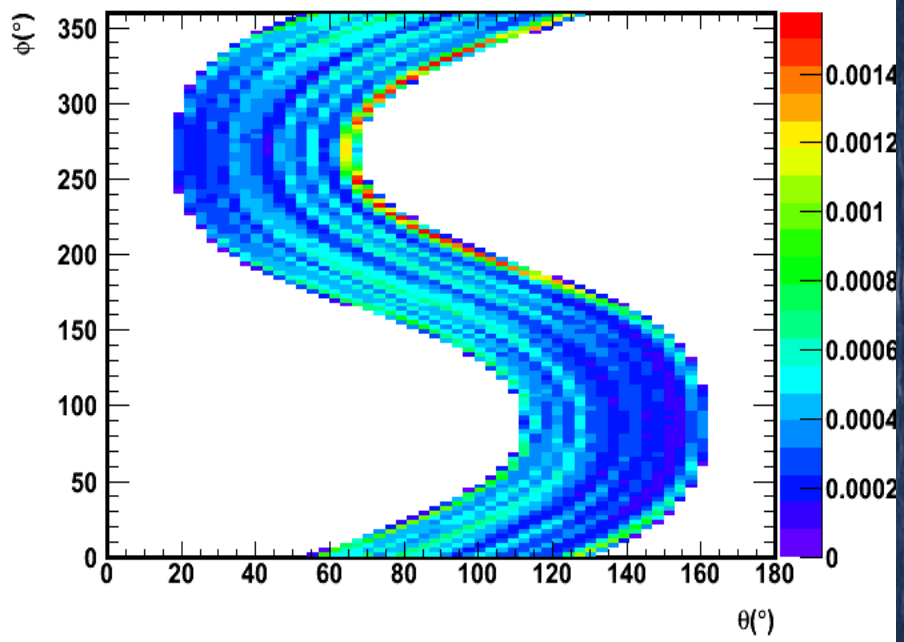
Background estimation

- The background is estimated by scrambling the data in time
- A fast algorithm is used for muon track reconstruction (Astrop. Phys. 34 (2011) 652-662)
- The effect of the visibility of the Sun is taken into account

All upward-going events from 2007-2008 data



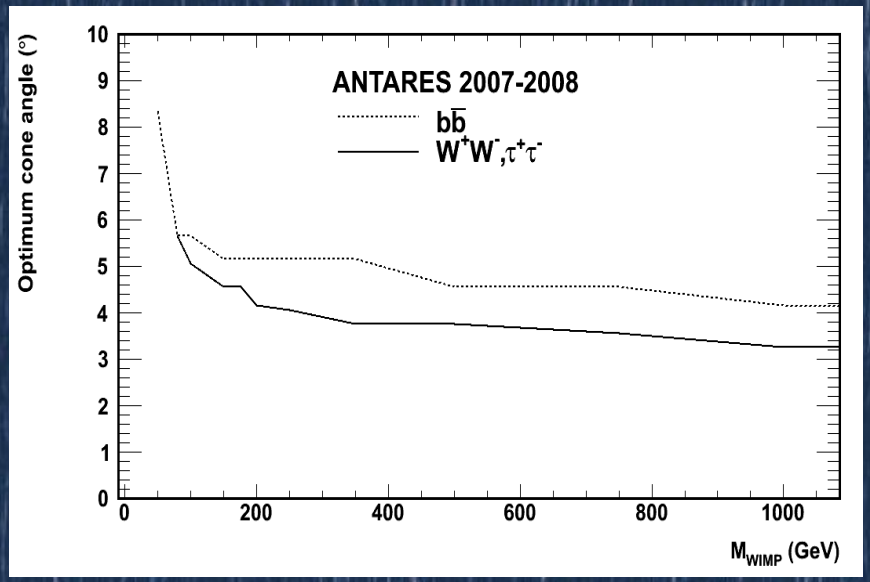
Example of Sun tracking in horizontal coordinates



Cut optimization

- Neutrino flux at the Earth x Detector Efficiency x Visibility → Signal
- Data in the Sun direction time scrambled → Background
- Cuts on the angular window size and on the track quality cut are chosen to optimize the flux sensitivity

$$Limit = \frac{m_{90}}{Aeff(Mwimp) * Teff}$$



Once the optimum quality cuts are chosen we proceed to unblind…

After unblinding

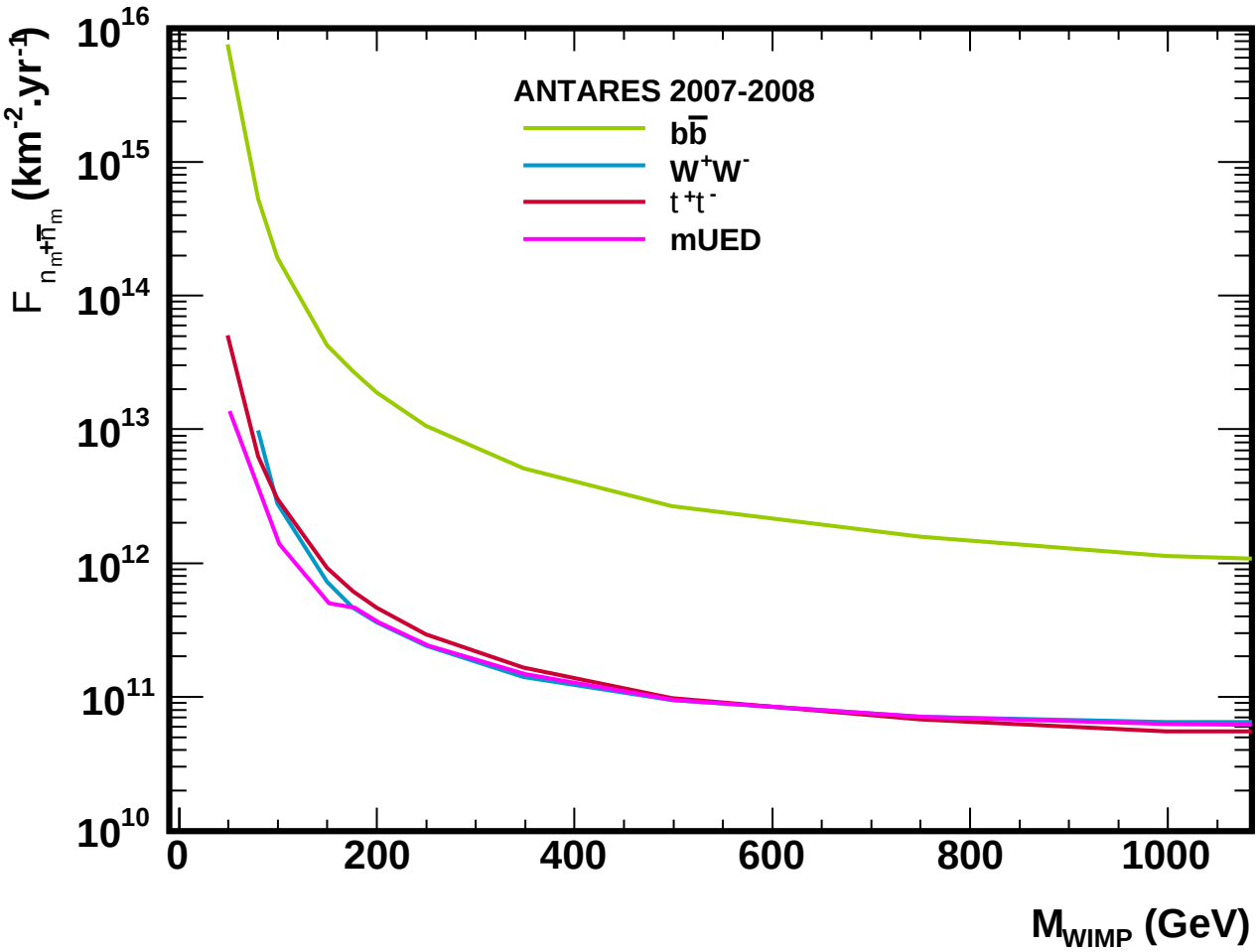
…no

und

(keep searching)

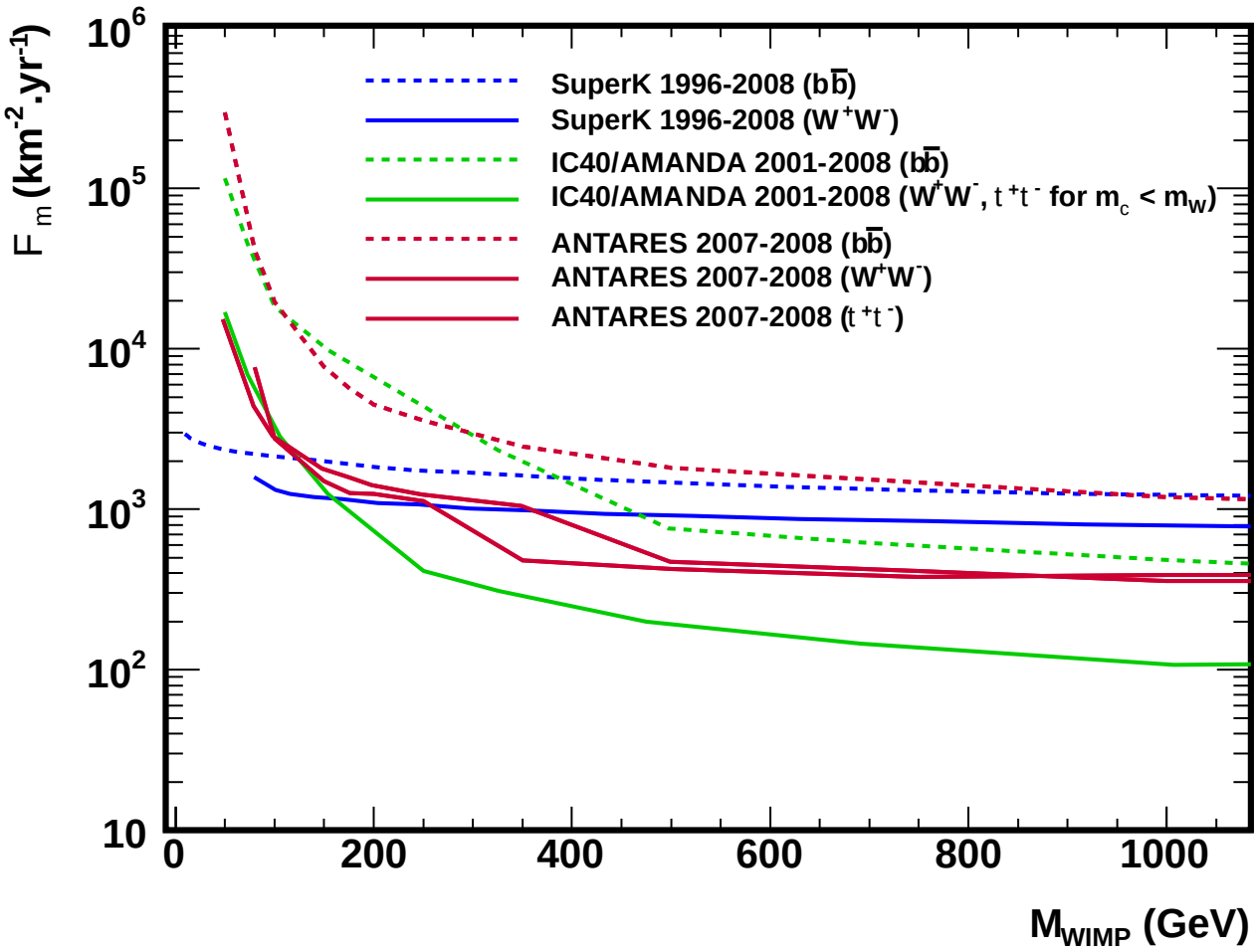
Neutrino flux limit

Neutrino + anti-neutrino flux limit ANTARES 2007-2008



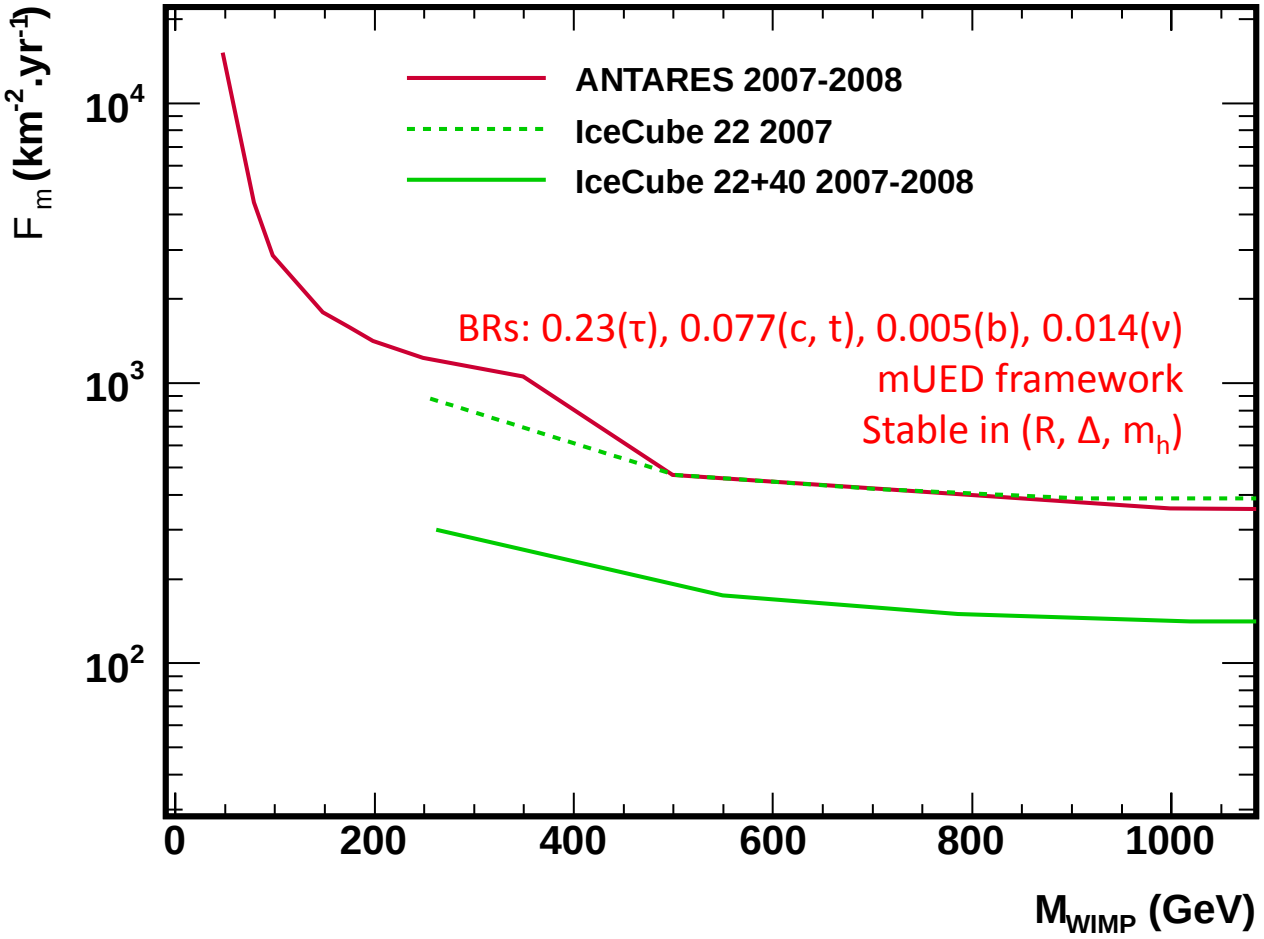
CMSSM: Muon flux

Muon flux limit for ANTARES 2007-2008 in the CMSSM framework



mUED: Muon flux

Muon flux limit for ANTARES 2007-2008 in the mUED framework



Cross section calculation

Differential neutrino flux is related with the annihilation rate as:

$$\frac{d\phi_\nu}{dE_\nu} = \frac{\Gamma}{4\pi d^2}\frac{dN_\nu}{dE_\nu},$$

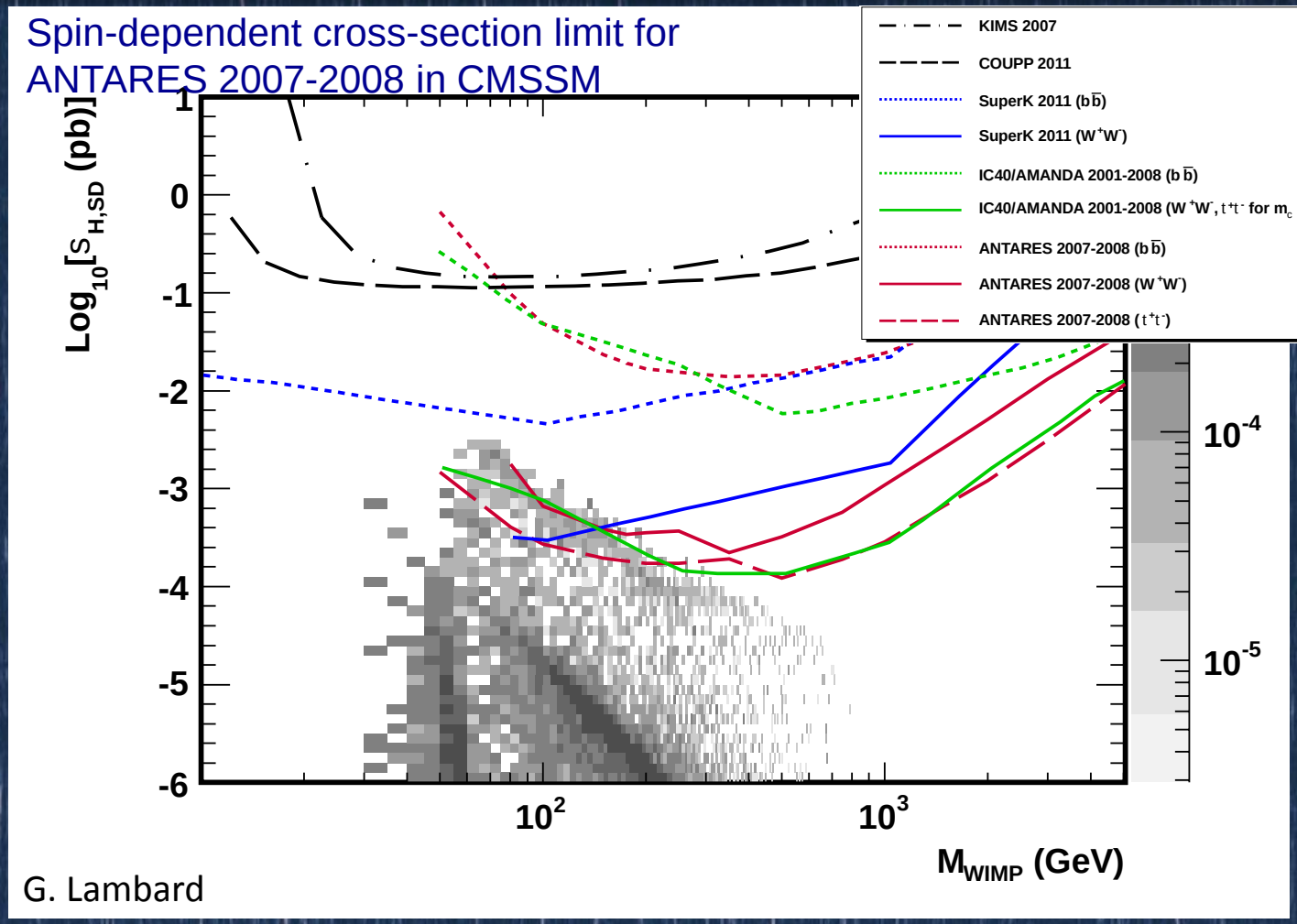
If we assume equilibrium between capture and annihilation in the Sun:

$$\Gamma \simeq \frac{C_\otimes}{2}.$$

where the capture rate can be expressed as:

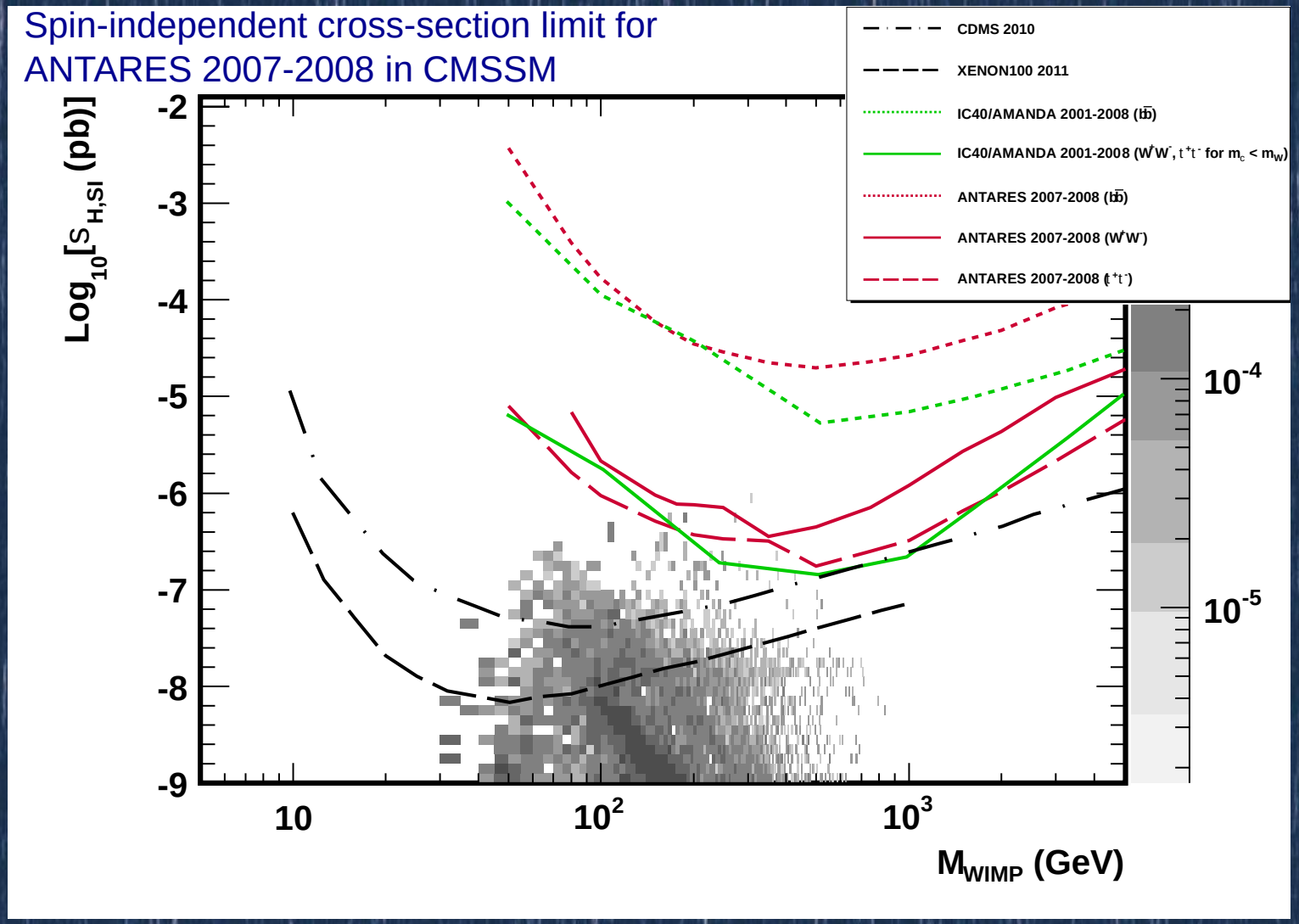
$$C_\otimes \simeq 3.35 \times 10^{18}\mathrm{s}^{-1} \times \left(\frac{\rho_{\mathrm{local}}}{0.3\,GeV \cdot cm^{-3}}\right) \times$$
$$\times \left(\frac{270\,\mathrm{km} \cdot \mathrm{s}^{-1}}{v_{\mathrm{local}}}\right) \times \left(\frac{\sigma_{H,SD}}{10^{-6}\,\mathrm{pb}}\right) \times \left(\frac{TeV}{M_{\mathrm{WIMP}}}\right)^2,$$

CMSSM: SD cross section limit

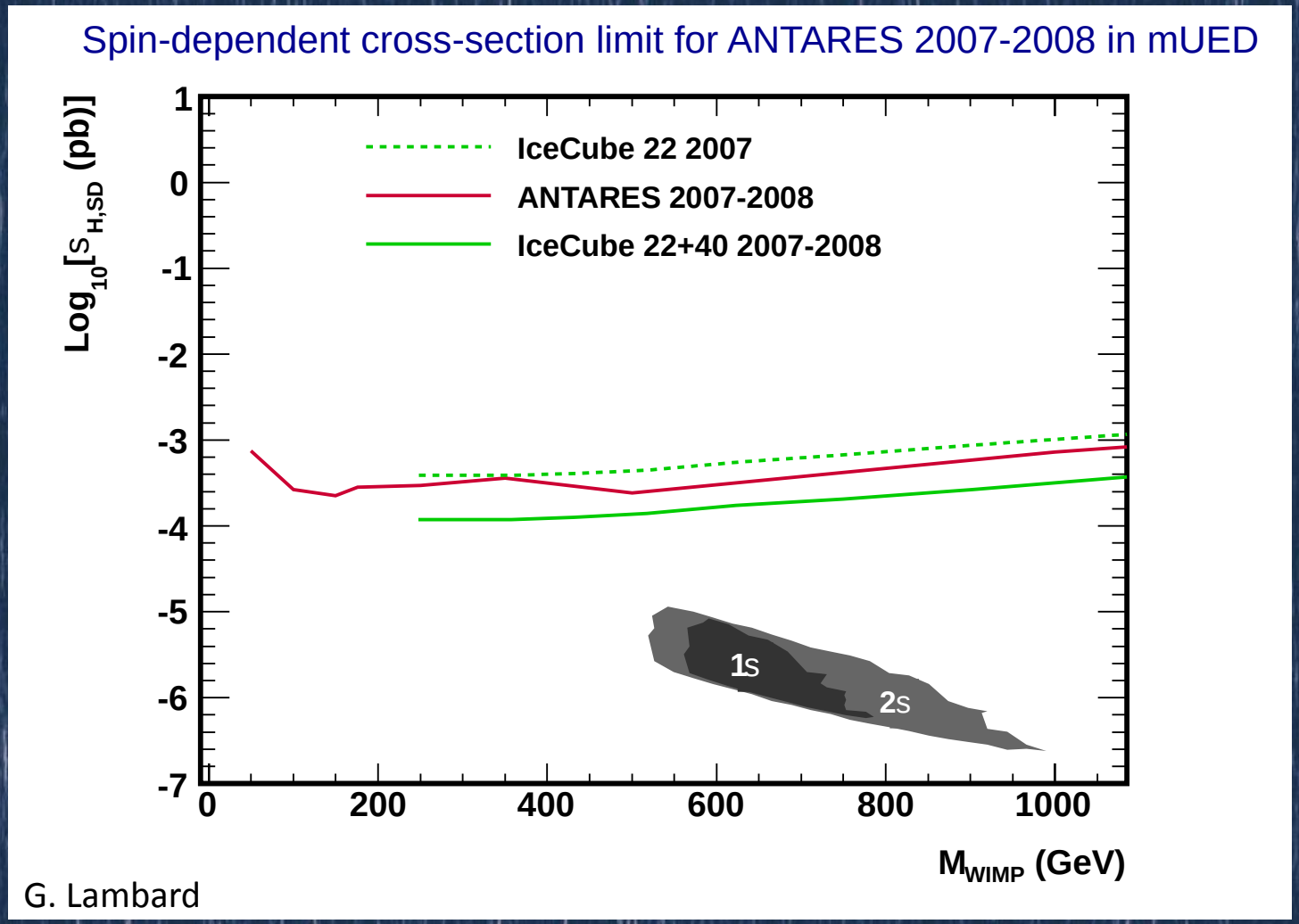


Compare SUSY predictions to observables as sparticles masses, collider observables, dark matter relic density, direct detection cross-sections, … **SuperBayes** (arXiv:1101.3296)

CMSSM: SI cross section limits

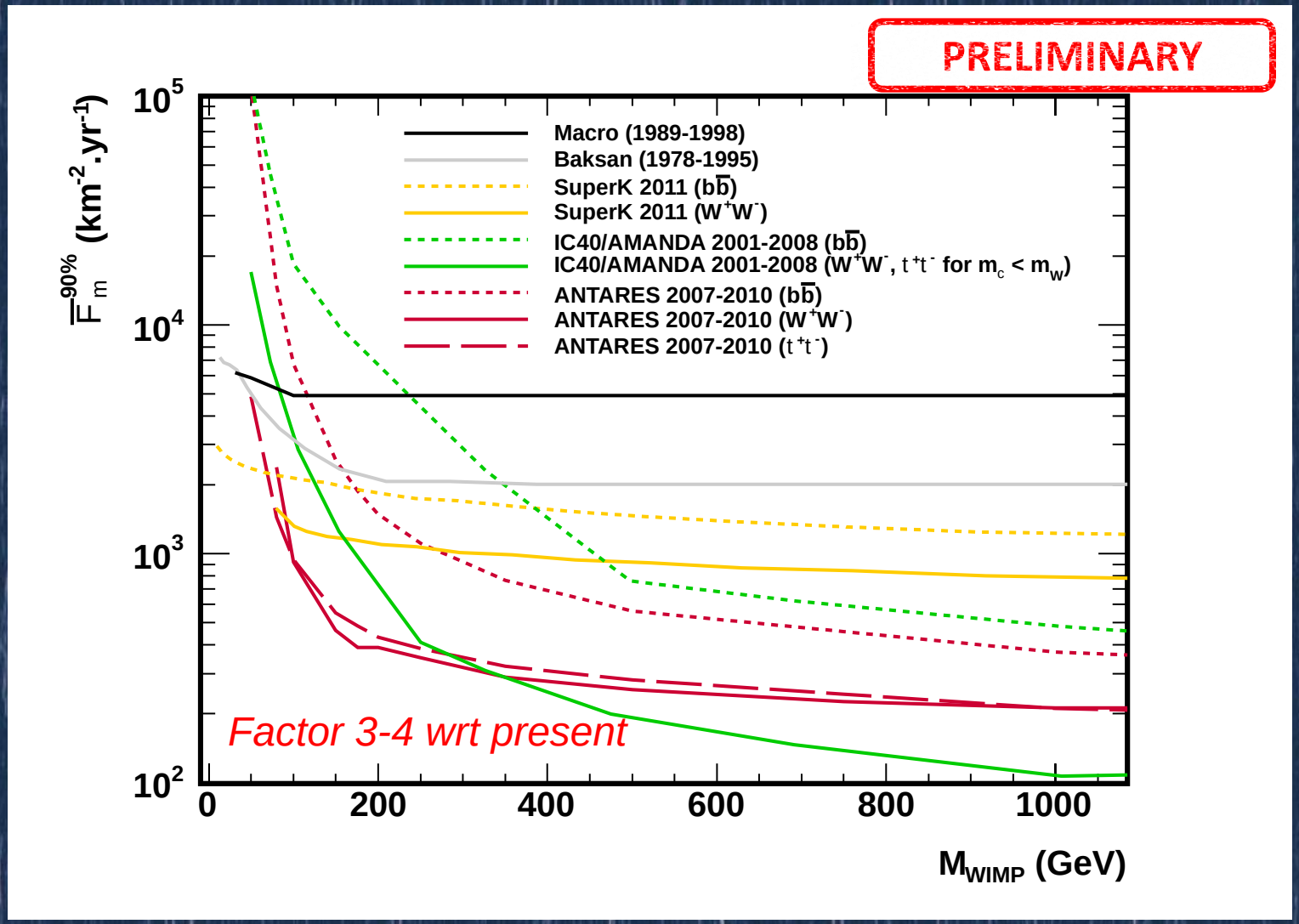


mUED: SD cross section limits



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))

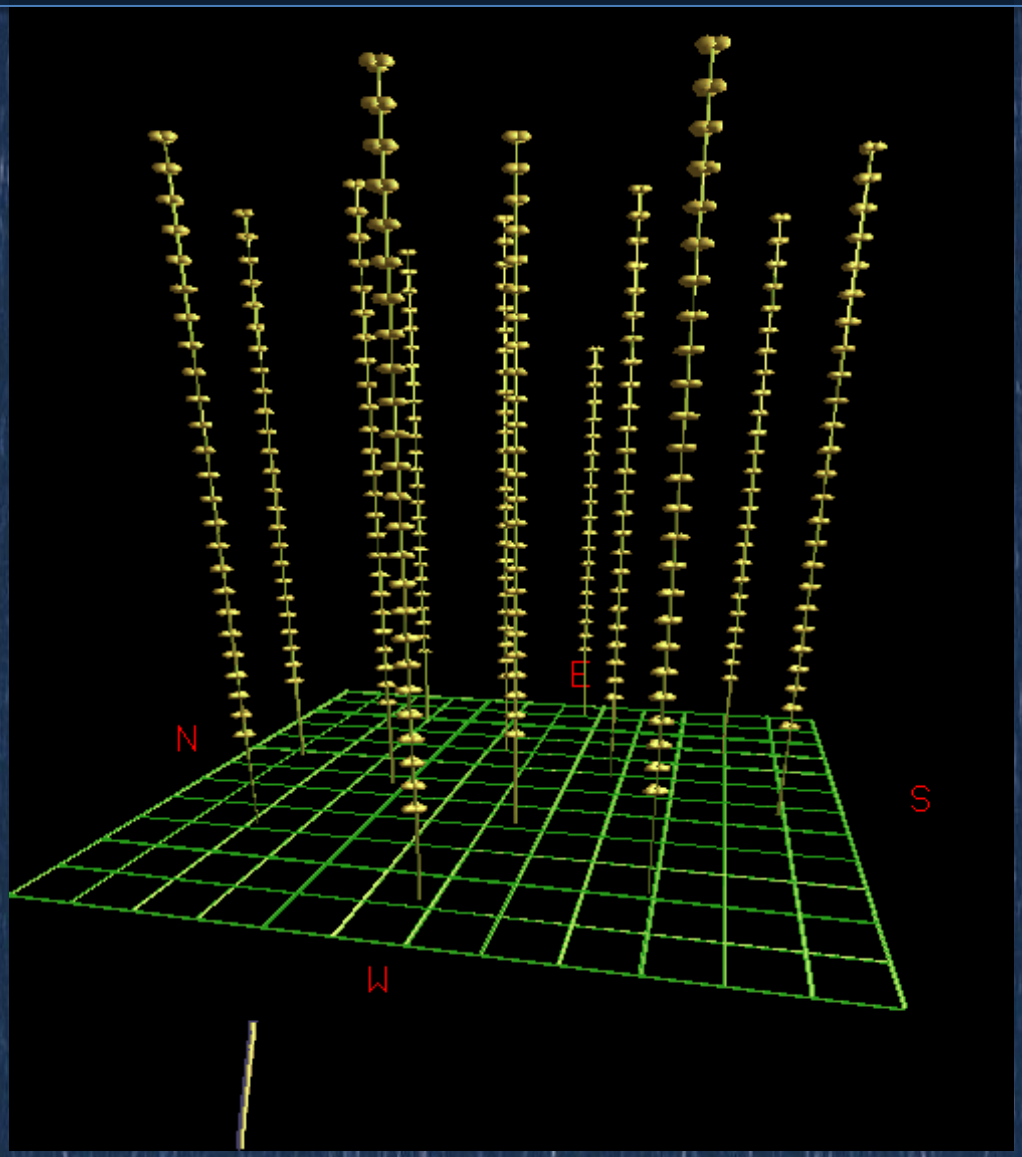
Prospects with 2007-2010 data: muon flux limit



Summary

- Dark matter is a major goal for neutrino telescopes (and an important complement to direct detection experiments)
- Computed the detector efficiency for two common dark matter models (CMSSM, mUED)
- First analysis done by looking at Sun. Limits for the CMSSM and mUED, in muon flux and SD cross-section calculated
- Analysis on 2007-2010 data in progress…
- Other sources (GC, dwarf galaxies…) also in the scope

Neutrino candidate with 12-line detector

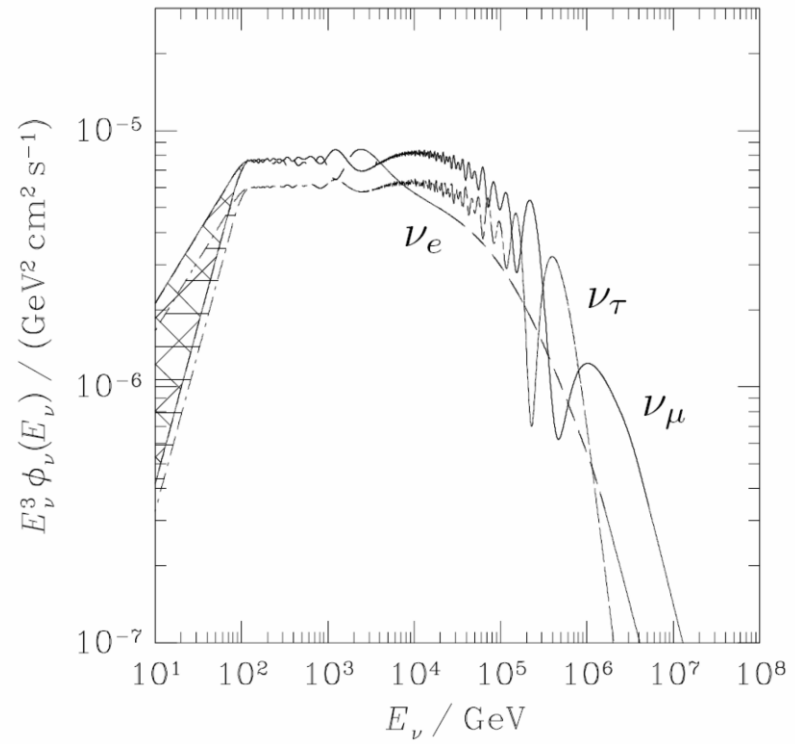


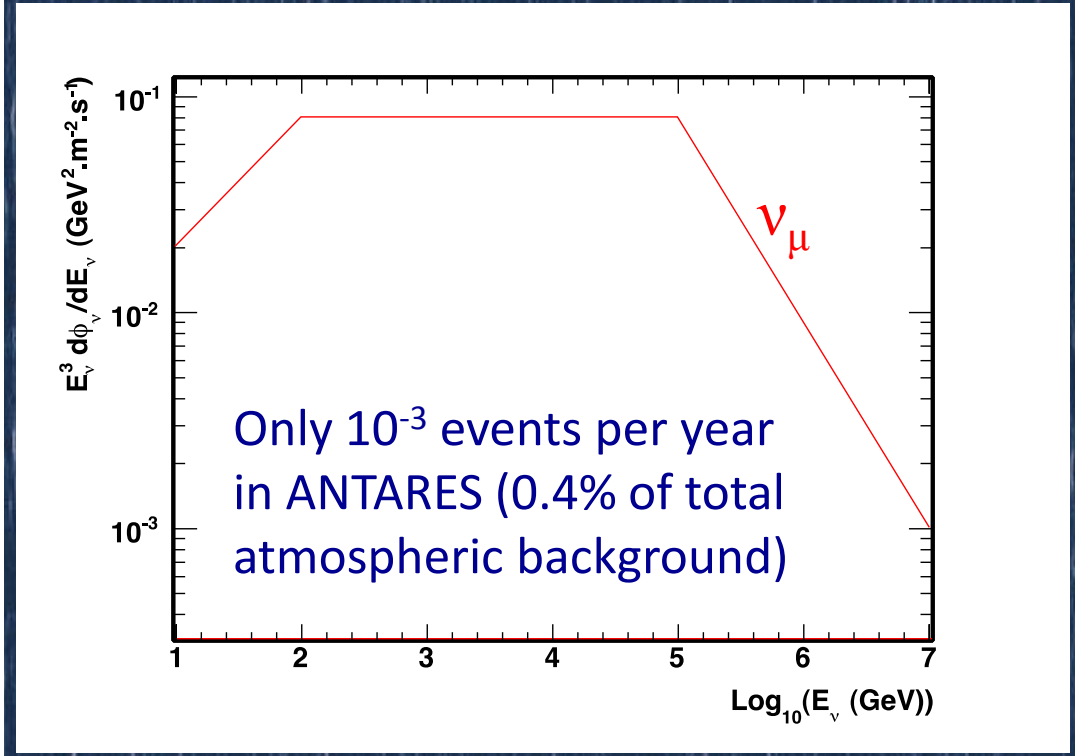
Backup

Background from the Sun

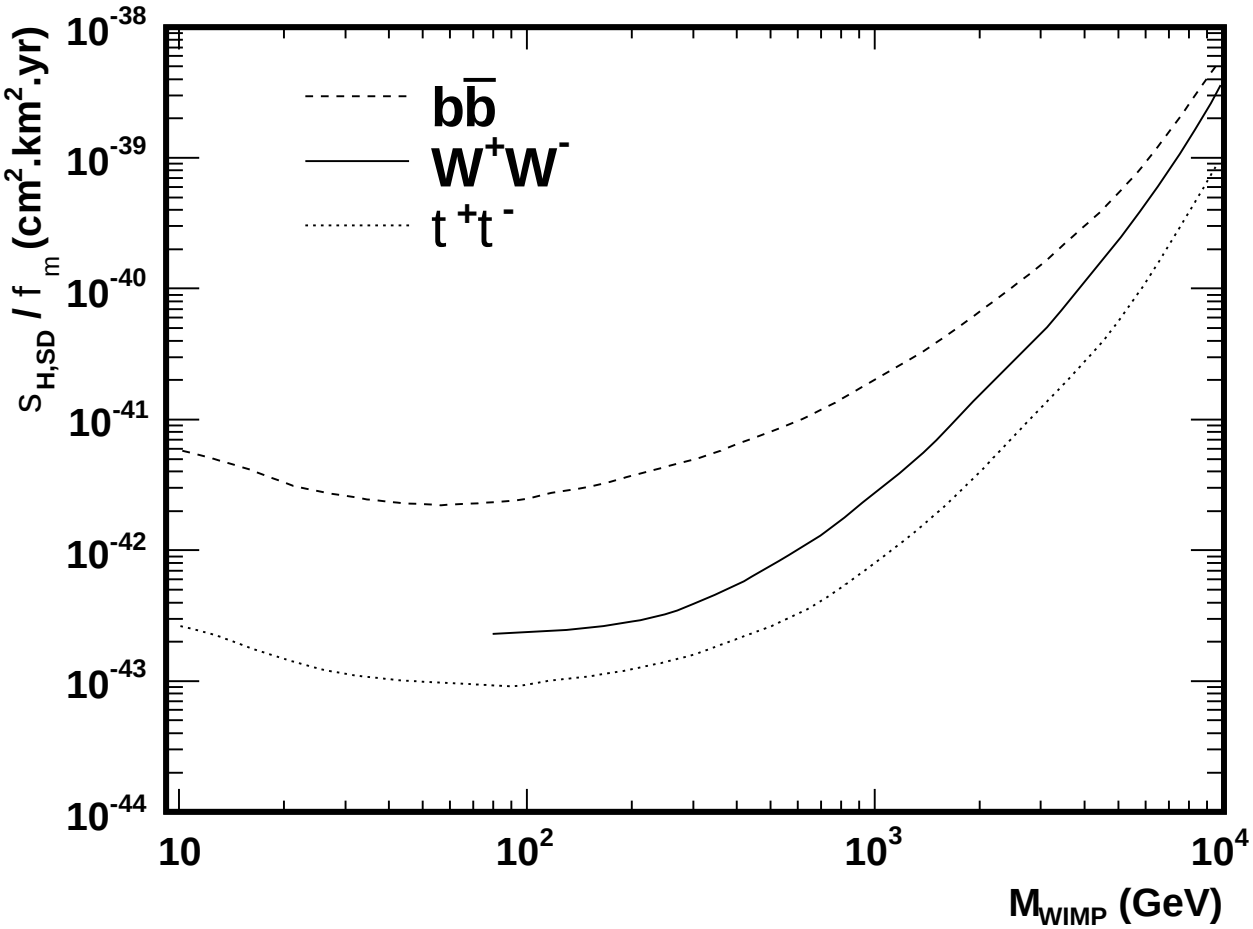
- The interaction of cosmic rays in the Sun (p-p) produces "atmospheric solar neutrinos", after the decay of the products (pions and muons)

De C. Hettlage et al., Astropart.Phys. 13 (2000) 45-50





SD cross section calculation

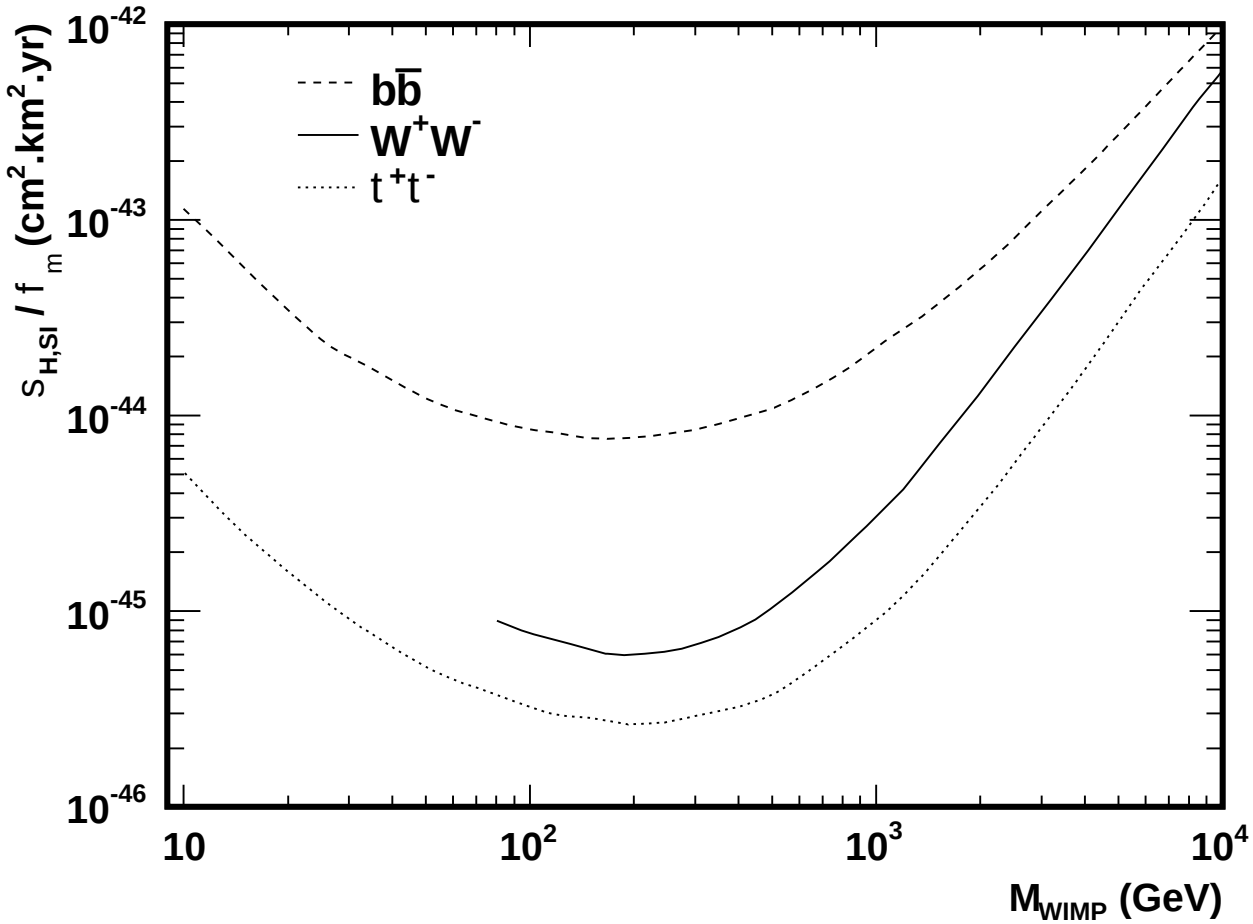


Conservative view on the local region:

- Jupiter Effect
- w/o additional disk in the dark matter halo
- local density 0.3 GeV.cm^{-3}

(arxiv:0903.2986v2)

SI cross section calculation



Conservative view on the local region:

- Jupiter Effect
- w/o additional disk in the dark matter halo
- local density 0.3 GeV.cm^{-3}

(arxiv:0903.2986v2)

Signal computation

- 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 Γ ~ 0.5 * C (equilibrium condition)

$$\frac{dj}{dE\,dW} = \frac{G}{4pd^2}\sum_i B_i \frac{dN_i}{dE_i}$$

$$C_{\otimes} \simeq 3.35\times10^{18}s^{-1}\times\left(\frac{\rho_{local}}{0.3\,GeV.cm^{-3}}\right)\times\left(\frac{270\,km.s^{-1}}{v_{local}}\right)\times \times\left(\frac{\sigma_{H,SD}}{10^{-6}\,pb}\right)\times\left(\frac{TeV}{M_{WIMP}}\right)^2$$

  - 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, Δ, 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

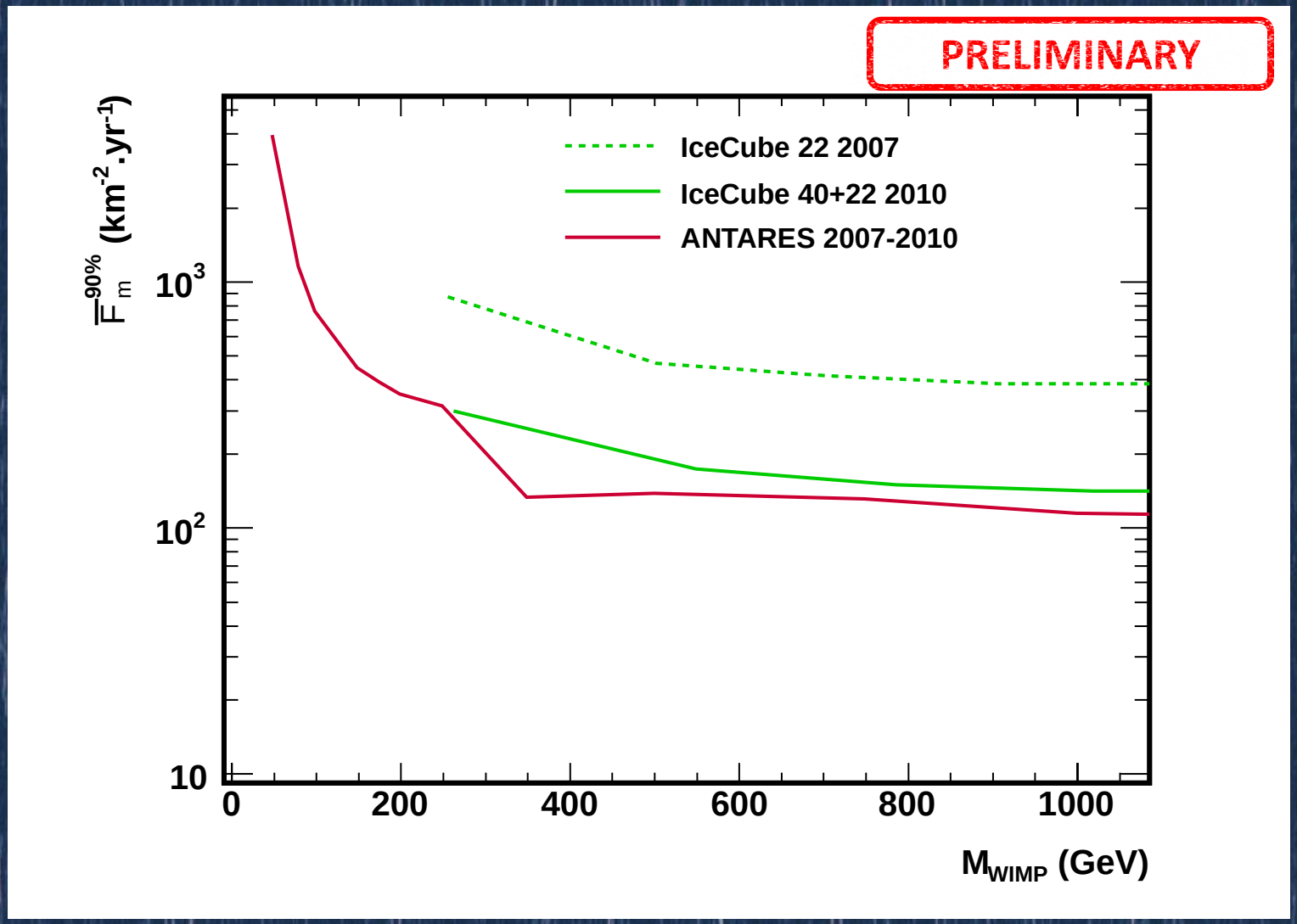
- Supersymmetry Parameters Extraction Routines for Bayesian Statistics

- 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

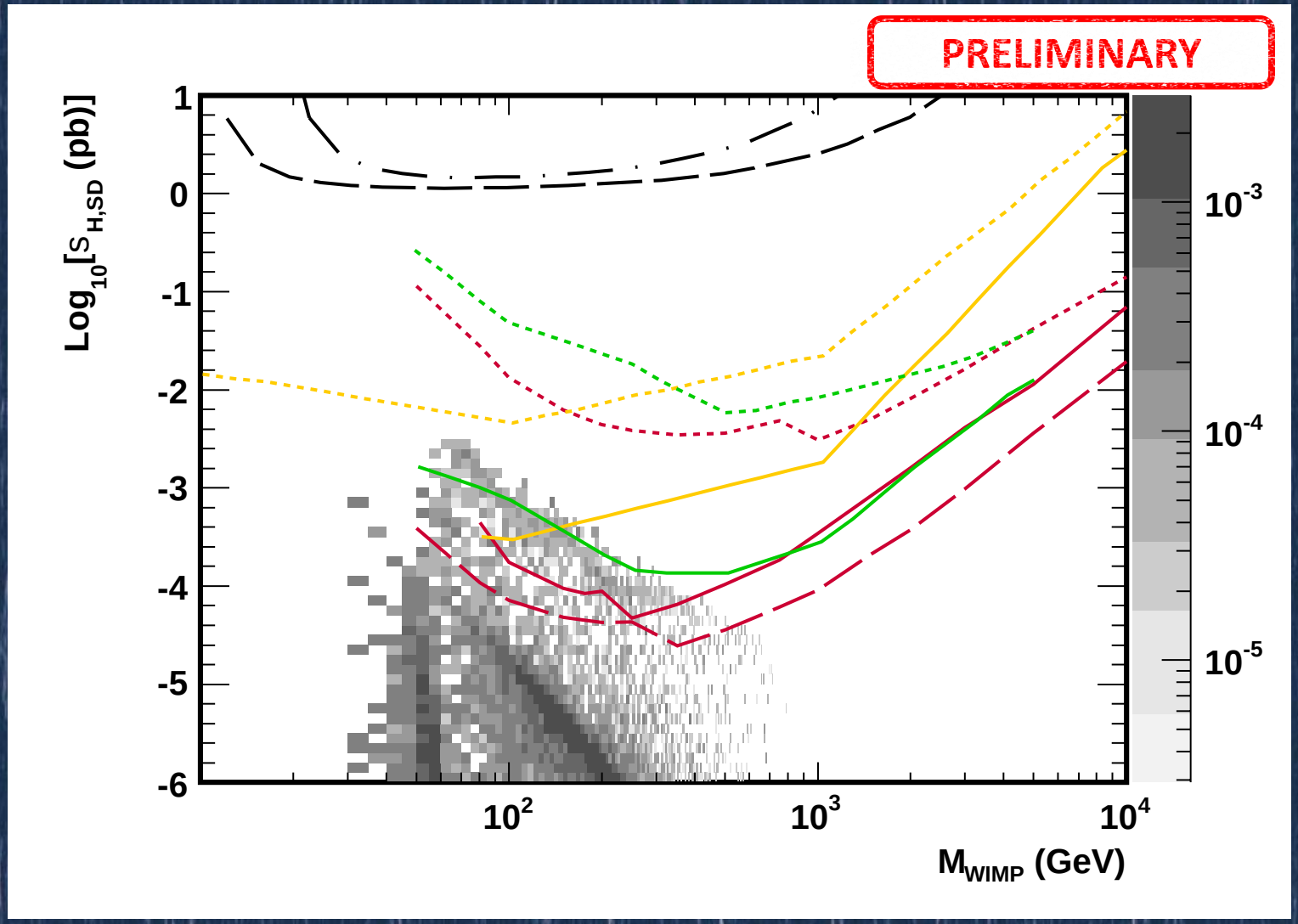
- Well documented (articles, Website), as DarkSUSY package

- Parameter set of CMSSM (m_0, $m_{1/2}$, A_0, $\tan\beta$)
- « Nuisance parameters » from SM (m_t, m_b, α_{em}, α_s)

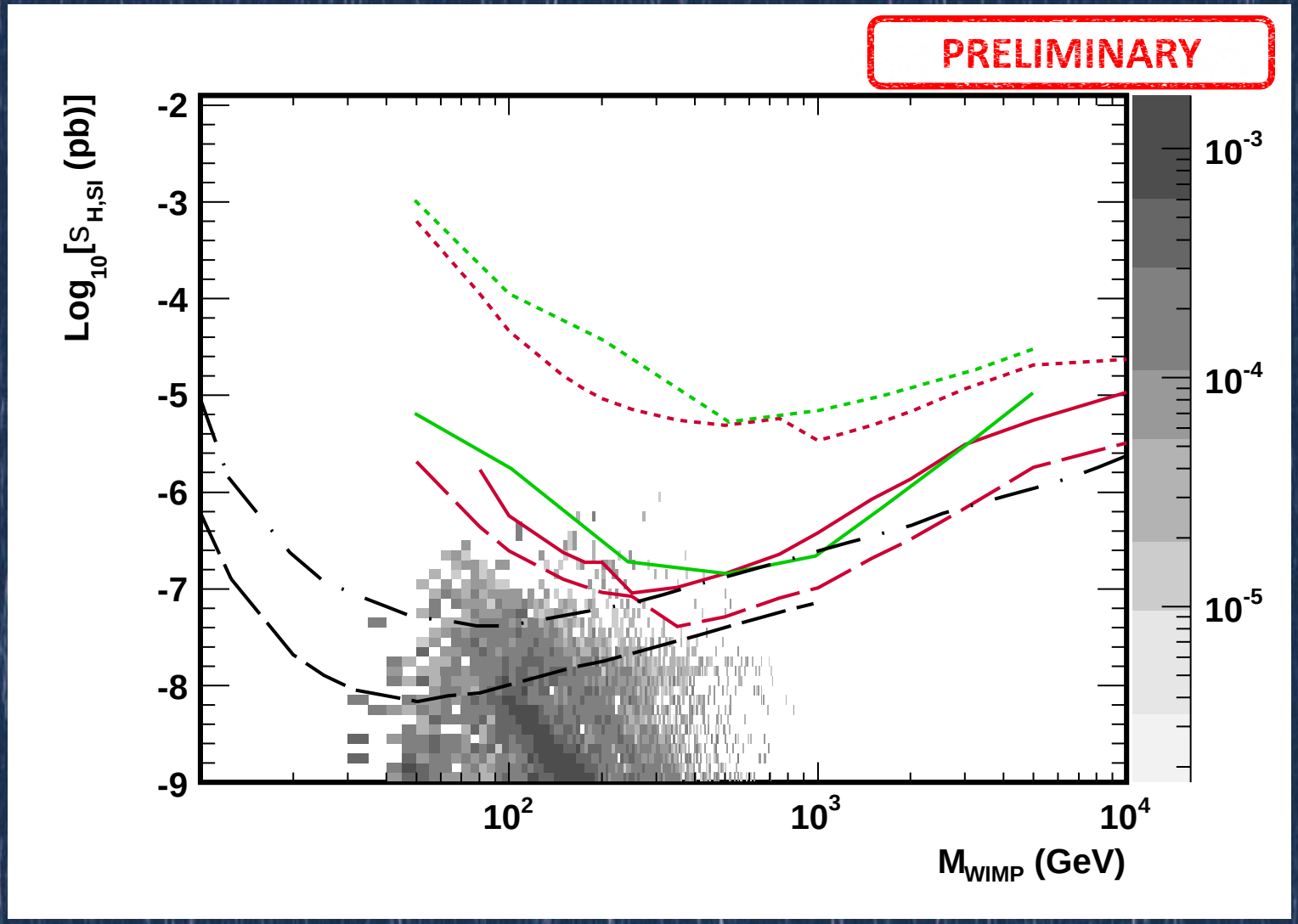
Prospects: muon flux limit



Prospects: SD cross section



Prospects: SI cross section



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