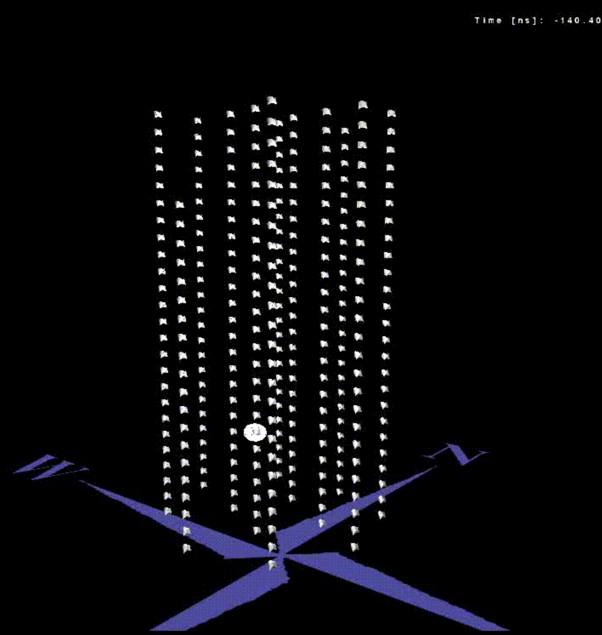
Searching for Dark Matter with the Antares neutrino telescope

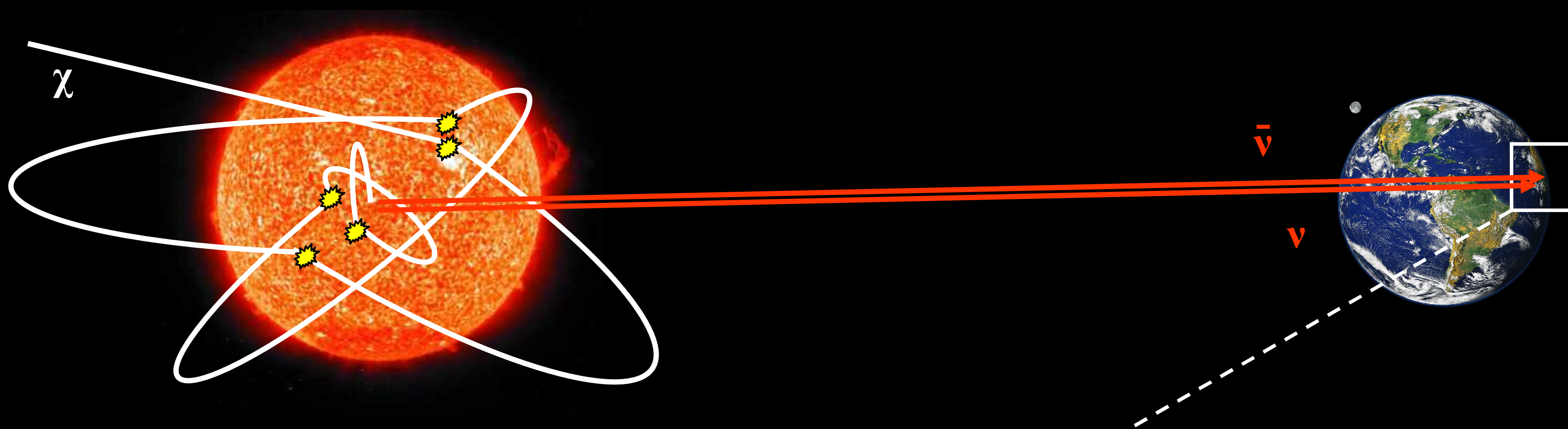


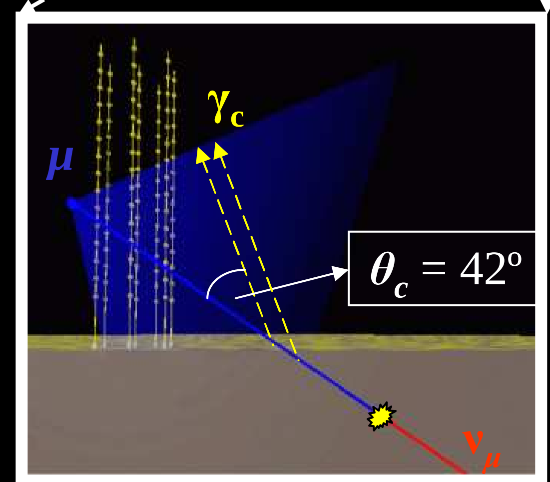
Gordon Lim – University of Amsterdam / Nikhef

- on behalf of the Antares Collaboration -

Outline

- ***Introduction***
  - *Indirect detection of Dark Matter with a neutrino telescope*
  - *The Antares neutrino telescope*
  - *Performance*
  - *Status overview & recent results*
- ***Antares prospects for neutralino annihilation in the Sun***
  - *mSUGRA neutrino flux predictions*
  - *Predicted Antares detection rates & exclusion limits*
  - *Comparison to direct detection experiments*
  - *Improvements*
- ***Preliminary data analysis results using Line 1-5 data***
- ***Conclusions & Outlook***

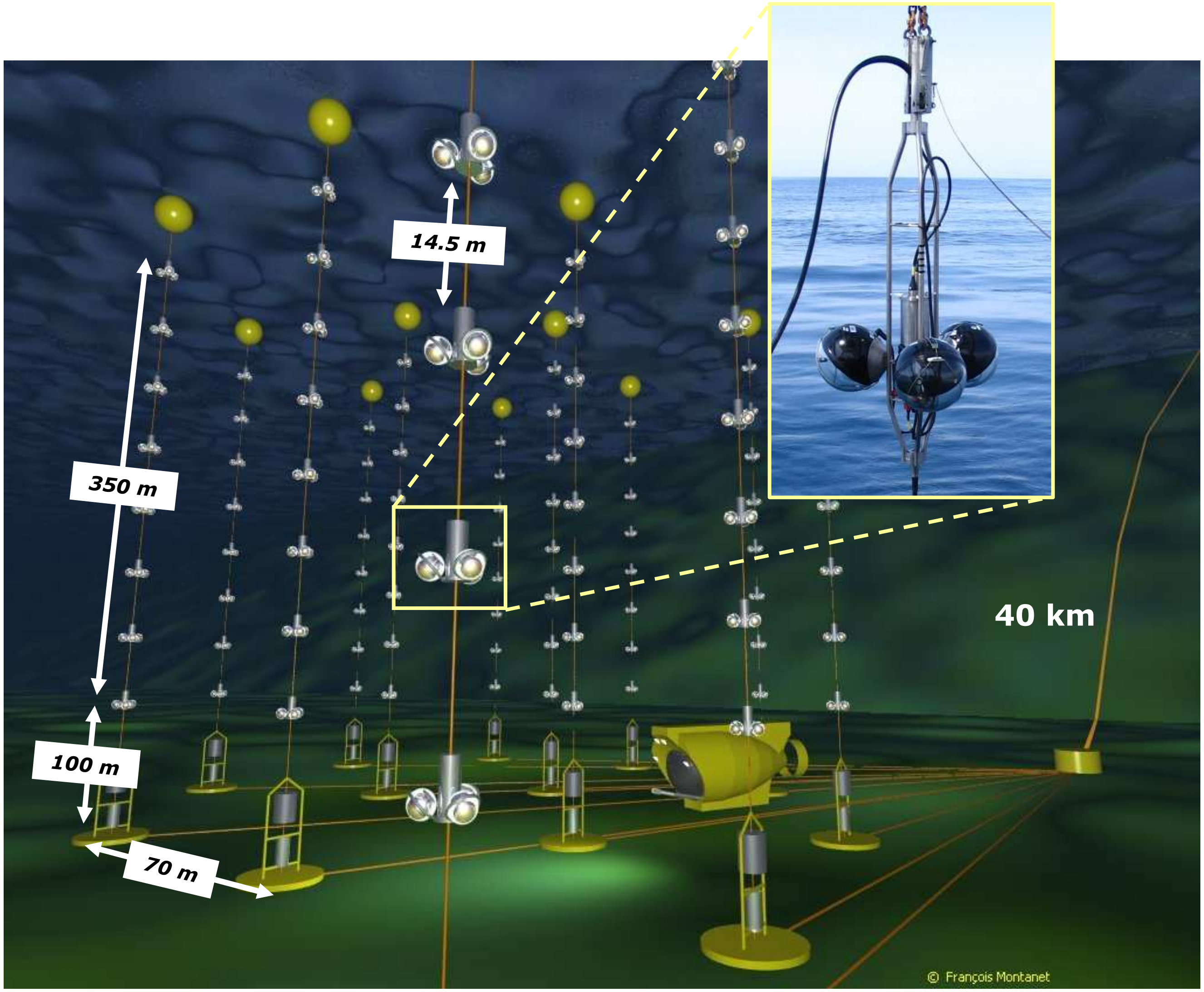


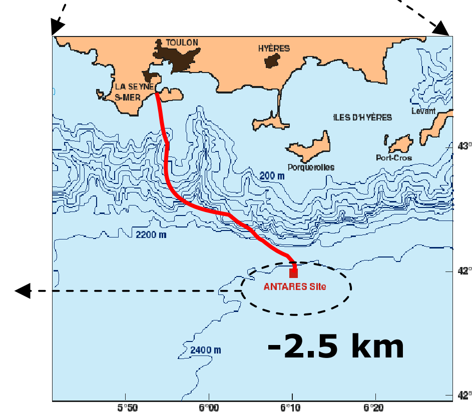


Indirect detection of WIMPs using neutrino telescopes:

- ***Relic WIMPs from the Big Bang traversing the universe undergo multiple elastic interactions with inside a massive celestial object (e.g. the Sun), lose kinetic energy and become gravitationally bound to the object.***
- ***Over time, the WIMP density in the core of the object increases. This enhances the WIMP annihilation rate significantly, resulting in a relatively high energy neutrino flux that will reach the Earth.***
- ***These neutrinos can interact through a CC interaction in the vicinity of a neutrino telescope, producing an energetic muon. When traversing the transparent medium of the telescope, the muon will emit Cherenkov light. By measuring the time & position of the photons using a 3D grid of PMTs, the neutrino track can be reconstructed.***

The Antares neutrino telescope

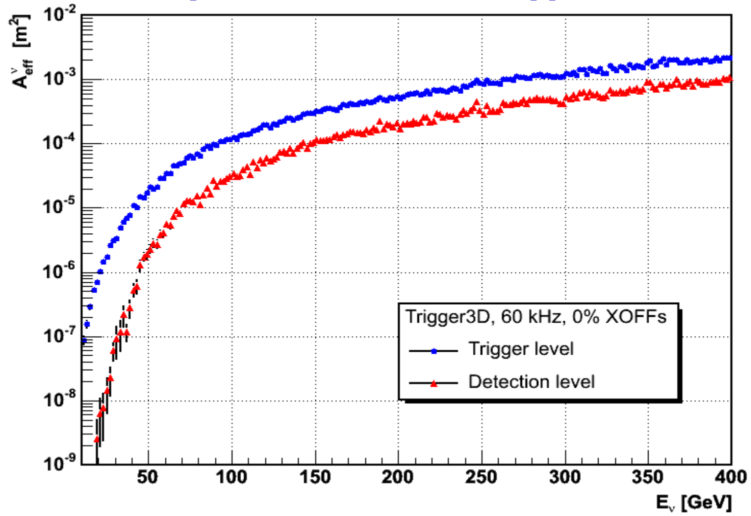




12 lines
25 storeys/line
3 PMTs/storey
900 PMTs

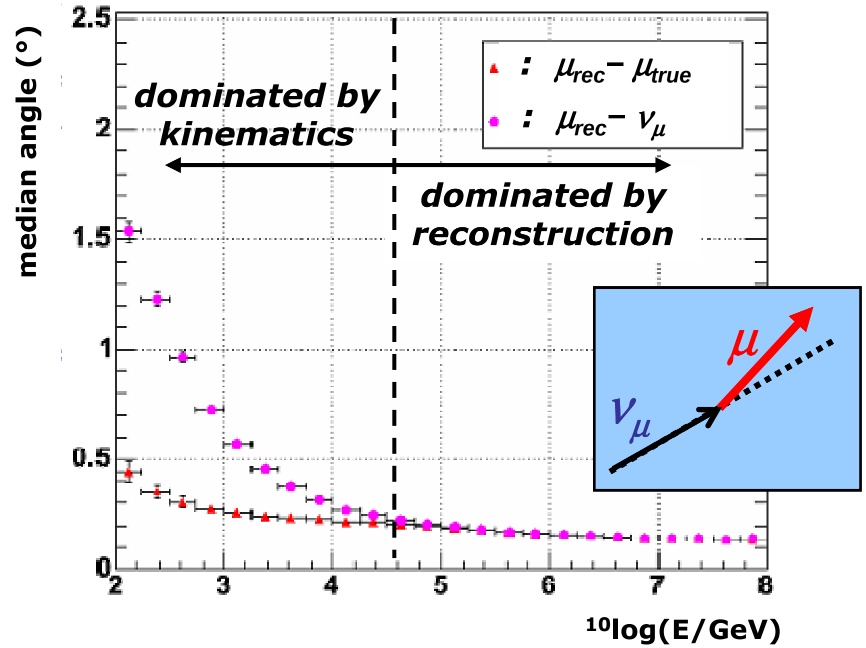
Performance

Neutrino Effective Area (detector sensitivity)

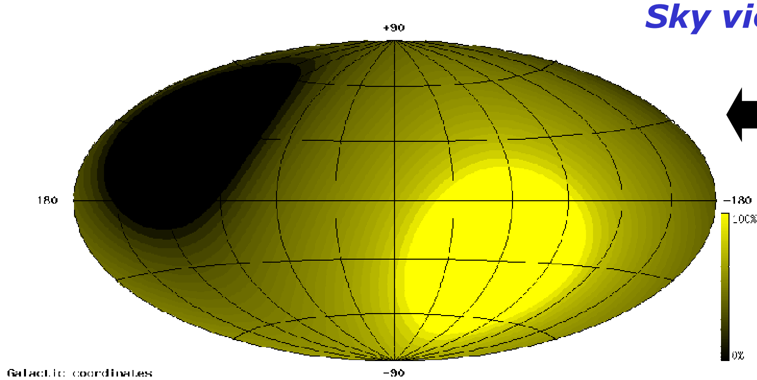


$$\frac{dN_{\text{observed}}}{dt} = \iint A^{\nu}_{eff}(E_\nu, \Omega)\, \frac{d\Phi(E_\nu, \Omega)}{dE_\nu\, d\Omega}\, dE_\nu\, d\Omega$$

Angular resolution

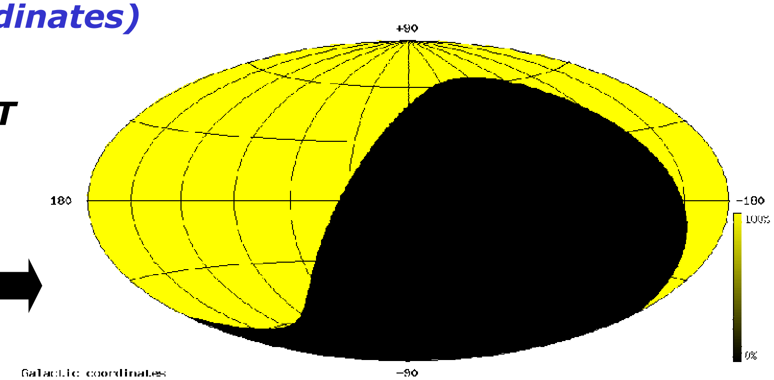


Sky view (in Galactic coordinates)

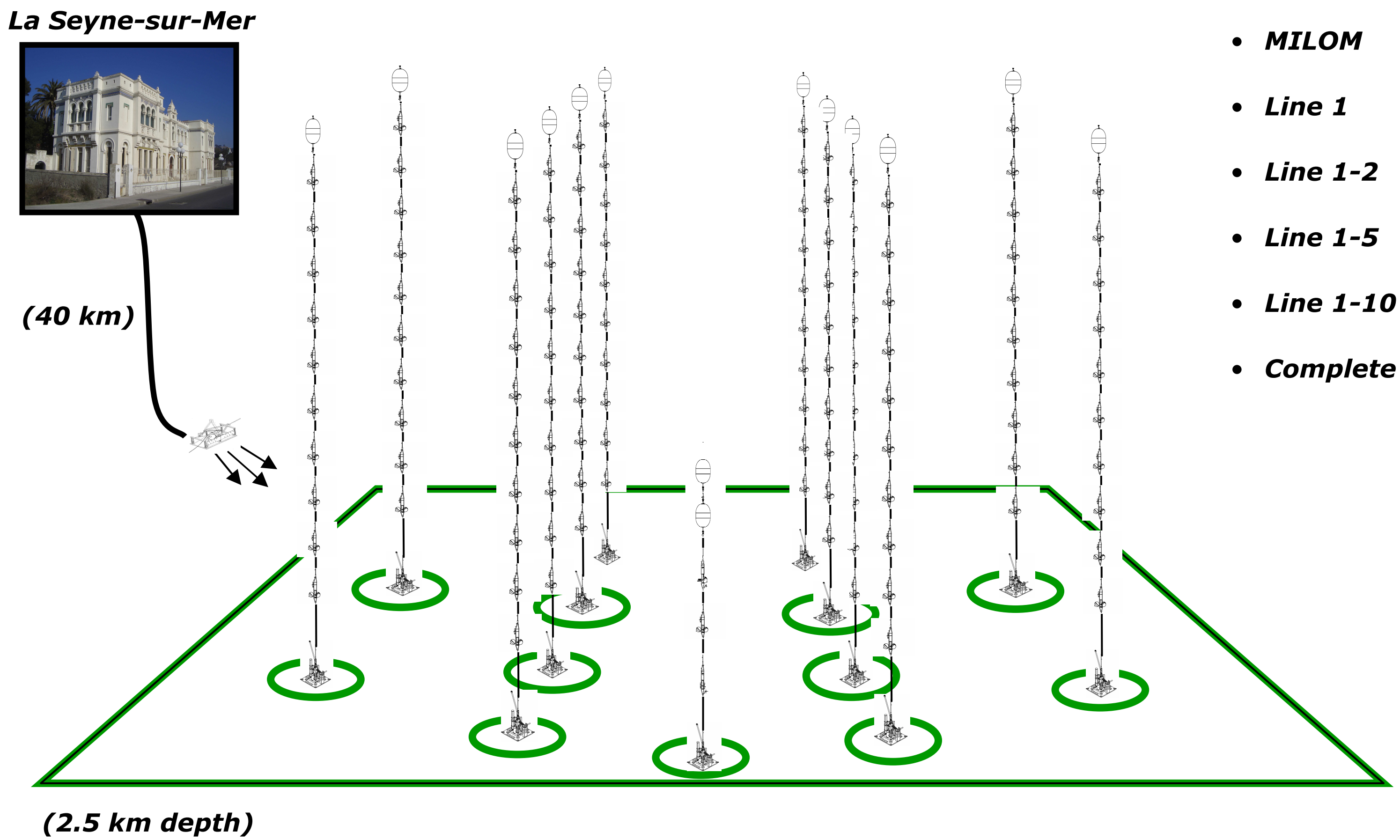


Antares/KM3NeT

Amanda/IceCube



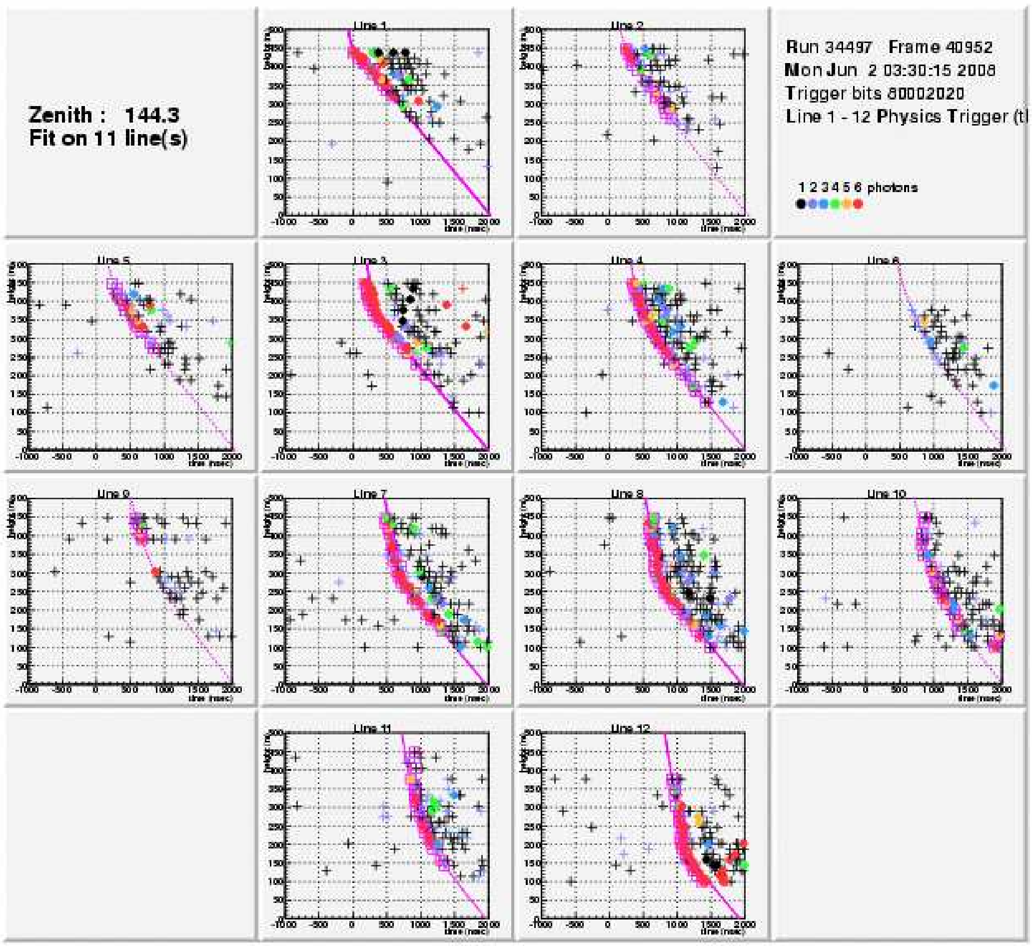
Status overview



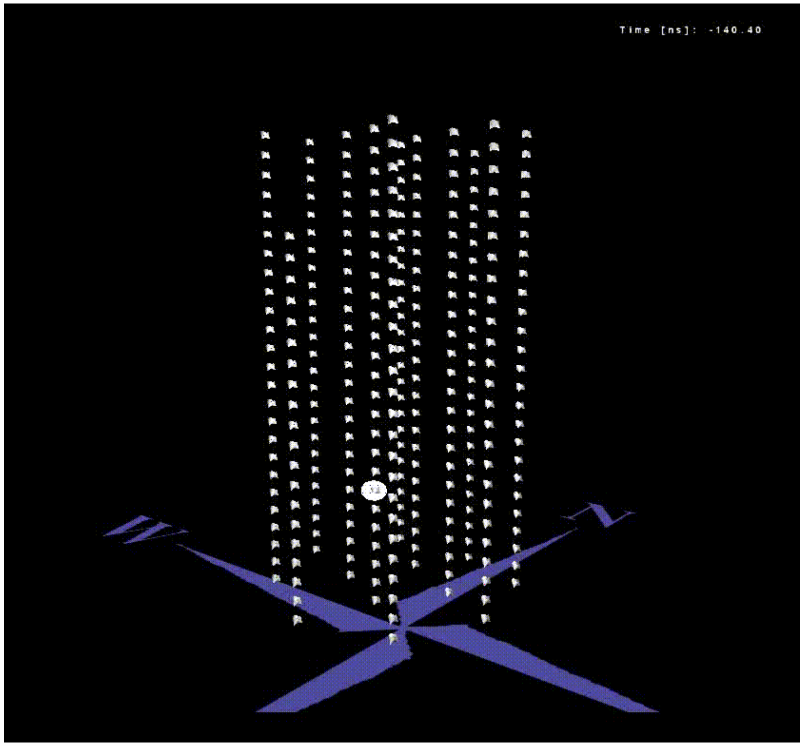
Data taking periods:

- MILOM : Mar '05 – Mar '06
- Line 1 : Mar '06 - Sep '06
- Line 1-2 : Sep '06 - Jan '07
- Line 1-5 : Jan '07 - Dec '07
- Line 1-10: Dec '07 - May '08
- Complete: May'08 onwards

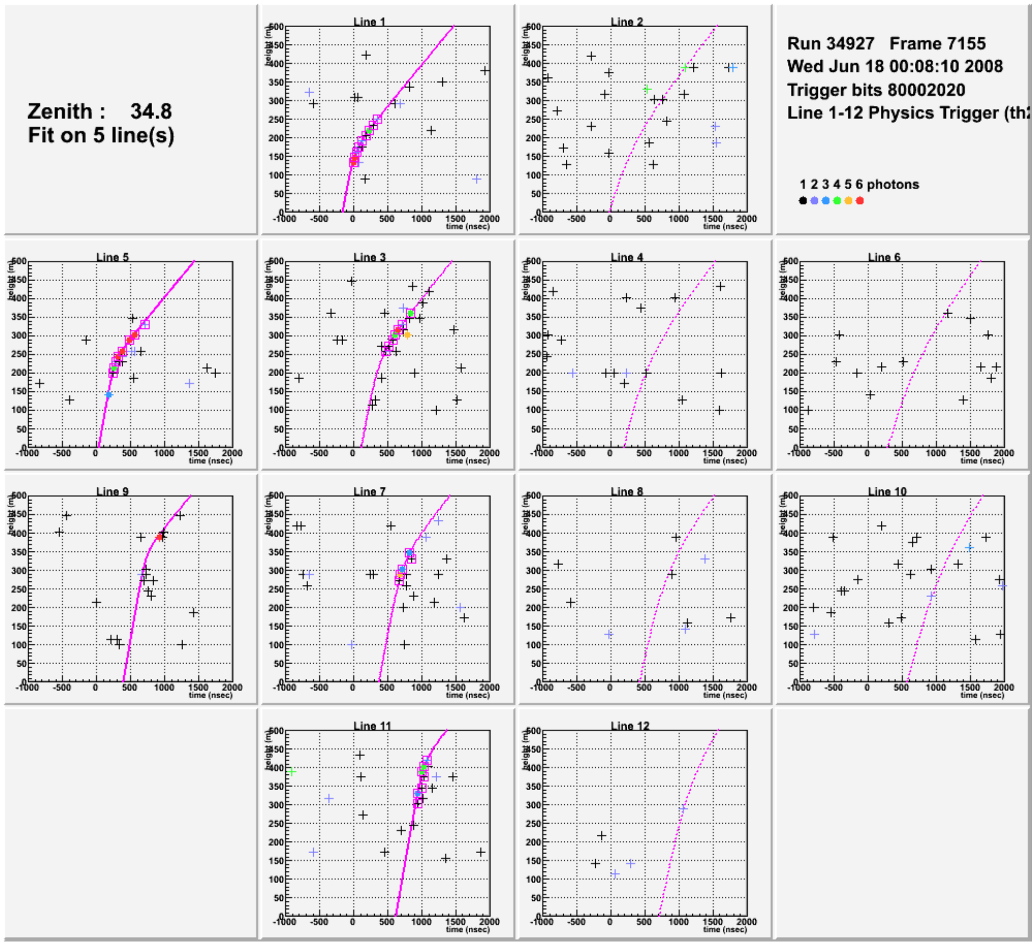
Recent results



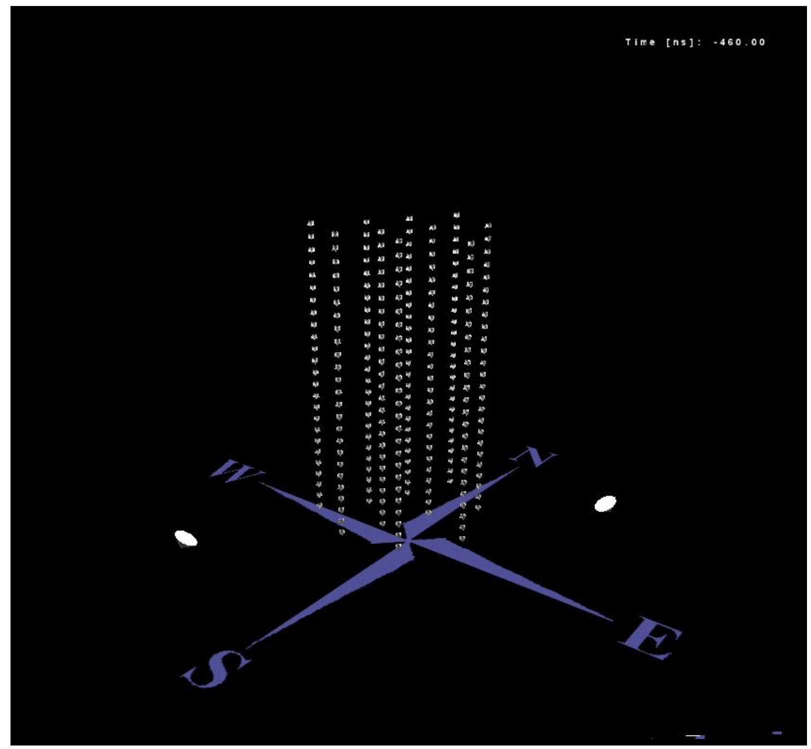
Example of a reconstructed down-going muon, detected in all 12 detector lines:



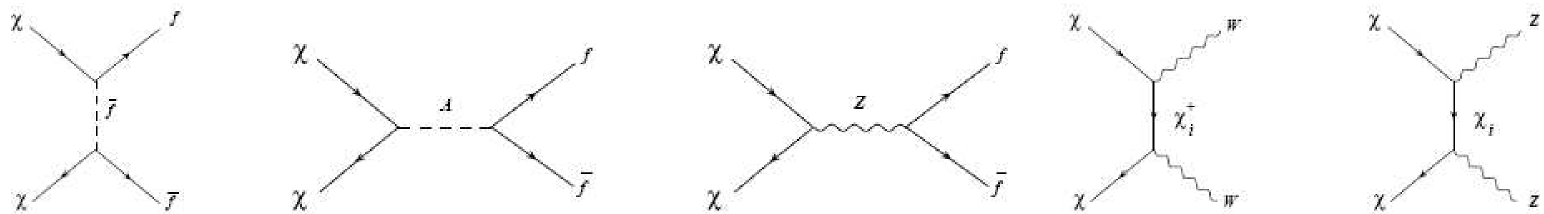
Recent results



Example of a ***reconstructed up-going muon*** ***(i.e. a neutrino candidate) detected in 6/12 detector lines:***



Antares prospects for detecting neutralino annihilation in the Sun



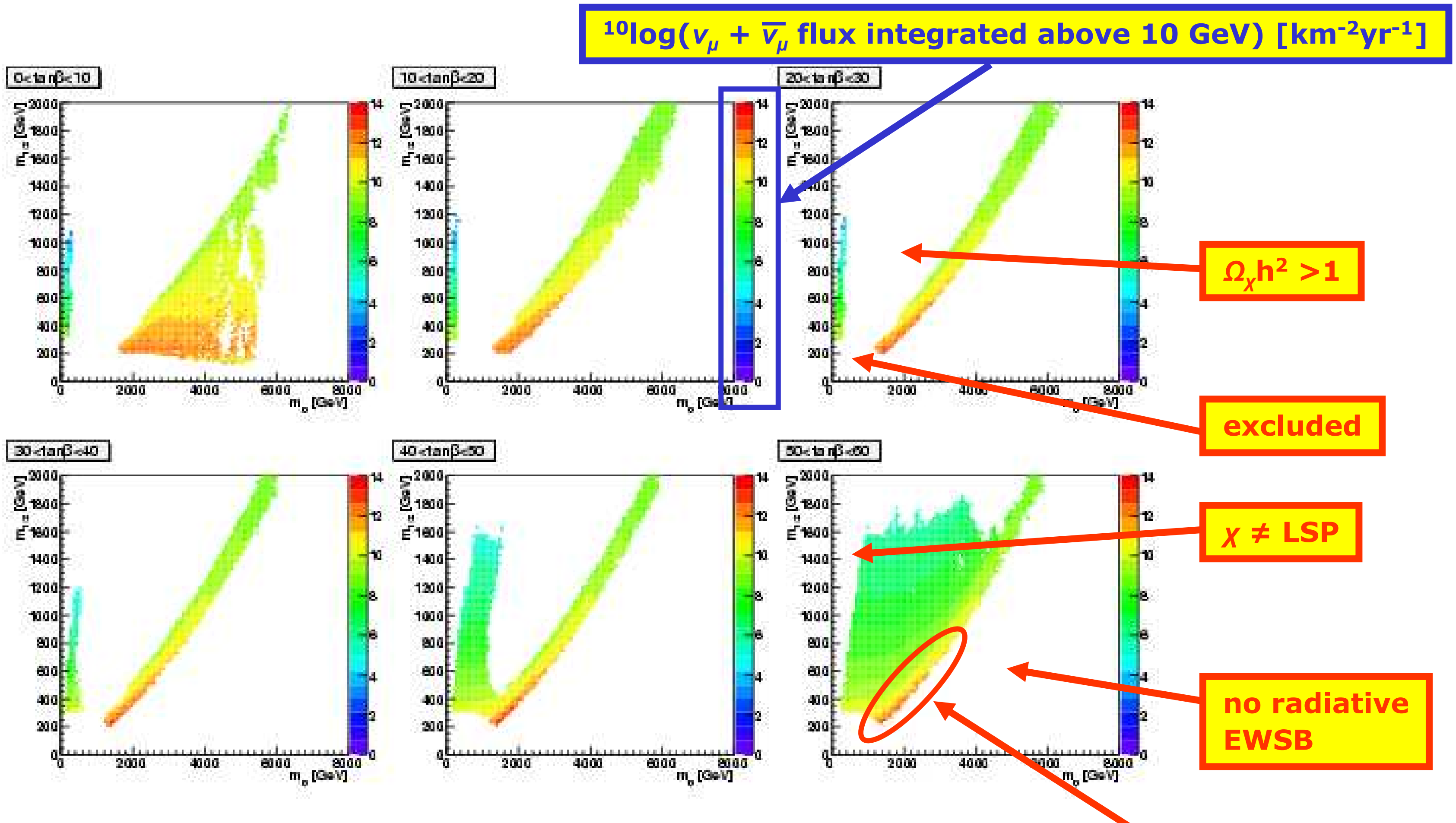
Theoretical input:

- ***mSUGRA as implemented in DarkSUSY + ISASUGRA***
- ***"Standard" neutrino oscillation scenario***
- ***Top quark mass = 172.5 GeV***
- ***Local halo density ρ_0 = 0.3 GeV/cm^3***

Experimental input:

- ***Complete detector (12 lines)***
- ***Conical cut around Sun = 3°***

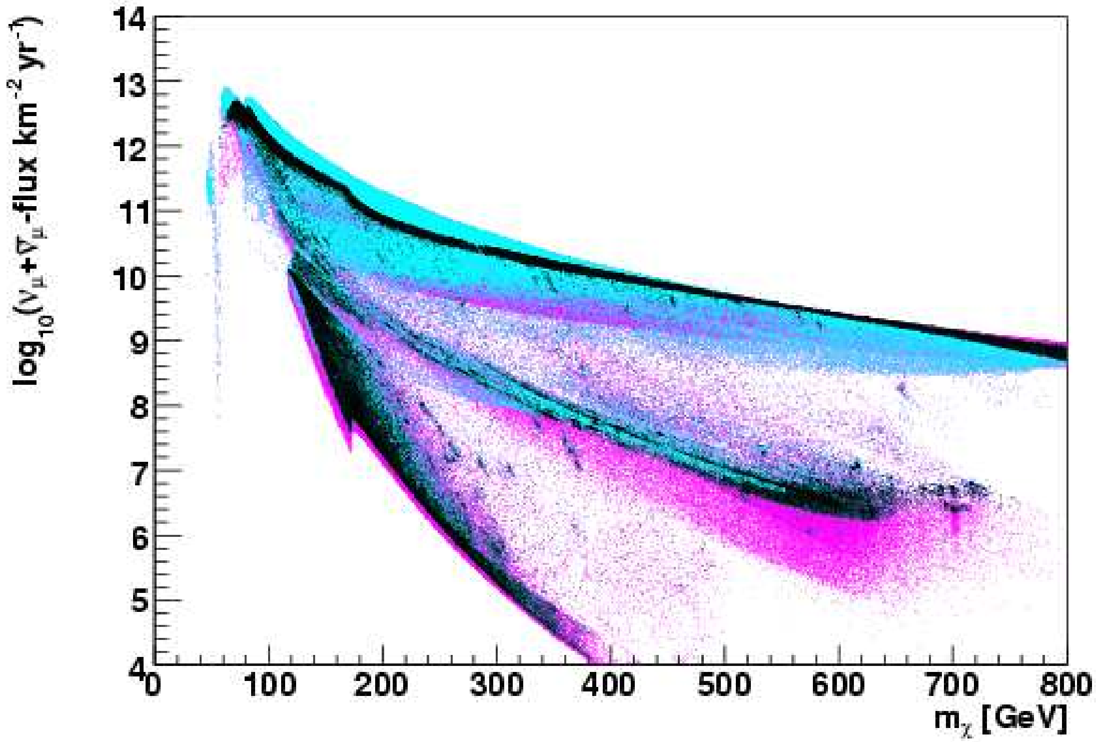
mSUGRA parameter space



- *$0 < m_0 < 8000$ GeV*
- *$0 < m_{1/2} < 2000$ GeV*
- *$0 < \tan(\beta) < 60$*
- *$-3m_0 < A_0 < 3m_0$*
- *sign(μ) = +1*

mSUGRA neutrino flux predictions

$\nu_\mu + \overline{\nu}_\mu$ flux (integrated above 10 GeV) from the Sun per km^2 per year vs. m_χ:



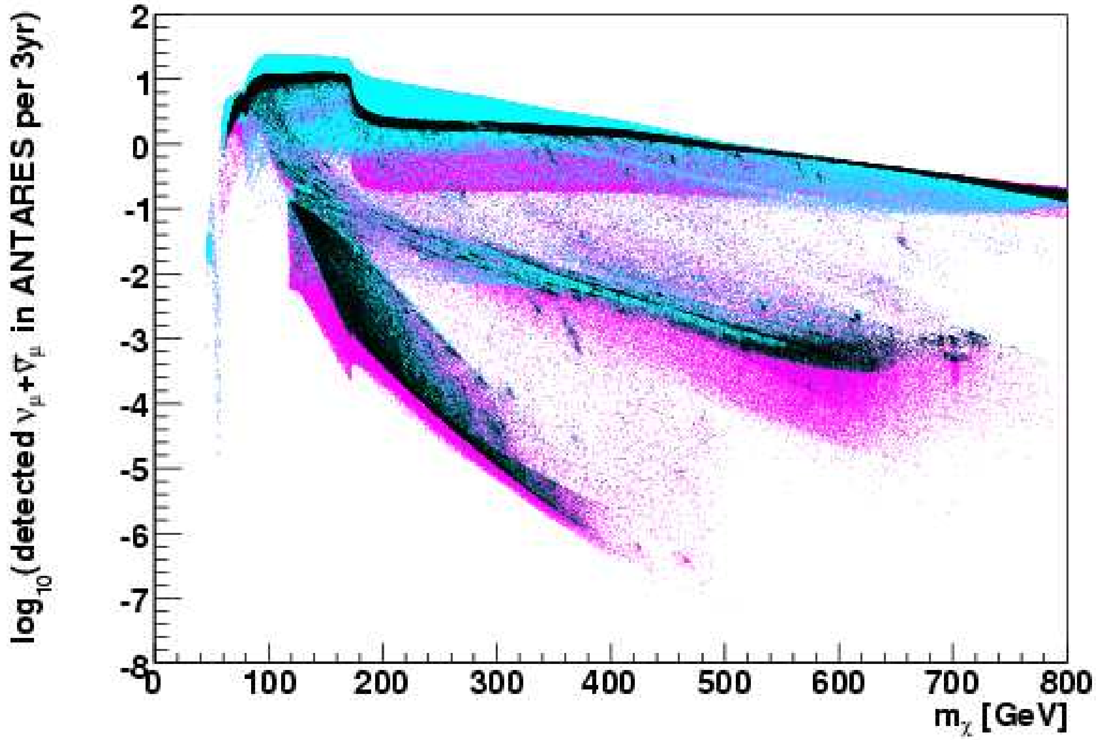
- ***: Models for which $\Omega_\chi h^2 < 1$***
- ***: Models for which $0.094 < \Omega_\chi h^2 < 0.129$***
- ***: Models for which $\Omega_\chi h^2 < 0.094$***

WMAP: $\Omega_{CDM}h^2 = 0.1126_{-0.013}^{+0.008}$

Antares detection rates

Detected $\nu_\mu + \overline{\nu}_\mu$ events from the Sun in Antares per 3 years vs. m_χ:

Detection rate (t) =
$\nu_\mu + \overline{\nu}_\mu$ flux (E_ν, θ_ν, t) ·
Effective Area (E_ν, θ_ν) ·
Sun's θ_ν distribution



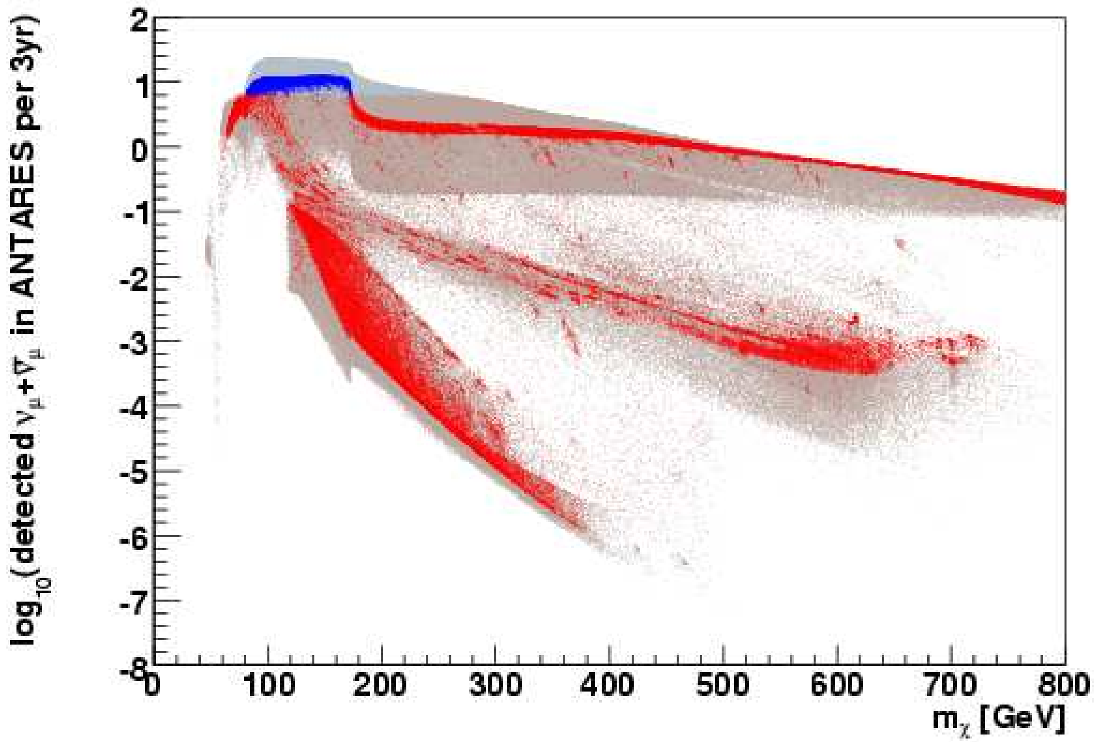
: Models for which $\Omega_\chi h^2 < 1$
: Models for which $0.094 < \Omega_\chi h^2 < 0.129$
: Models for which $\Omega_\chi h^2 < 0.094$

Antares exclusion limits

Excludable $\nu_\mu + \bar{\nu}_\mu$ detection rate from the Sun in Antares per 3 years vs. m_χ:

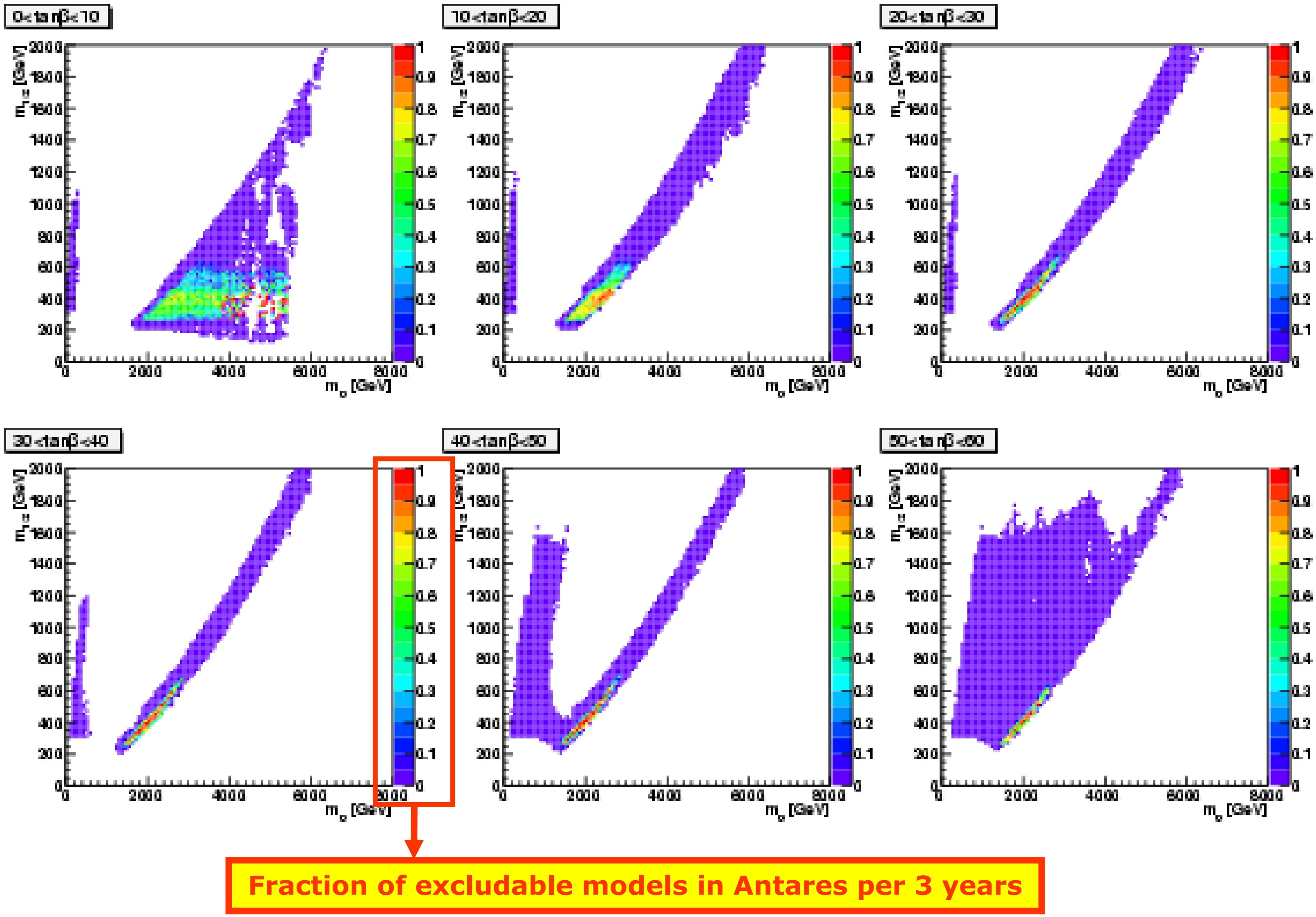
"Excludable" =
Signal is distinguishable from the background at 90% C.L. (Feldman-Cousins scheme)

<u>Background:</u>
***atmospheric neutrinos* (Volkova) & misreconstructed *atmospheric muons* within a 3° cone**



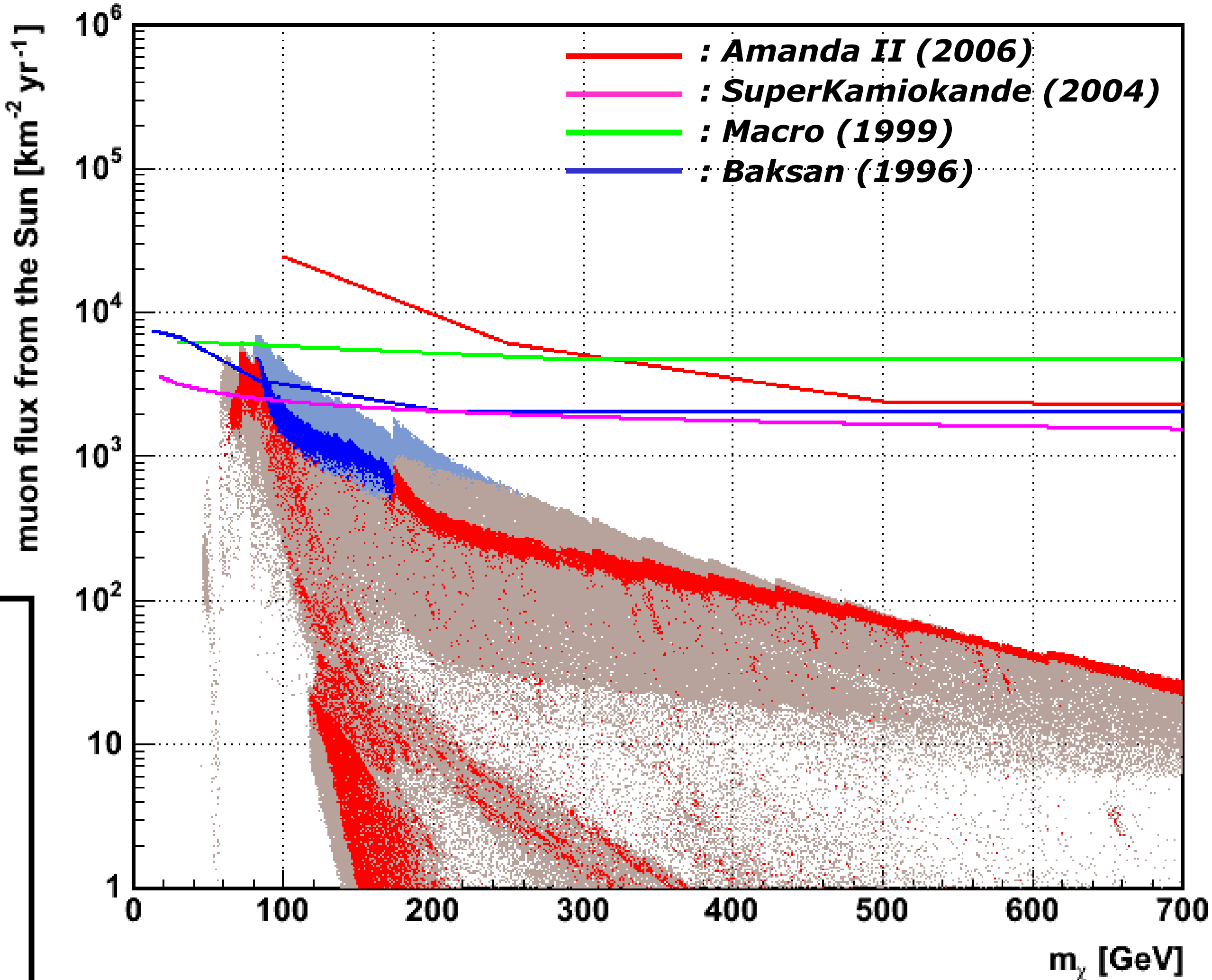
- ***: Excludable models for which $0.094 < \Omega_\chi h^2 < 0.129$***
- ***: Excludable models for which $\Omega_\chi h^2 < 1$***
- ***: Non-excludable models for which $0.094 < \Omega_\chi h^2 < 0.129$***
- ***: Non-excludable models for which $\Omega_\chi h^2 < 1$***

Antares exclusion limits



Antares exclusion limits

μ flux from the Sun excludable by Antares per km² per year vs. m_χ



: Excl. models, $0.094 < \Omega_\chi h^2 < 0.129$

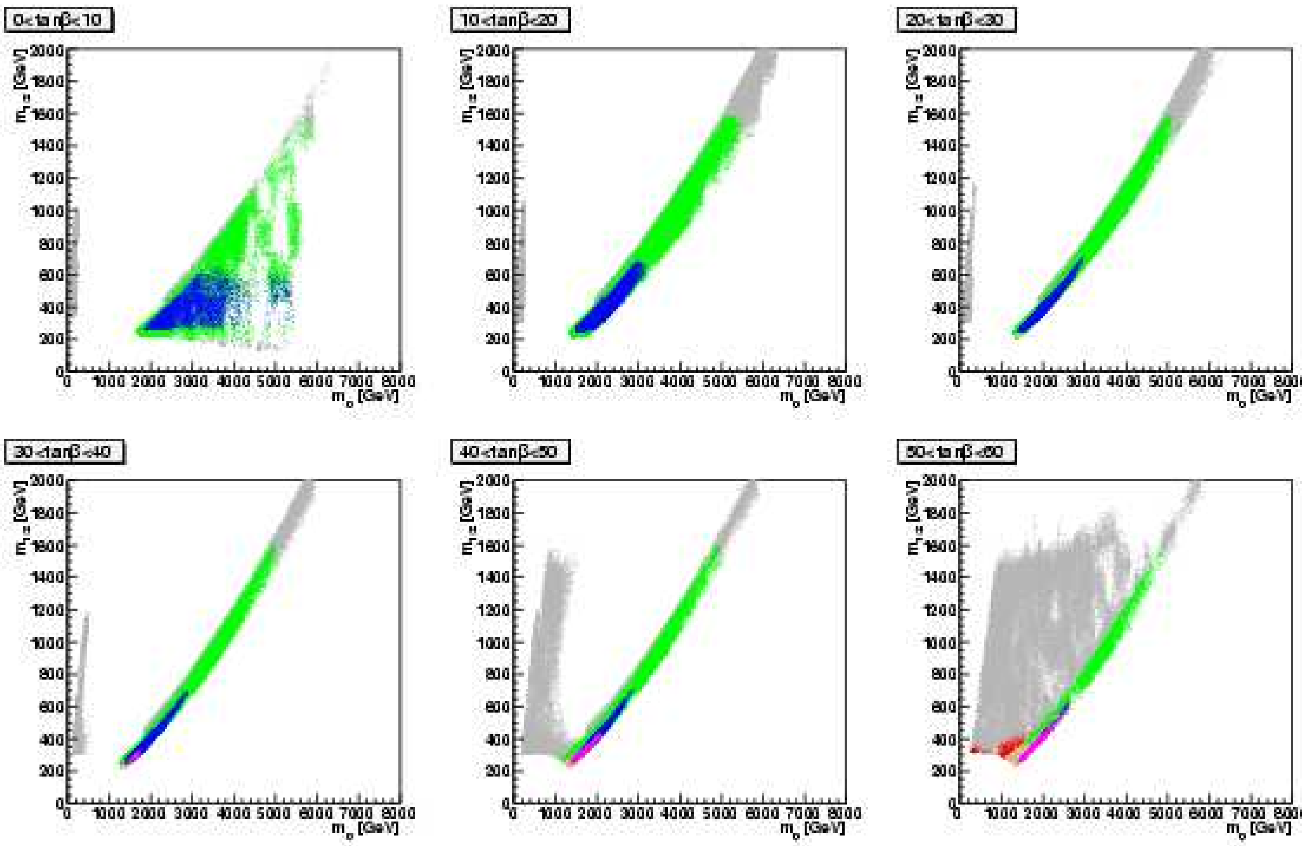
: Excl. models, $\Omega_\chi h^2 < 1$

: Non-excl. models, $0.094 < \Omega_\chi h^2 < 0.129$

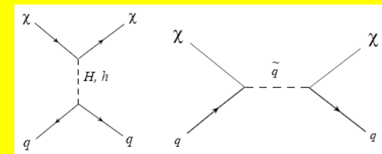
: Non-excl. models, $\Omega_\chi h^2 < 1$

Comparison to CDMS 2008 limit

(CDMS : Direct detection experiment sensitive to the spin-independent χp -> χp cross section)



"spin-independent" =



-> models where the Higgsino fraction of the χ is relatively large are dominant

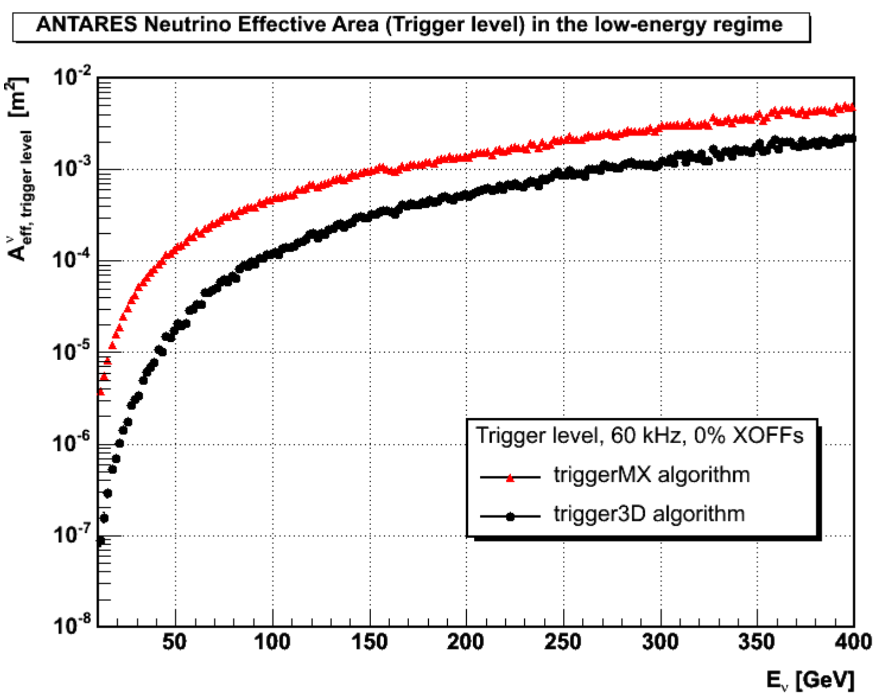
-> the regions excludable by Antares and direct detection experiments are correlated

mSugra - ANTARES/KM3NeT Sensitivity - CDMS 2008 Limit

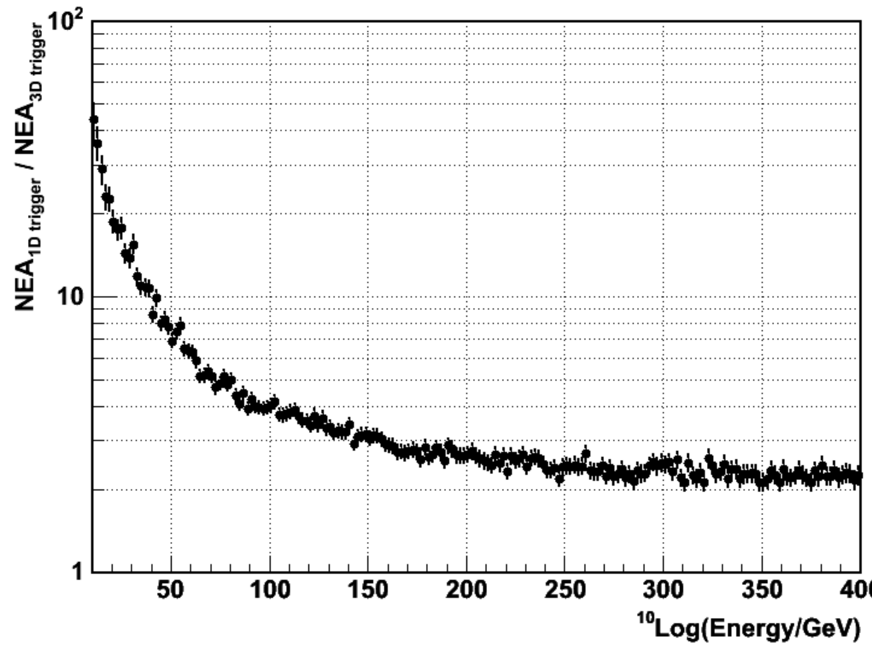
- Not excluded CDMS, within ANTARES sensitivity
- Excluded CDMS, within ANTARES sensitivity
- Not excluded CDMS, within KM3NeT sensitivity
- Excluded CDMS, within KM3NeT sensitivity
- Excluded CDMS, outside ANTARES/KM3NeT sensitivity
- Not excluded CDMS, outside ANTARES/KM3NeT sensitivity

Improvements

- *Directional trigger: lower energy threshold by using directional information of a potential neutrino source. Already operational for the Galactic Centre*
- *Dedicated low-energy reconstruction algorithm*



Effective Area *at the trigger level*, for the default & directional trigger algorithm



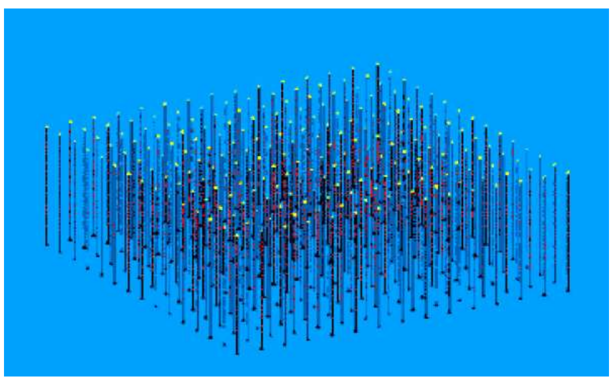
Relative difference in Effective Area between the two algorithms

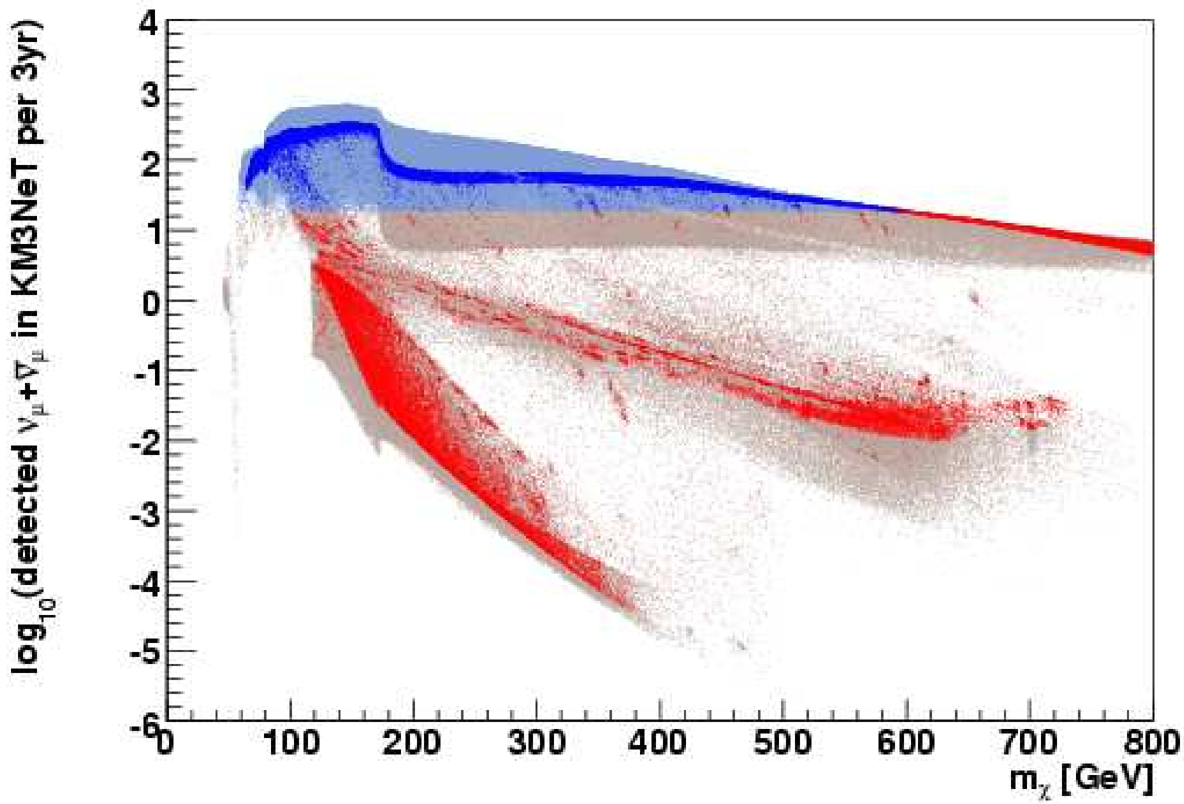
Outlook: KM3NeT

Excludable $\nu_\mu + \bar{\nu}_\mu$ detection rate from the Sun in KM3NeT per 3 years vs. M_χ:

Example geometry:

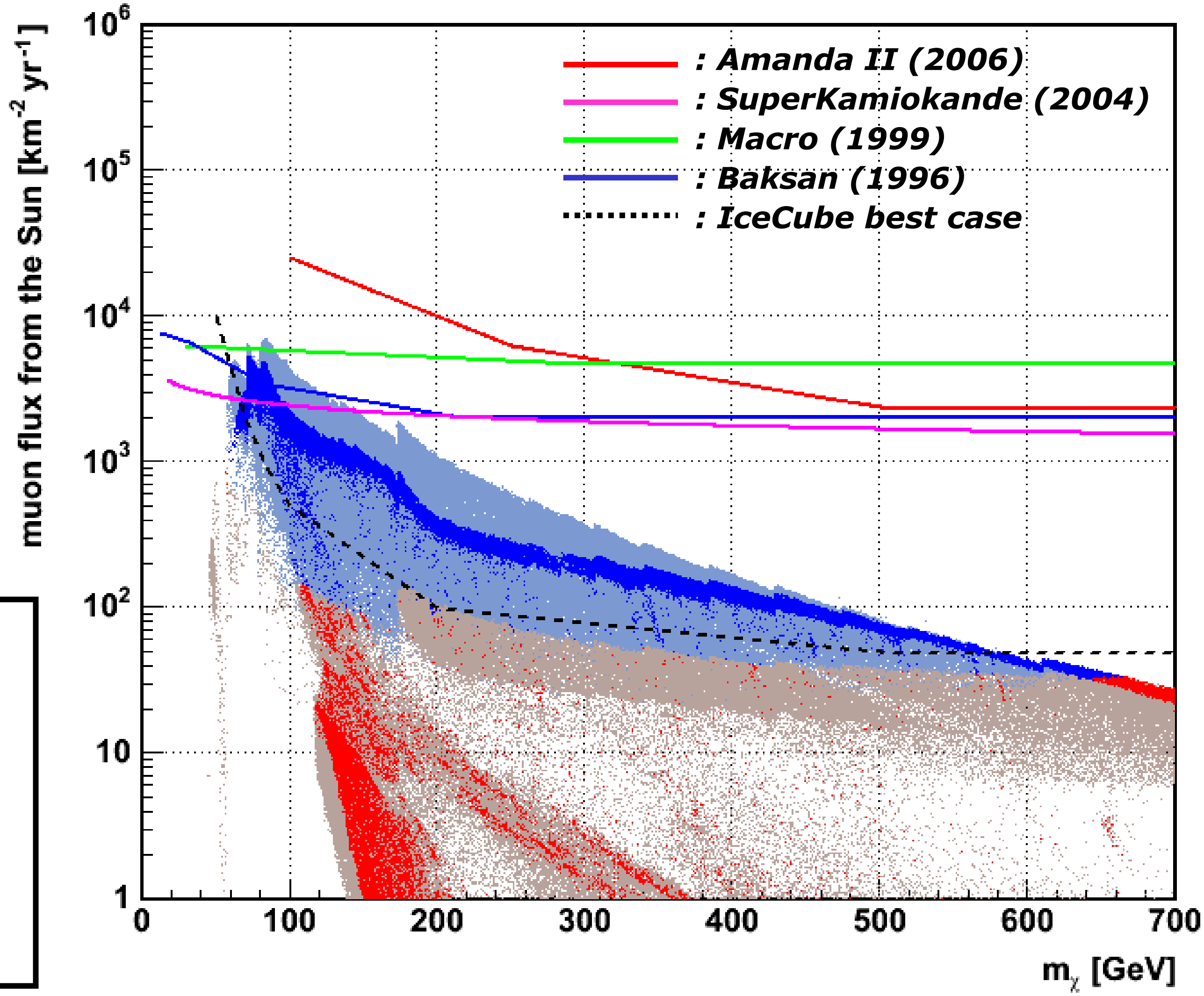
- 15x15 lines (square)
- 36 storeys / line
- 21 (3”) PMTs / storey





Outlook: KM3NeT

μ flux from the Sun excludable by KM3NeT per km² per year vs. m_χ



: Excl. models, $0.094 < \Omega_\chi h^2 < 0.129$

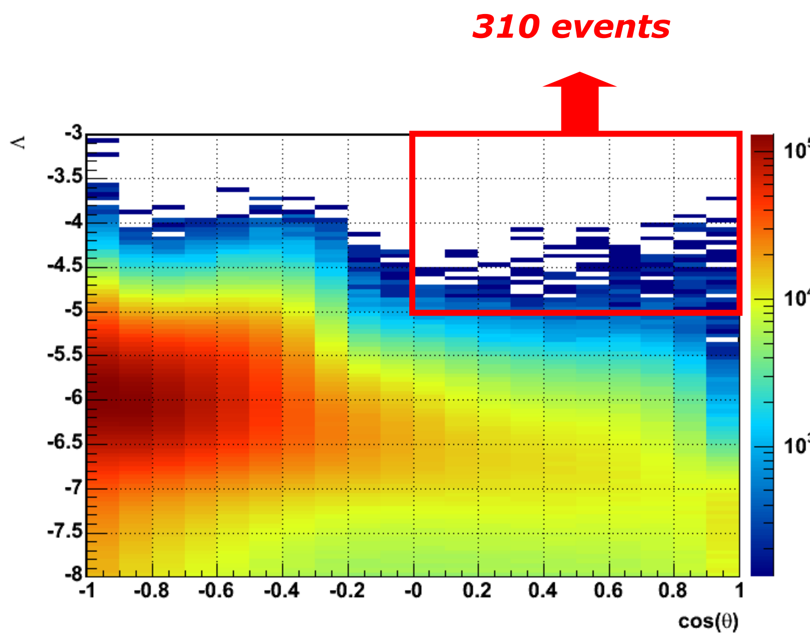
: Excl. models, $\Omega_\chi h^2 < 1$

: Non-excl. models, $0.094 < \Omega_\chi h^2 < 0.129$

: Non-excl. models, $\Omega_\chi h^2 < 1$

Preliminary data analysis results using Line 1-5 data

- *Preliminary results, analysis ongoing*
- *Data: A subsample of all "Line 1-5" data runs (2007)*
- *Effective detector lifetime = 167.9 days*



Data & Background

N_{obs} = 310 events :

- $N_1 = (\theta_1, \varphi_1, t_1)$
- $N_2 = (\theta_2, \varphi_2, t_2)$

...

- $N_{310} = (\theta_{310}, \varphi_{310}, t_{310})$

scramble θ, φ and t

$N_{bg} = 310^3 - 310 = 2.98 \cdot 10^7$ events :

- $N_1 = (\theta_1, \varphi_1, t_1)$
- $N_2 = (\theta_1, \varphi_1, t_2)$

...

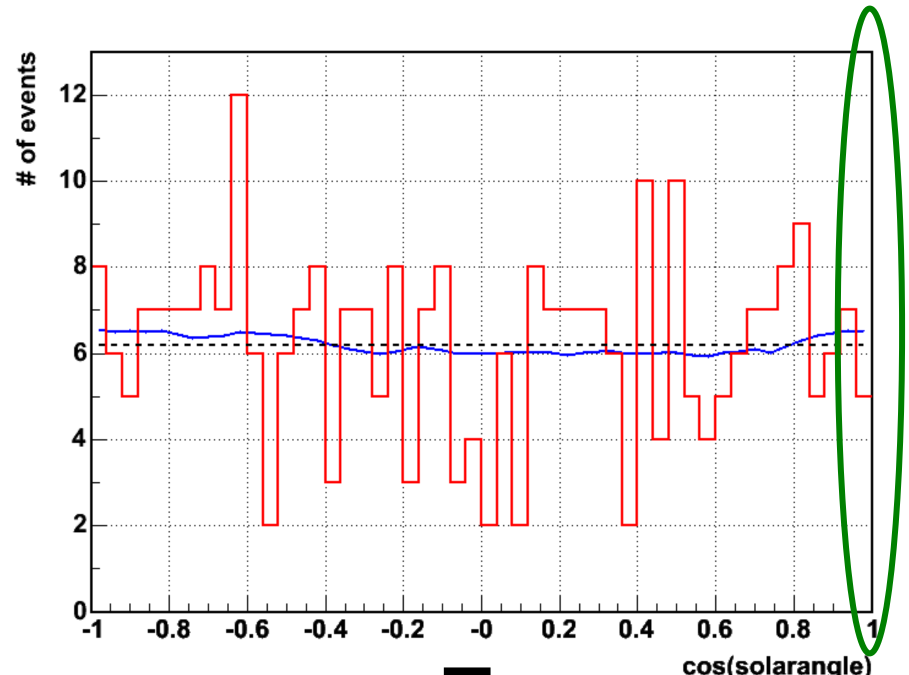
- $N_{311} = (\theta_1, \varphi_2, t_1)$
- $N_{312} = (\theta_1, \varphi_2, t_2)$

...

etc.

(MC simulation of atmospheric neutrinos according to Honda flux results in $N_{bg, MC}$ = 325 events)

Cos(solarangle) distribution for N_{obs} and N_{bg} :



consistent with isotropic background, no apparent signal excess

Analysis method

- ***Quantify the statistical significance of the observed conerate with respect to the conerate due to background, i.e. derive an upper limit on the # of signal events as a function of the coneangle.***
- ***Optimise for the coneangle.***
- ***Take upperlimit on the # of signal events and divide by the neutrino effective area times the effective lifetime..***

-> Upper limit on the neutrino flux from the Sun

- ***Multiply the upper limit on the neutrino flux with the neutrino cross section, the target density, the probability of transmission through the Earth & the average muon range..***

-> Upper limit on the muon flux from the Sun

Conclusions

- ***Antares***
  - *Detector completed in May '08*
  - *Data show that the detector is working within the design specifications*
  - *Milestone towards a Km^3 underwater detector*

- ***Indirect detection of Dark Matter with Antares***
  - *"Focus point region" of mSUGRA parameter space partly excludable*
  - *Complementary to direct detection experiments*
  - *Flux limits compatible with other experiments*

- ***Data analysis***
  - *Line 1-5 data (2007) analysis in final phase*

- ***Outlook***
  - *Improvements*
  - *KM3NeT*

On behalf of the Antares Collaboration:

Thank you for your attention!

Spare: Effective Area

$$\frac{dN_{\text{observed}}}{dt} = \iint A^{\nu}_{eff}(E_\nu, \Omega) \frac{d\Phi(E_\nu, \Omega)}{dE_\nu \, d\Omega} dE_\nu \, d\Omega$$

what we are measuring — what we are looking for

$$A^{\nu}_{eff}(E_\nu, \Omega) = V_{eff}(E_\nu, \Omega) \, \sigma(E_\nu) \, \rho N_A \, P_{\text{Earth}}(E_\nu, \Omega)$$

where

- $\sigma(E_\nu)$: the neutrino interaction cross-section
- ρN_A : the nucleon density in/near ANTARES
- $P_{\text{Earth}}(E_\nu, \Omega)$: the neutrino transmission probability through the Earth
- $V_{eff}(E_\nu, \Omega)$: ***the Effective Volume***, a detector dependent quantity that represents the sensitive volume of ANTARES

intrumental characteristics
detector geometry
trigger efficiency
reconstruction efficiency
event selection efficiency

Spare: Φ_ν -> Φ_μ conversion

$$\frac{d\phi_\mu}{dE_\nu} = (\rho N_A)\frac{d\phi_\nu}{dE_\nu}\int_0^{E_\nu}\frac{d\sigma_\nu}{dE_\mu}R_{eff}(E_\mu)dE_\mu$$

$$= (\rho N_A)\sigma_\nu(E_\nu)\frac{d\phi_\nu}{dE_\nu}\int_0^{E_\nu}\frac{dP_\mu}{dE_\mu}R_{eff}(E_\mu)dE_\mu$$

$\frac{dP_\mu}{dE_\mu}$ = the probability to produce a muon in the energy range E_μ to E_μ +dE_μ

average muon range

: neutrino

: anti-neutrino