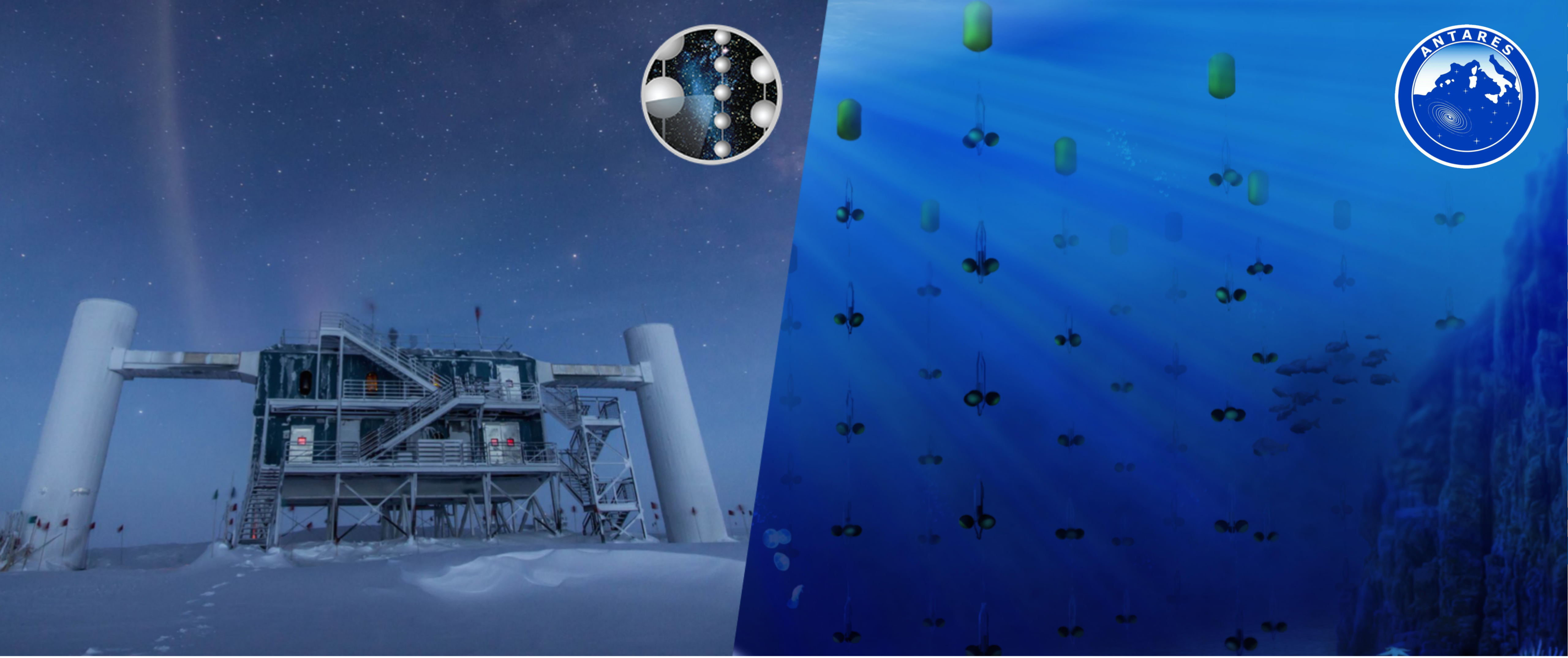


Combined Search for Dark Matter in the Galactic Centre using IceCube and ANTARES

Nadège Iovine

Promotor :
Juanan Aguilar Sánchez

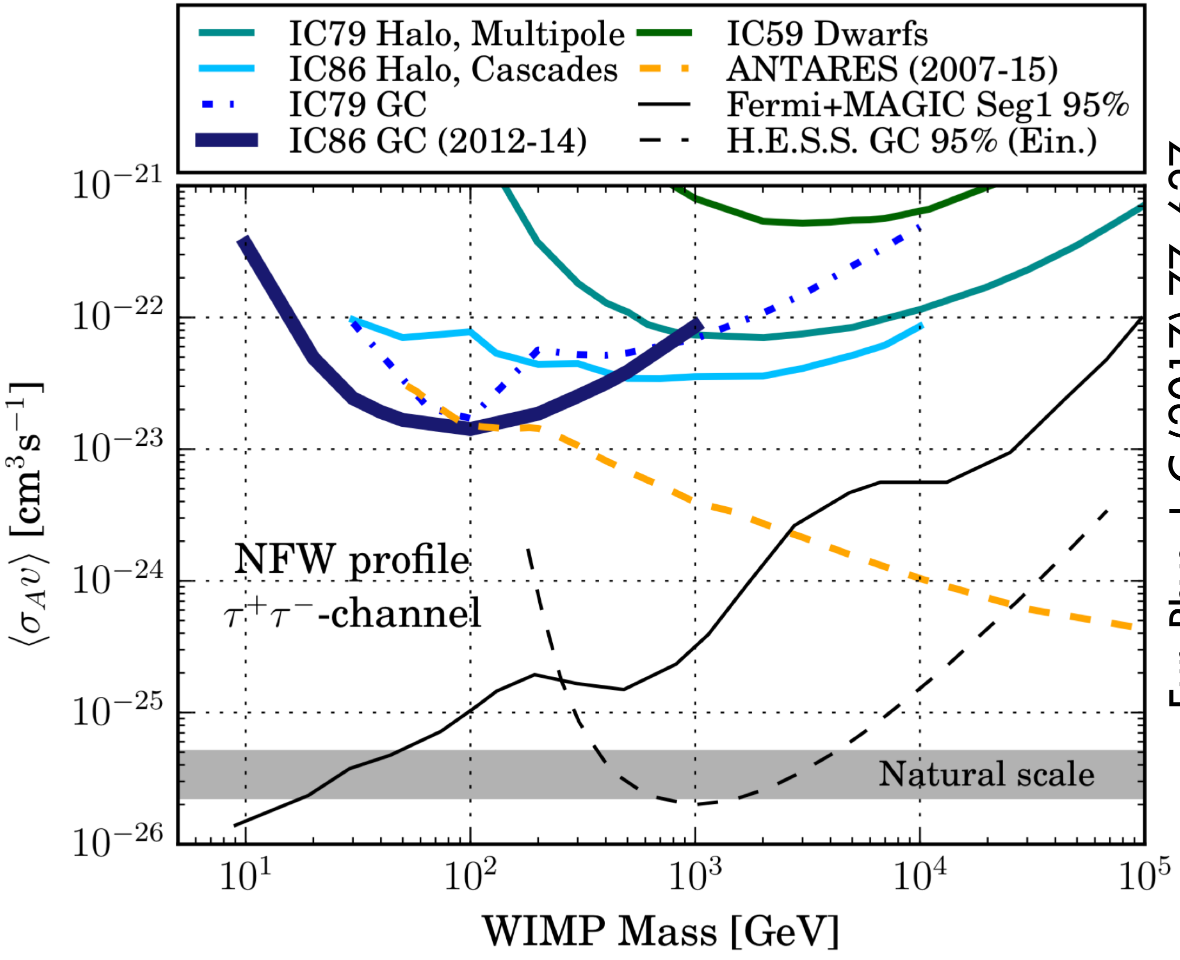
Motivations

Physical Goal:

- Improve the limit on $\langle\sigma_A v\rangle$ in the region where ANTARES and IceCube are comparable
  → between **50** and **1000** GeV

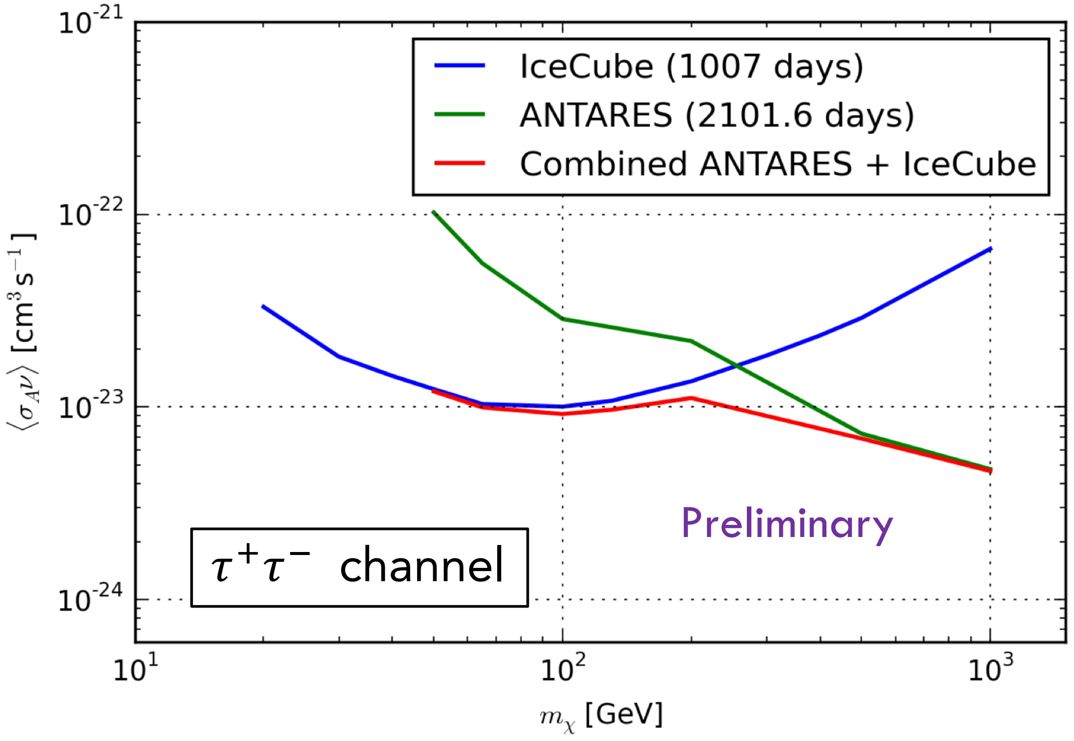
Further Goal:

- Understand and unify the analysis method of the two collaborations



Eur. Phys. J. C (2017) 77: 627

Feasability Study: Sensitvities



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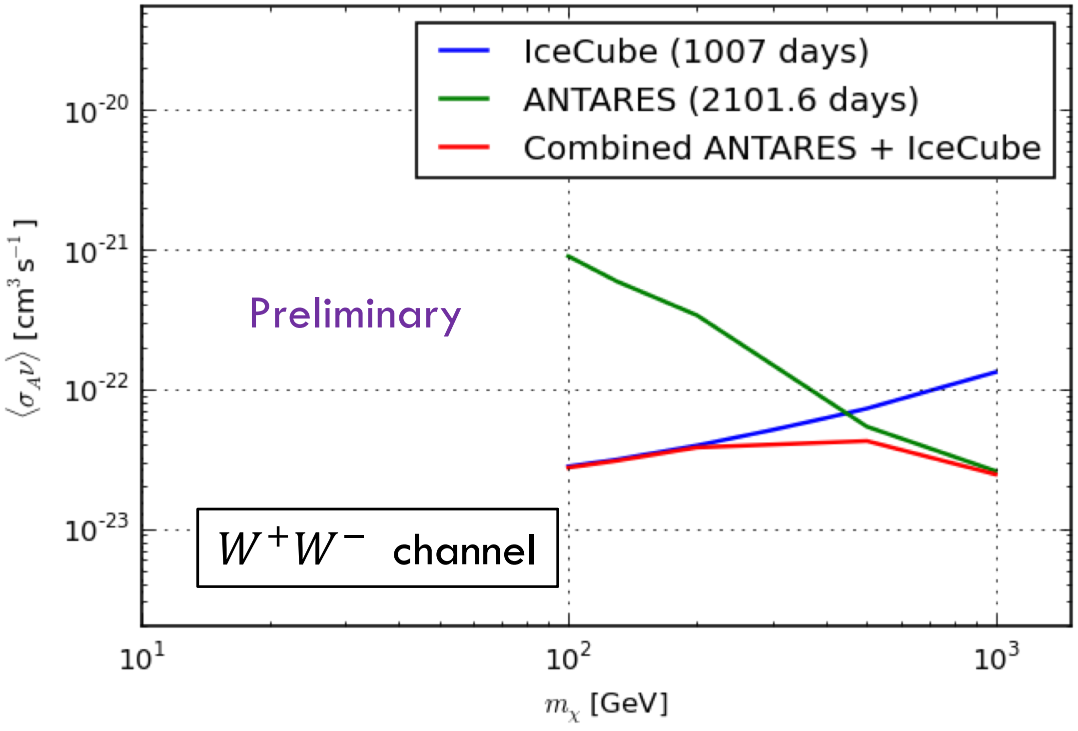
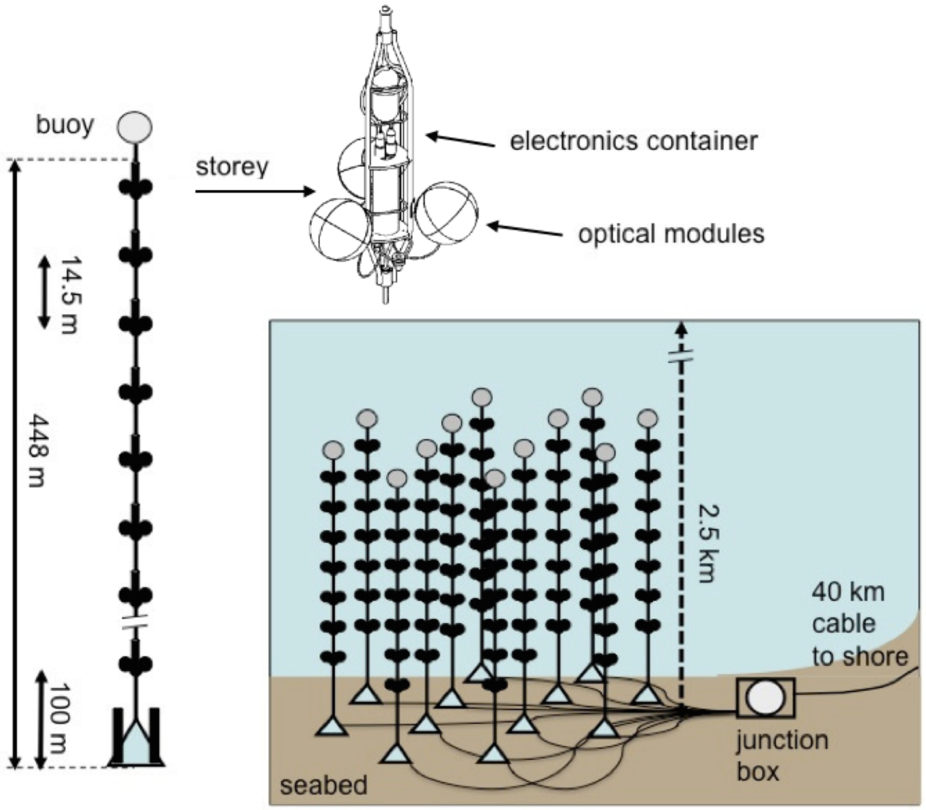


Different Detector Systematics

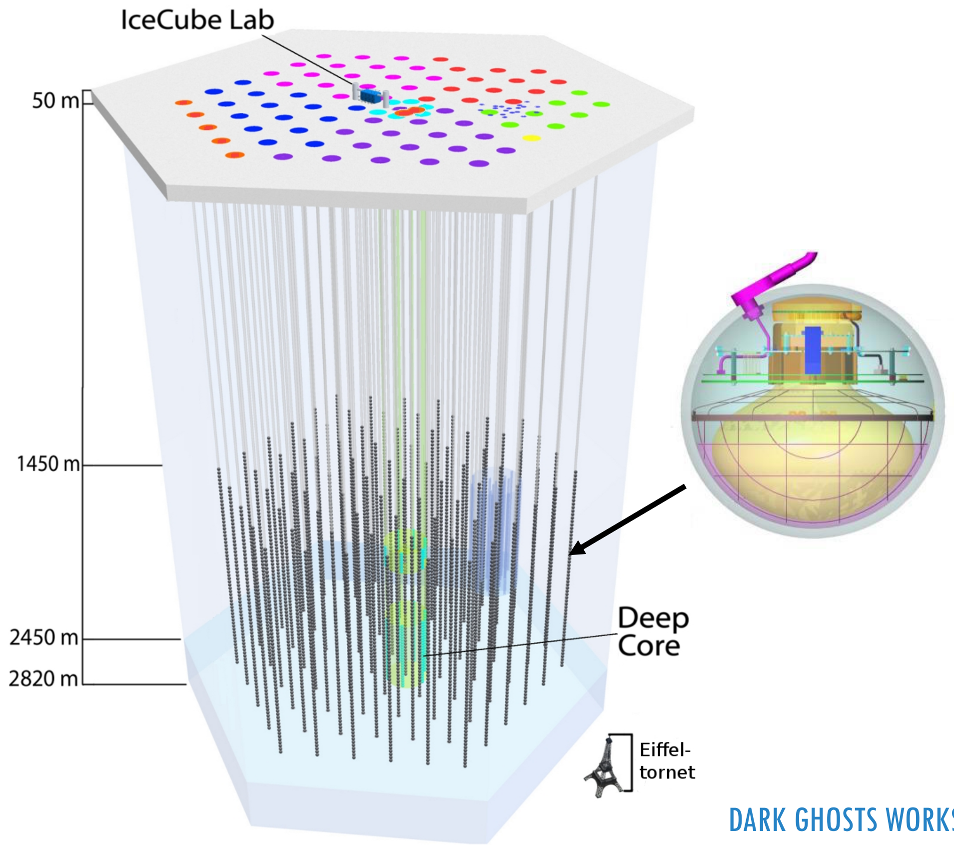
ANTARES

→ Located in the Mediterranean Sea
→ Composed of 1000 PMTs on 12 cables



IceCube

→ Located at the South Pole
→ Composed of 5160 PMTs on 86 cables

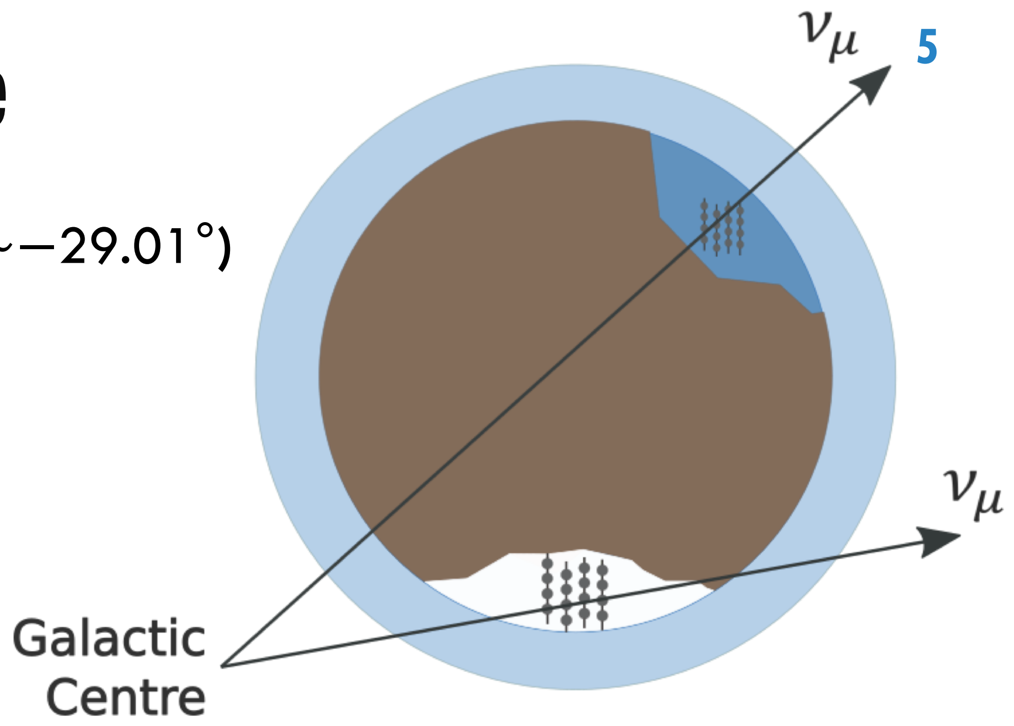


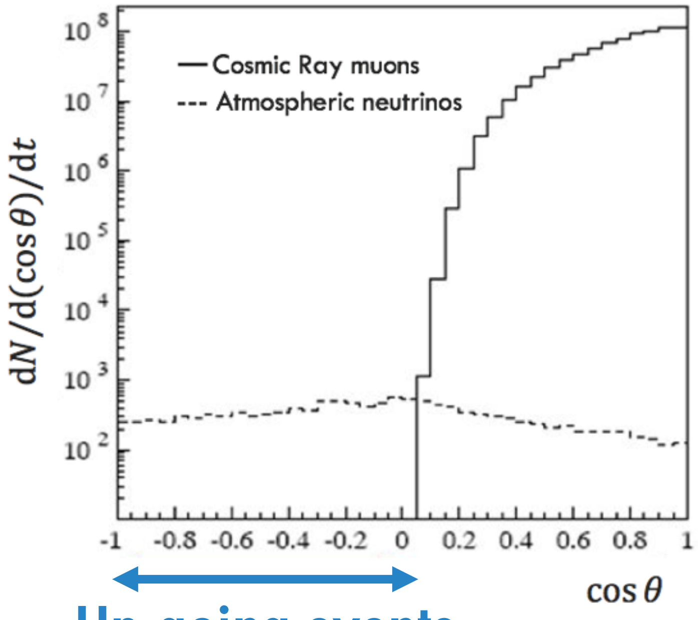
Coverage of the Galactic Centre

The Galactic Centre is located in the South Hemisphere ($\delta \sim -29.01°$)

→ Neutrinos coming from the GC are seen as

- Up-going events by **ANTARES**
- Down-going events by **IceCube**





Up-going events

Background:

Dominated by atmospheric muons and neutrinos

→ Produced by the interaction of cosmic rays with the high atmosphere

For **up-going** events:

The Earth acts as a shield against atmospheric muons

Indirect Search in the Galactic Centre

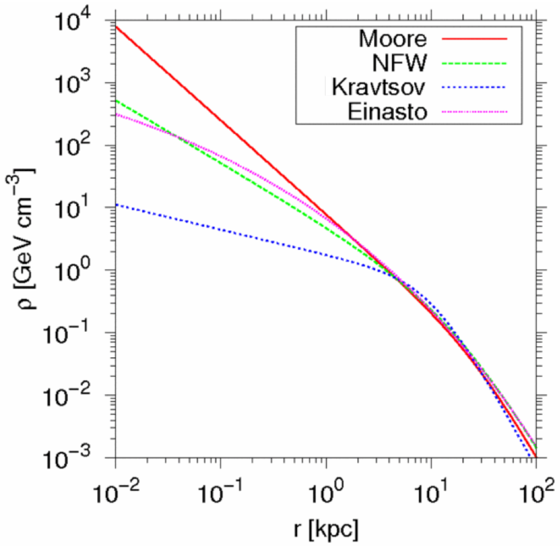
$$\frac{\mathrm{d}\phi_\nu}{dE_\nu} = \frac{1}{2}\frac{\langle\sigma_A v\rangle}{4\pi\, m_\chi^2}\frac{dN_\nu}{dE_\nu}\int_0^{\Delta\Omega} d\Omega \int_{l.o.s} \rho_\chi^2(r(s,\Psi,\theta))ds$$

Indirect Search in the Galactic Centre

$$\frac{d\phi_\nu}{dE_\nu} = \frac{1}{2}\frac{\langle\sigma_A v\rangle}{4\pi\, m_\chi^2}\,\frac{dN_\nu}{dE_\nu}\int_0^{\Delta\Omega} d\Omega \int_{l.o.s} \rho_\chi^2(r(s,\Psi,\theta))ds$$

Astrophysics input

J-factor



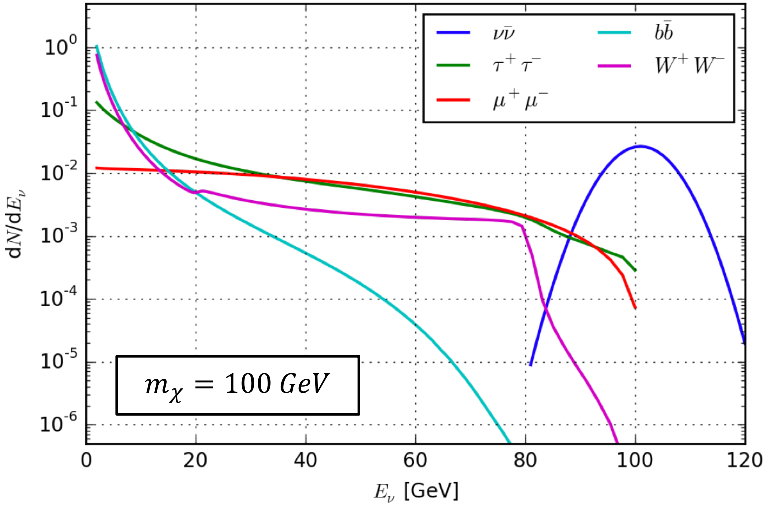
Cirelli et al., 1012.4515v4

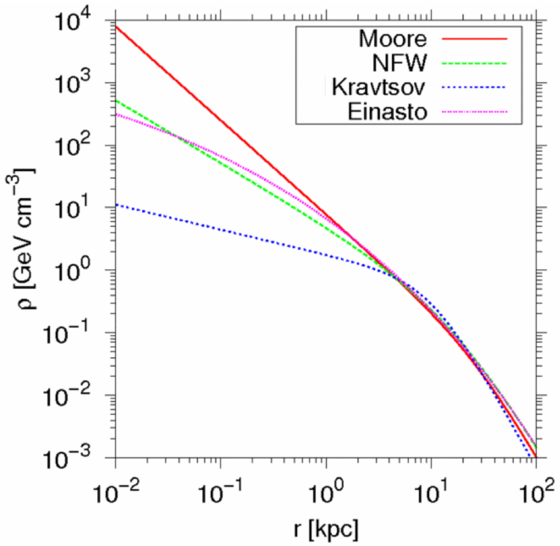
Indirect Search in the Galactic Centre

$$\frac{d\phi_\nu}{dE_\nu} = \frac{1}{2}\frac{\langle\sigma_A v\rangle}{4\pi\, m_\chi^2}\frac{dN_\nu}{dE_\nu}\int_0^{\Delta\Omega} d\Omega \int_{l.o.s} \rho_\chi^2(r(s,\Psi,\theta))ds$$

Theory input (SUSY?)

Astrophysics input
J-factor





[Cirelli et al., 1012.4515v4]

Indirect Search in the Galactic Centre

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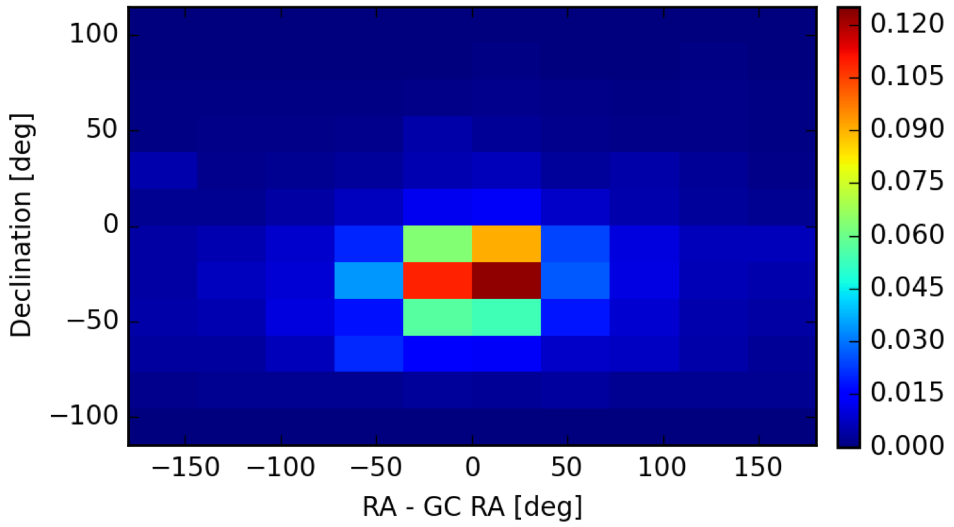
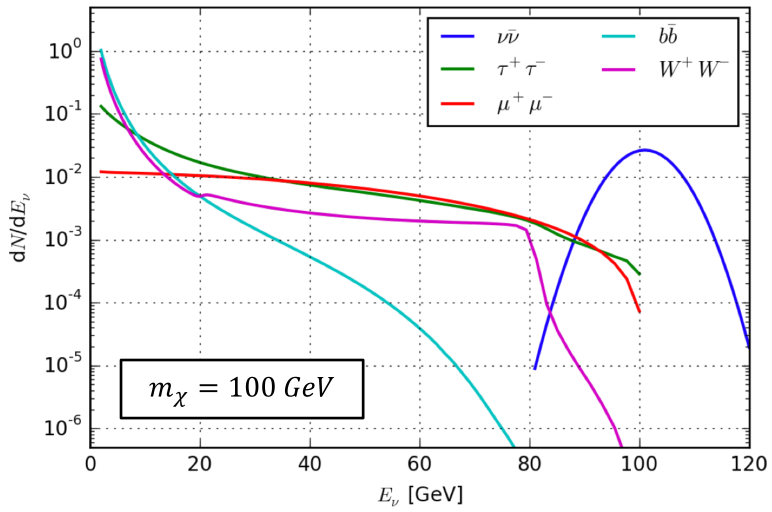
Measurement

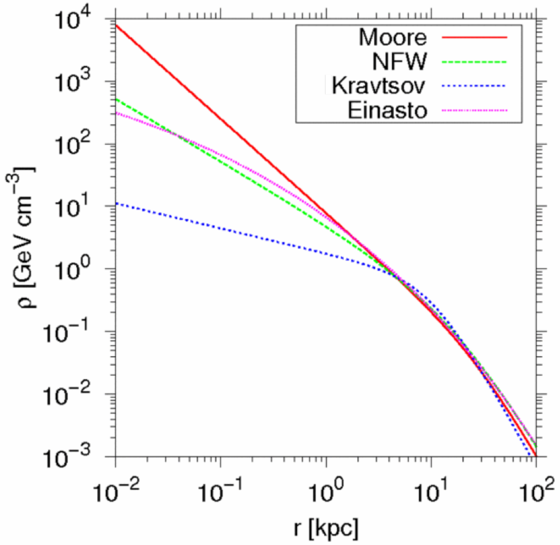
Theory input (SUSY?)

Astrophysics input

J-factor







[Cirelli et al., 1012.4515v4]

Indirect Search in the Galactic Centre

$$\frac{d\phi_\nu}{dE_\nu} = \frac{1}{2}\frac{\langle\sigma_A v\rangle}{4\pi\, m_\chi^2}\frac{dN_\nu}{dE_\nu}\int_0^{\Delta\Omega} d\Omega \int_{l.o.s} \rho_\chi^2(r(s,\Psi,\theta))ds$$

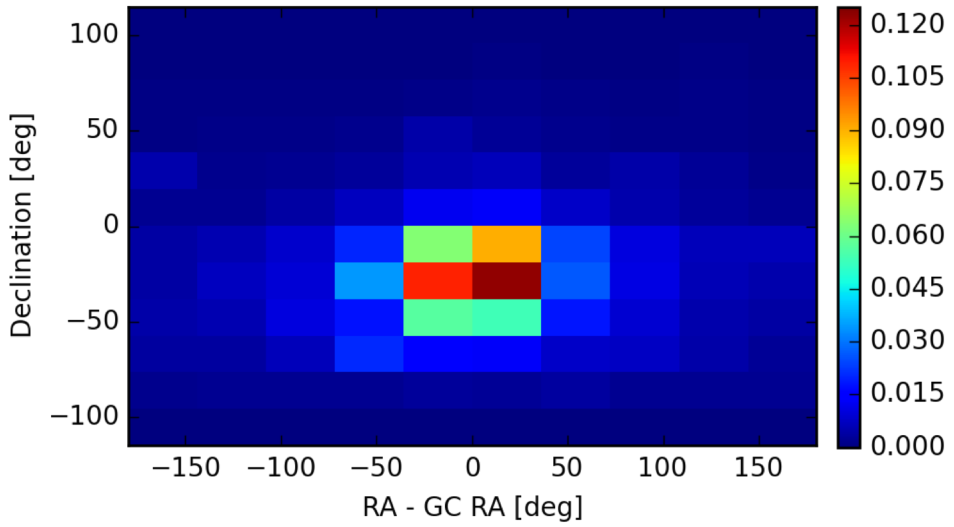
Constrain

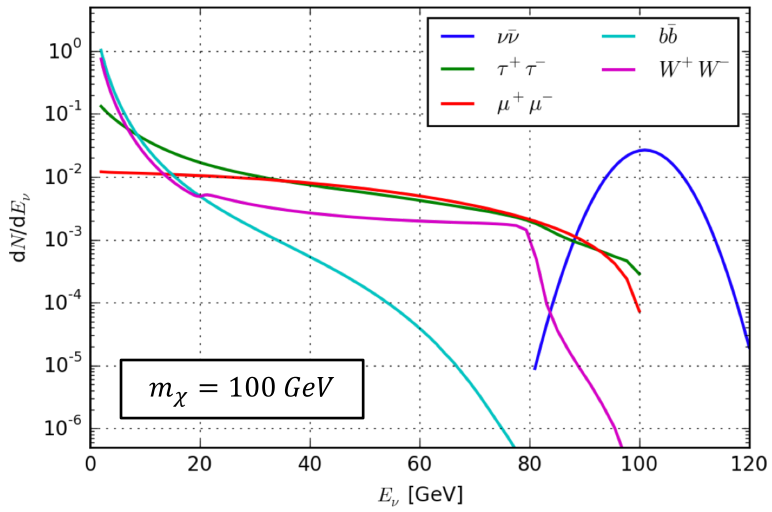
Measurement

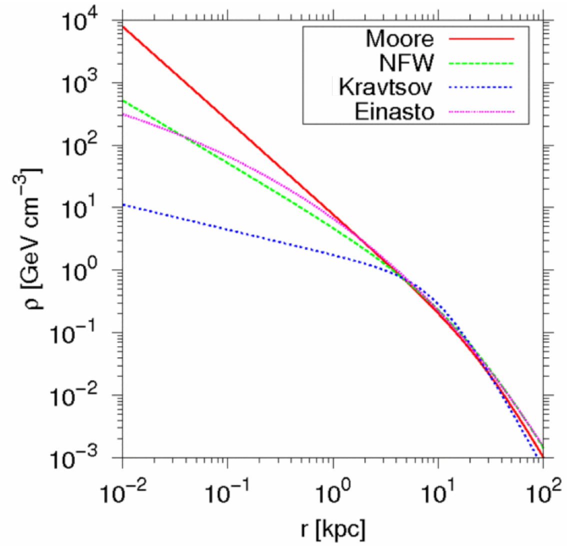
Theory input (SUSY?)

Astrophysics input

J-factor







[Cirelli et al., 1012.4515v4]

Weighting of Signal Simulation

Integrated Weight:

$$w = \frac{1}{2}\frac{\langle\sigma_A v\rangle}{4\pi m_\chi^2} J_{int}\, A \qquad \text{with} \qquad A = \int A_{eff}\,\frac{dN_\nu}{dE}\,T_{livetime}\,dE$$

Each Event has a different weight:

$$w_i = \frac{1}{2}\frac{\langle\sigma_A v\rangle}{4\pi m_\chi^2} J_\psi\,\frac{w_{OW}}{N_{events}}\,\frac{dN_\nu}{dE}\,T_{livetime}$$

Weighting of Signal Simulation

Integrated Weight:

J-factor
Computed at 30° using CLUMPY

$$w = \frac{1}{2}\frac{\langle\sigma_A v\rangle}{4\pi m_\chi^2} J_{int} A \quad \text{with} \quad A = \int A_{eff} \frac{dN_\nu}{dE} T_{livetime}\, dE$$

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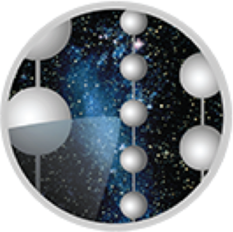

$$w_i = \frac{1}{2}\frac{\langle\sigma_A v\rangle}{4\pi m_\chi^2} J_\psi \frac{w_{OW}}{N_{events}} \frac{dN_\nu}{dE} T_{livetime}$$

Weighting of Signal Simulation

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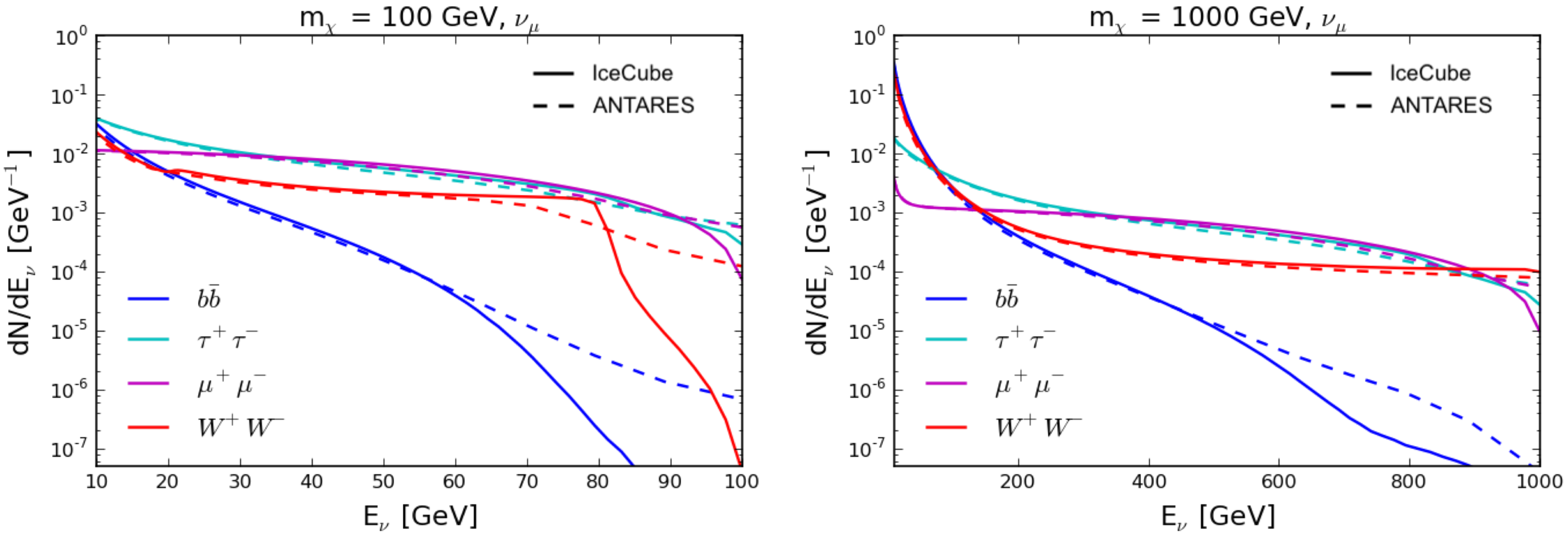
Neutrino Spectrum at Earth

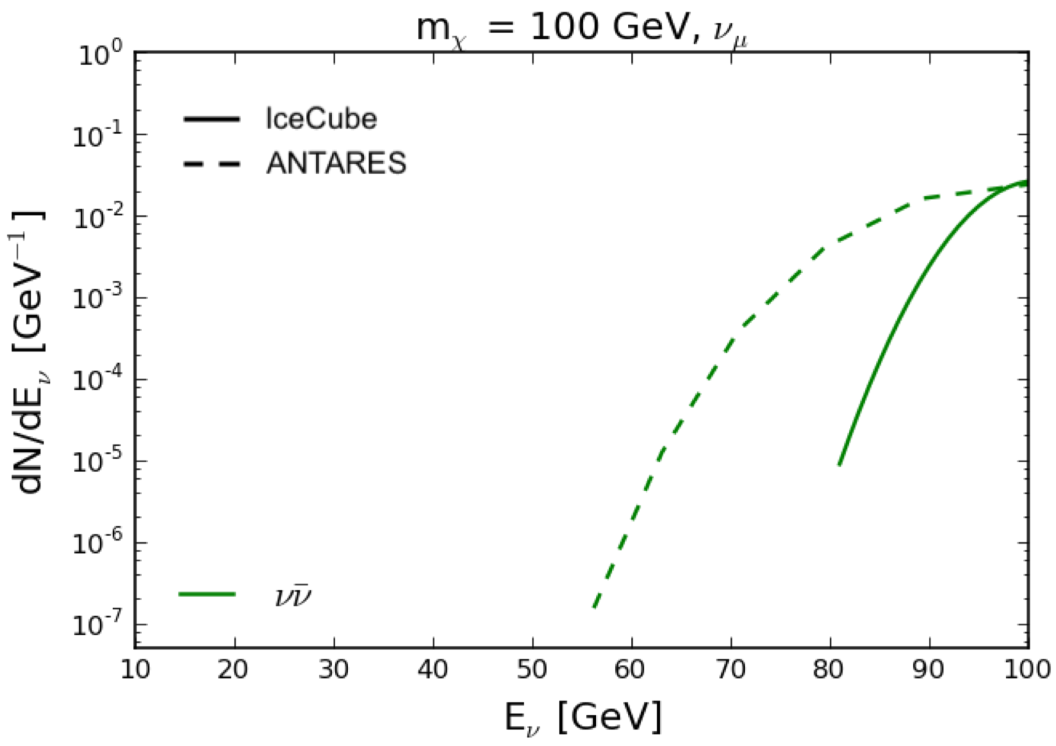
- **ANTARES:** Cirelli Spectra with EW corrections
  → http://www.marcocirelli.net/PPPC4DMID.html
- **IceCube:** Spectra produced with Pythia for the IC86 GC Analysis [arXiv:1705.08103]

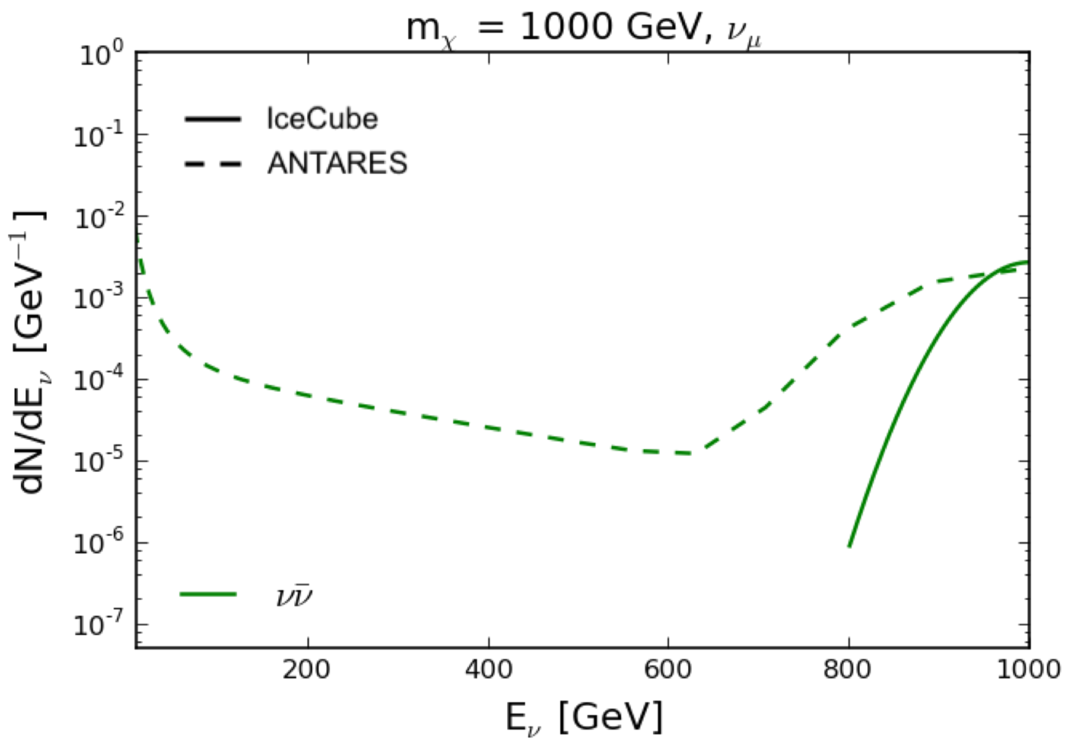


Neutrino Spectrum for $\nu\bar{\nu}$ Channel

→ IceCube Spectra are Gaussians centred on the WIMP mass

→ At high energy there is **“tail” behaviour** in the spectra used by ANTARES





Datasets

WIMP channels considered: $W^+W^-, \tau^+\tau^-, \mu^+\mu^-, b\bar{b}$ and $\nu\bar{\nu}$

WIMP masses considered: 50, **65**, 100, **130**, 200, **300**, **400**, 500, 1000

Lifetime: 2101.6 days from 2007 to 2015

Two reconstruction algorithm are used:

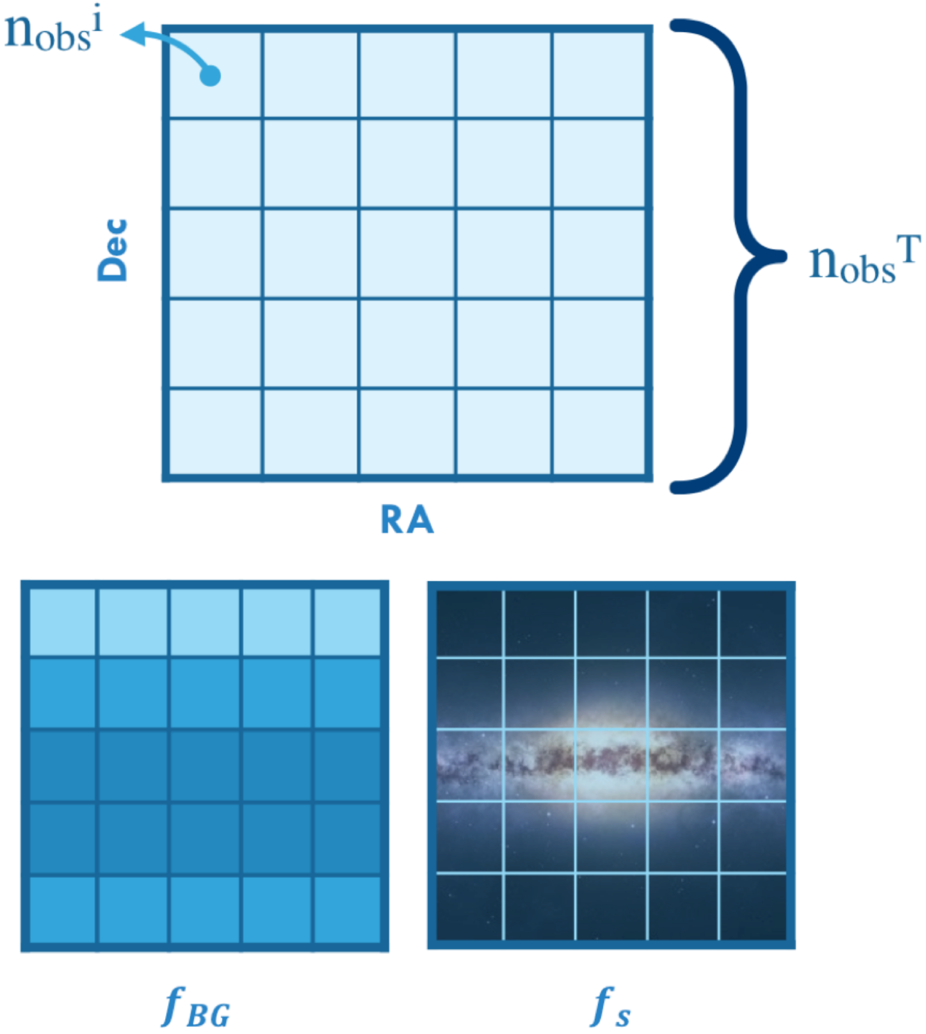
- Single-Line (BBFit) below 250 GeV
- Multi-Line (AAFit) above 250 GeV

Lifetime: 1006 days from May 2012 to May 2015

IC86 GC WIMP Search dataset

Exchange of data between the collaborations has been approved

Statistical Analysis: Binned Method



[Picture from J. A. Aguilar]

$$\mathcal{L}(\mu) = \prod_{i}^{N_{bins}} \text{Poisson}\left(n^{i}_{obs}\,;n^{T}_{obs}\,f(i\,;\mu)\right)$$

$$f(i\,;\mu) = \mu\,f_s(i) + (1-\mu)\,f_{BG}(i)$$

- Obtain best estimate on the signal fraction μ by minimizing $-\log\mathcal{L}$
- Upper limit on the signal fraction $\mu_{90\%}$ using the Feldman-Cousins method

Code can be found here:

https://github.com/sflis/MLSandbox

Combined Likelihood

$$\mathcal{L}_{comb}(\mu) = \prod_{k=0}^{1} \mathcal{L}_k(\mu)$$

$$-\log \mathcal{L}_{comb}(\mu) = \underbrace{-\log \mathcal{L}_{\mathrm{A}}(\mu_A)}_{\text{ANTARES}} \underbrace{-\log \mathcal{L}_{\mathrm{I}}\,(\mu_I)}_{\text{IceCube}}$$

Where we are **minimising** the parameter μ defined as:

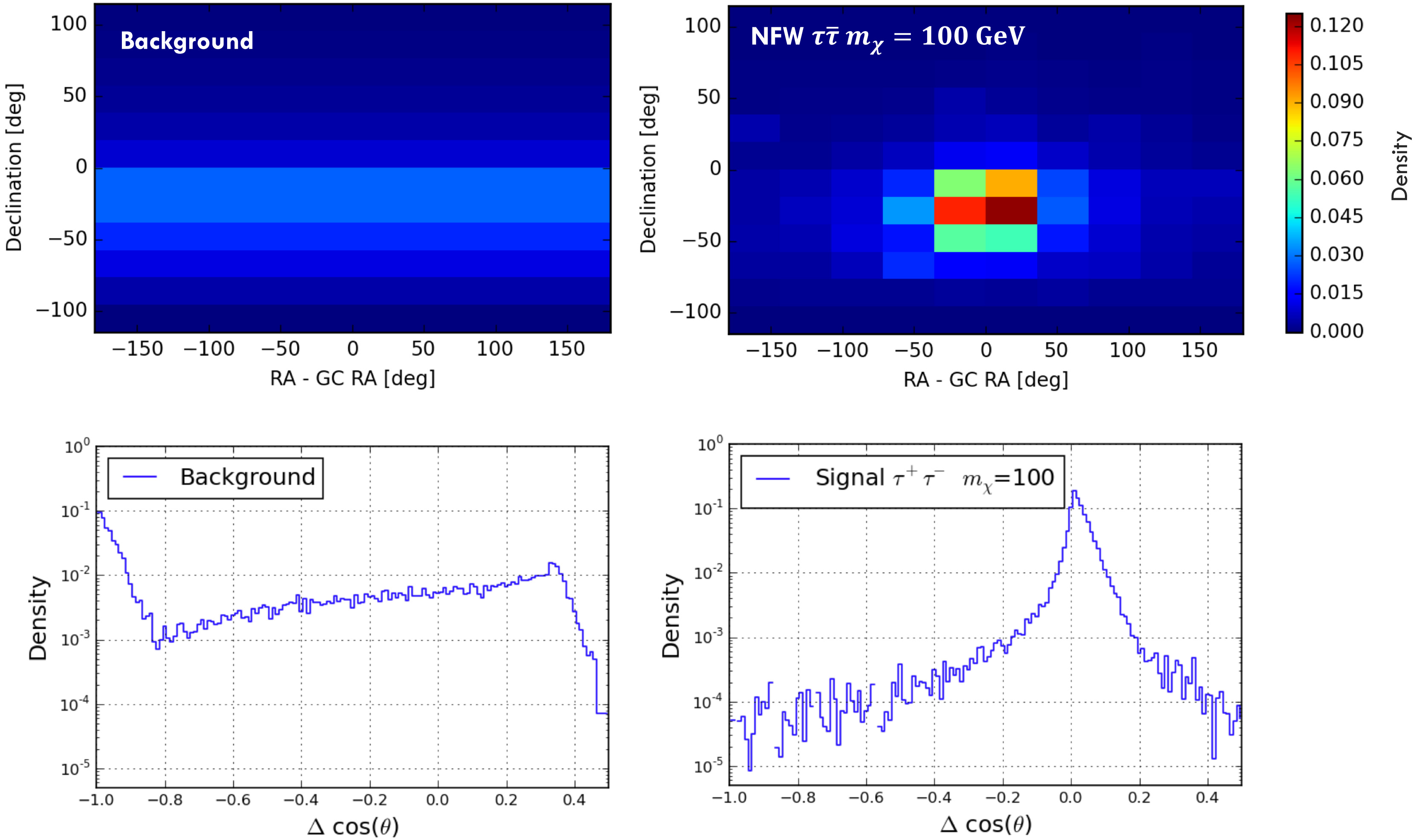
$$\mu = \frac{n_{sig}}{n_{obs}^T} = \frac{n_{sig}^A + n_{sig}^I}{n_A^T + n_I^T} = \frac{n_{sig}(\,w_A + w_I\,)}{n_{obs}^T(\,f_A + f_I\,)}$$

relative signal efficiencies (w)

relative background efficiencies (f)

$$\mu_{\mathrm{i}} = \frac{\mathrm{n}_{\mathrm{sig}}^{i}}{n_i^T} = \frac{w_i\, n_{sig}}{f_i\;\, n_{obs}^T} = \frac{w_i}{f_i}\,\mu$$

Background and Signal PDFs



Conclusion

- Comparison of ANTARES and IceCube analysis methods
- Harmonisation of neutrino spectra

  → Computation of new PDF and Acceptance for ANTARES

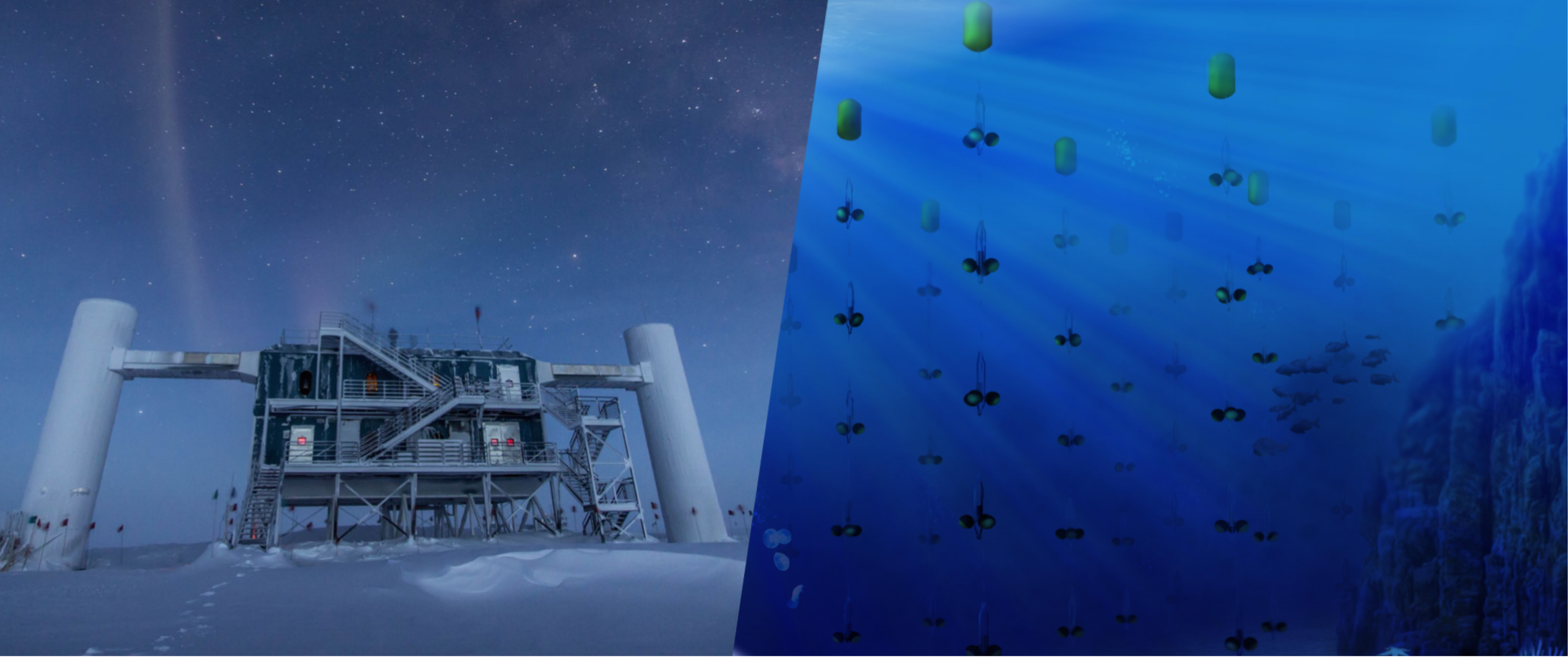
Near Future:

- Obtain the combined sensitivities
- Unblinding of this analysis
- Publication of a paper common to IceCube and ANTARES

Outlooks:

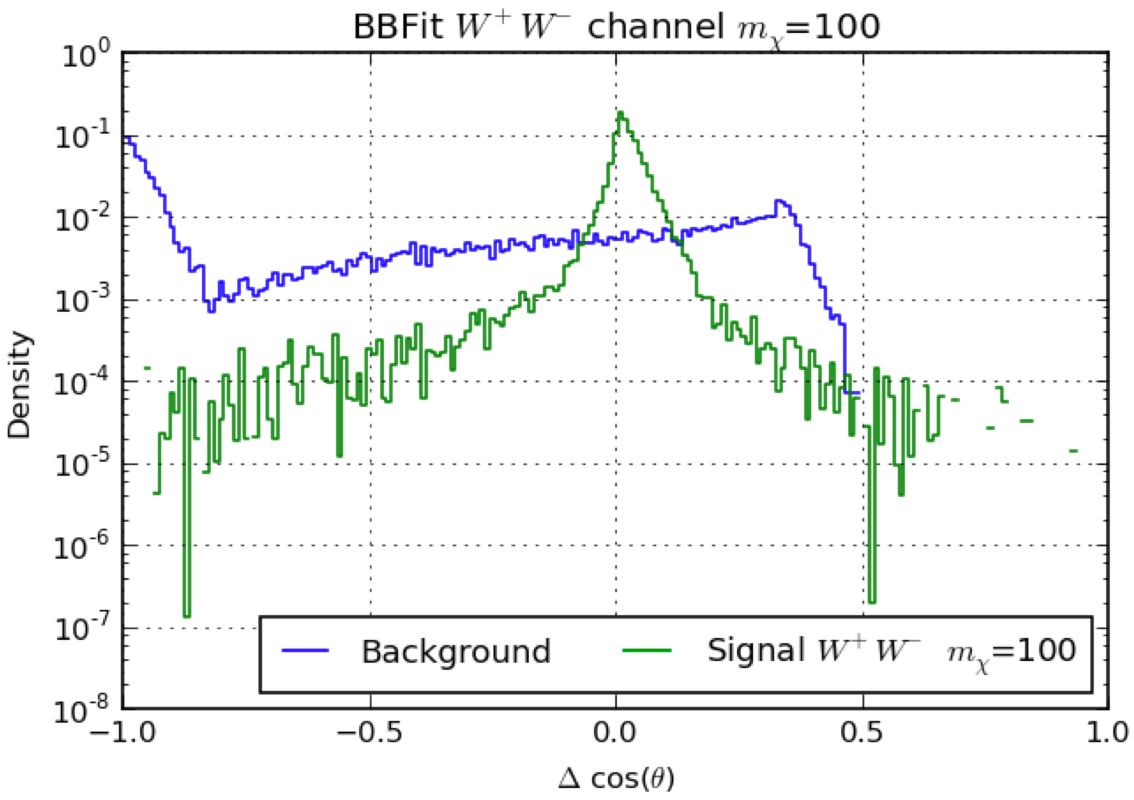
Move to Unbinned Likelihood Method

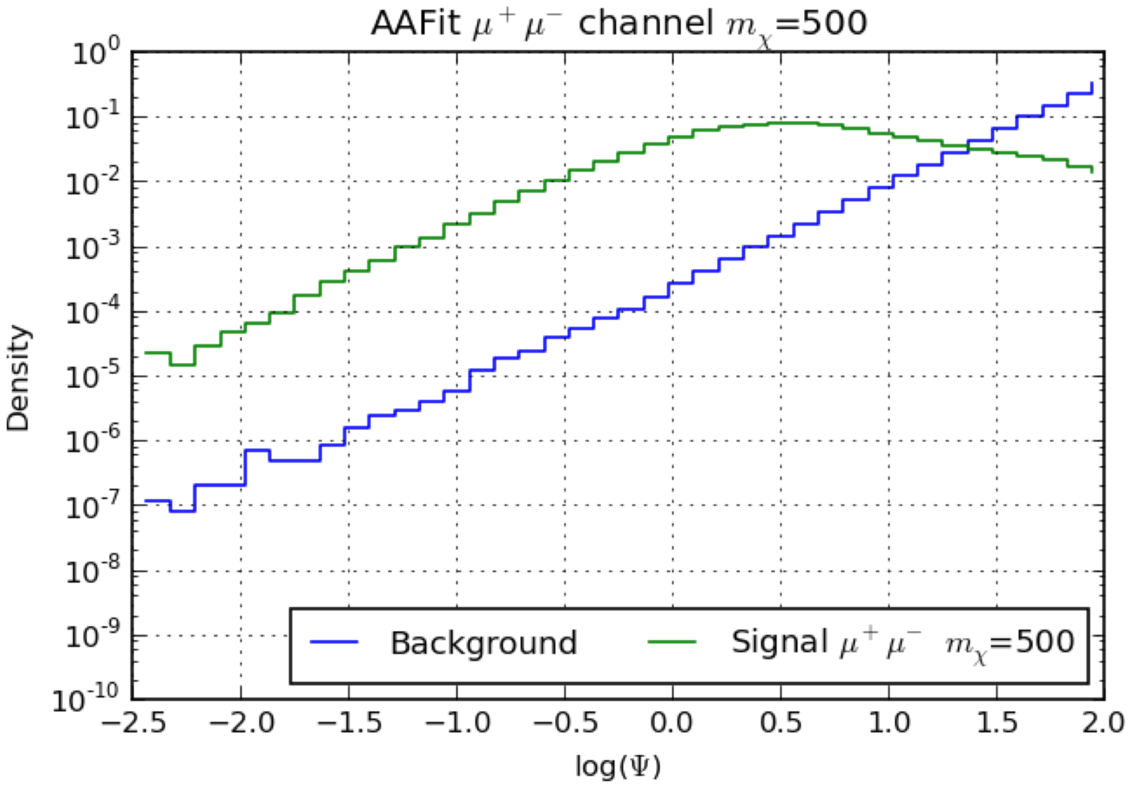
- Extend the datasets used to more years
- Development of the unbinned likelihood method



Backup Slides

ANTARES PDFs





Signal Efficiencies

$$w = \frac{1}{2}\frac{\langle\sigma_A \upsilon\rangle}{4\pi m_\chi^2} J_{int}\ A_{ANT} \xrightarrow{=} n_{sig}^{A}$$

$$w_i = \frac{1}{2}\frac{\langle\sigma_A \upsilon\rangle}{4\pi m_\chi^2} J_\psi \frac{w_{OW}}{N_{events}} \frac{dN_\nu}{dE} T_{livetime} \xrightarrow{\sum w_i} n_{sig}^{I}$$