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

Nadège Iovine
Juan Antonio Aguilar Sánchez
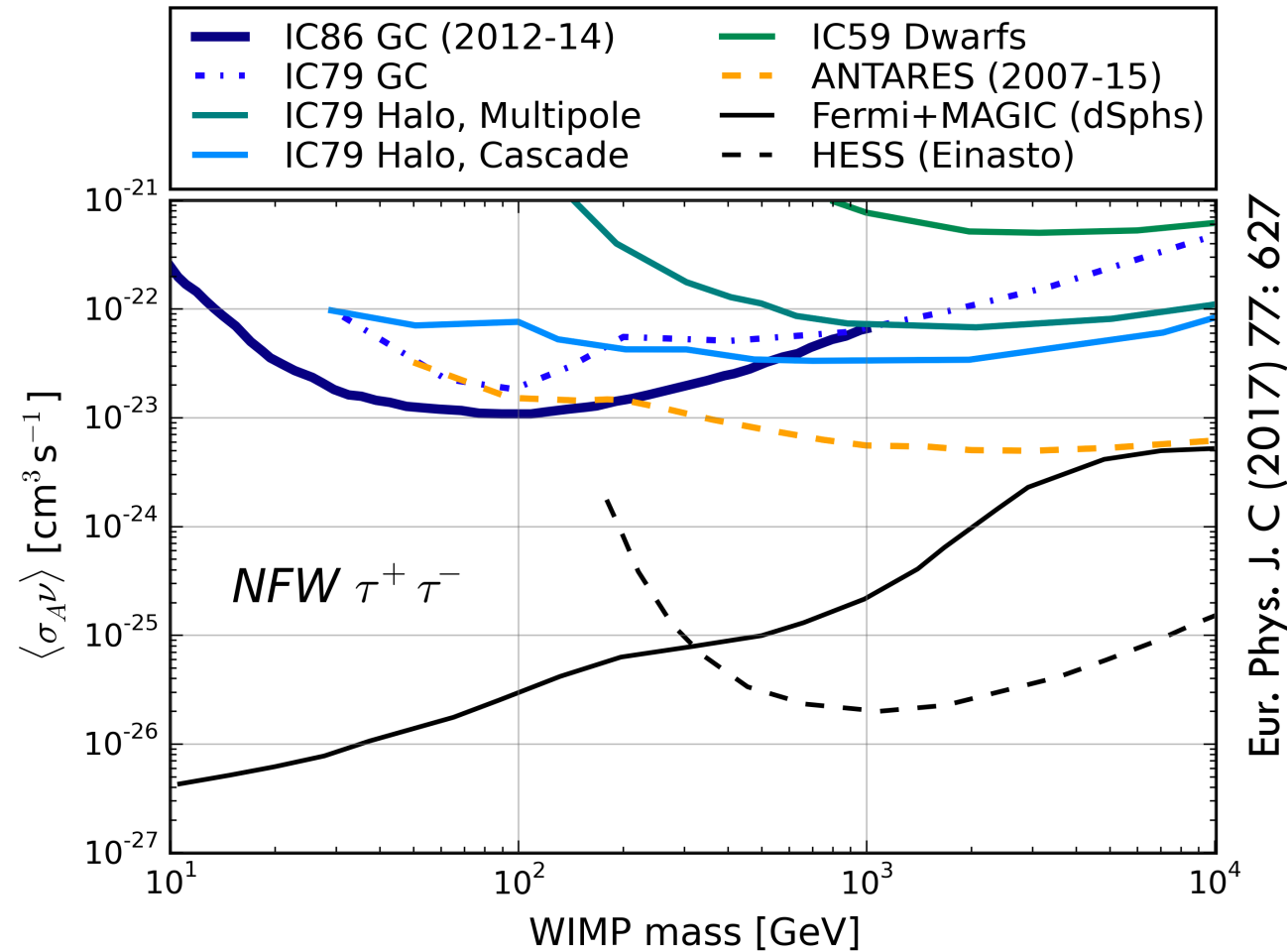Sebastian Baur
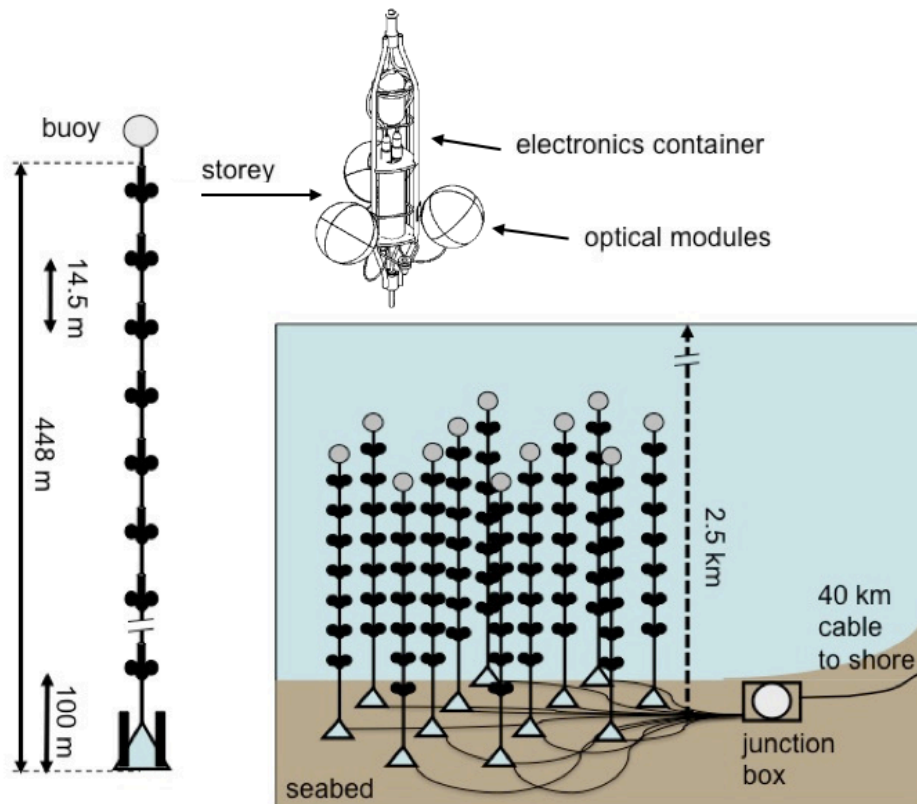Sara Rebecca Gozzini
Juan de Dios Zornoza Gómez
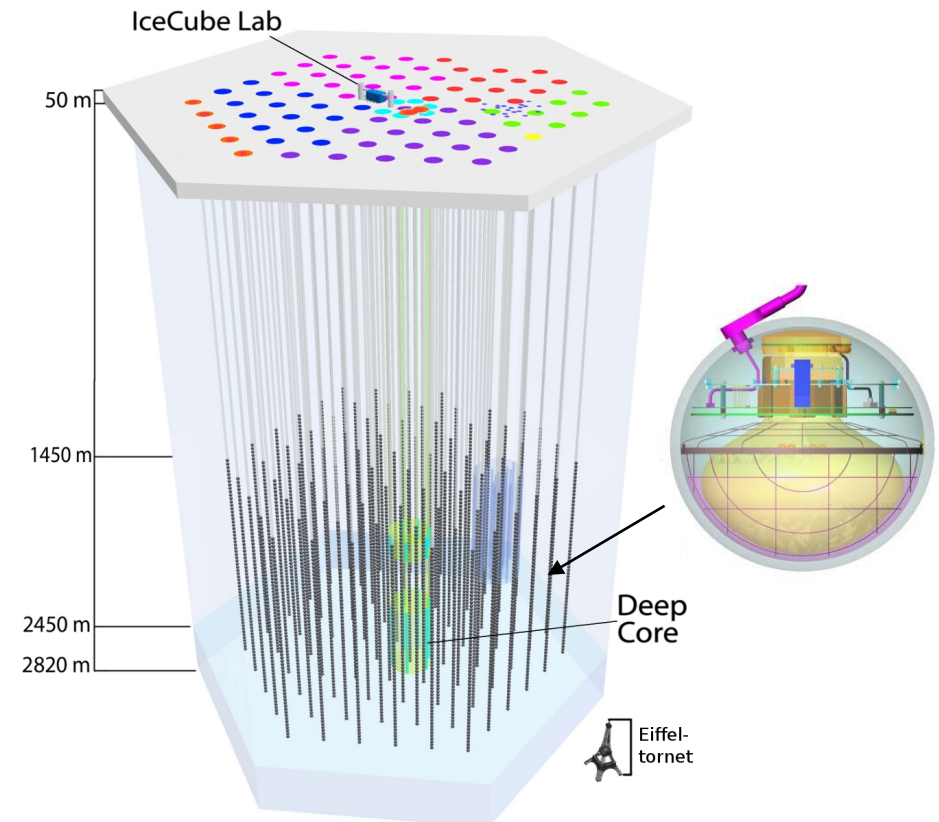
Motivations

Detectors

ANTARES

→ Located in the Mediterranean Sea
→ Composed of 885 PMTs on 12 cables

IceCube

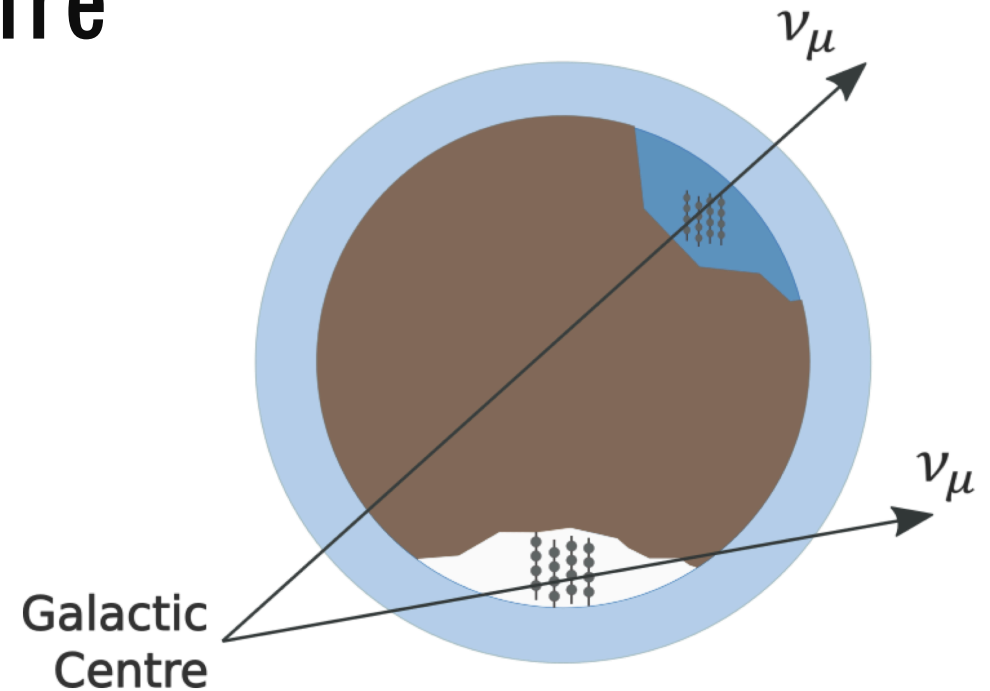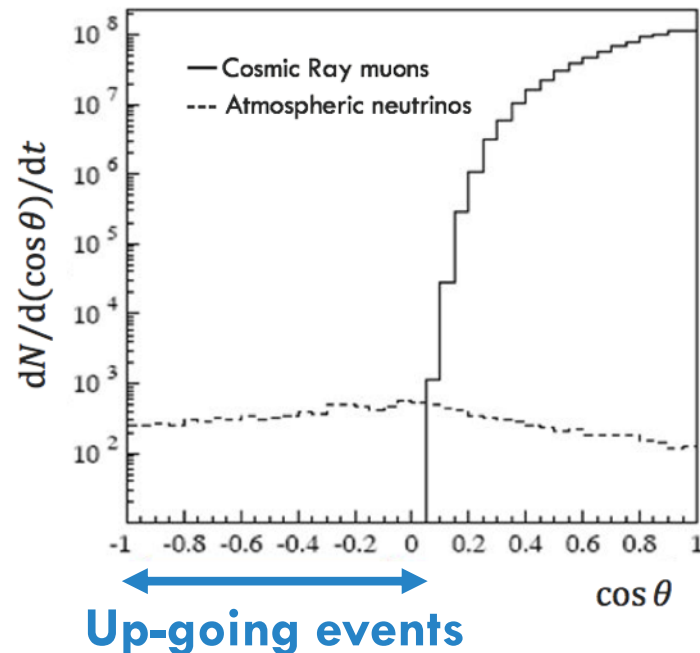→ Located at the South Pole
→ Composed of 5160 PMTs on 86 cables

Coverage of the Galactic Centre

Galactic Centre located at dec $\sim -29.01°$

$\rightarrow$ Neutrinos coming from the GC are seen as

- Up-going events by **ANTARES** (75% visibility)
- Down-going events by **IceCube**

Up-going events

Background of both experiments:

Dominated by atmospheric muons and neutrinos

For **up-going** events:

The Earth acts as a shield against atmospheric muons

Datasets

WIMP channels : $W^+W^-, \tau^+\tau^-, \mu^+\mu^-$ and $b\bar{b}$
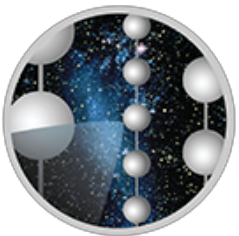
WIMP masses: 17 masses ranging from 50 to 1000 GeV

Lifetime: 2101.6 days from 2007 to 2015
Data from ***ANTARES 9 years DM Milky Way Search*** [Phys. Let. B (2017) 769:249]

Two reconstruction algorithm are used:

- Single-Line reconstruction (QFit)
  → Reconstruct only zenith
- Multi-Line reconstruction (λFit)

Lifetime: 1006 days from May 2012 to May 2015
Data from ***IceCube 3 years DM Milky Way Search*** [Eur. Phys. J. C (2017) 77: 627]
Taken with the IC86 configuration
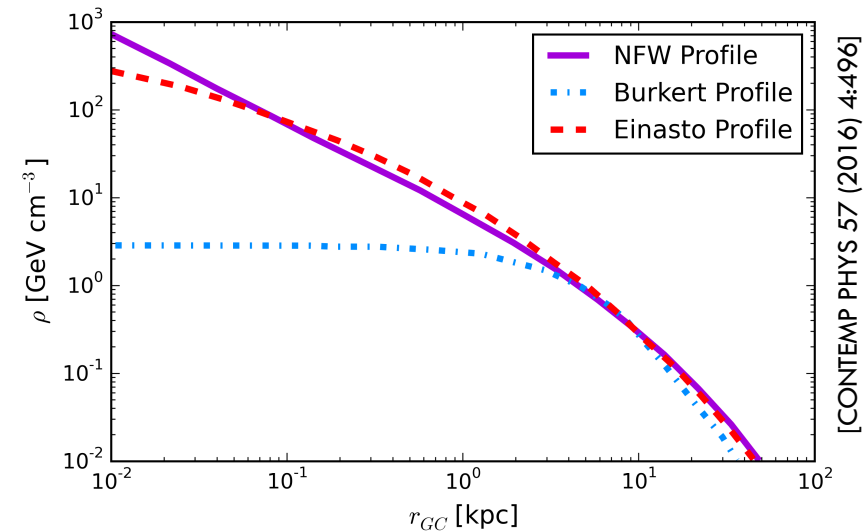
Indirect Search in the Galactic Centre

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

Indirect Search in the Galactic Centre

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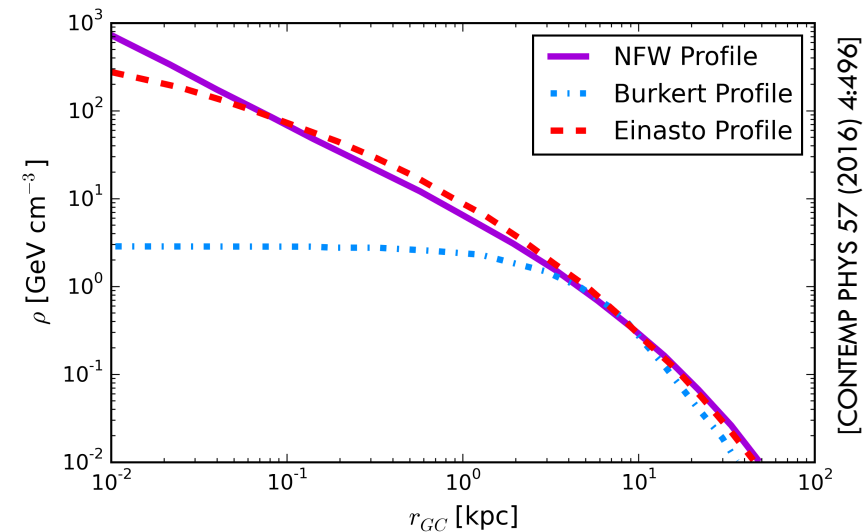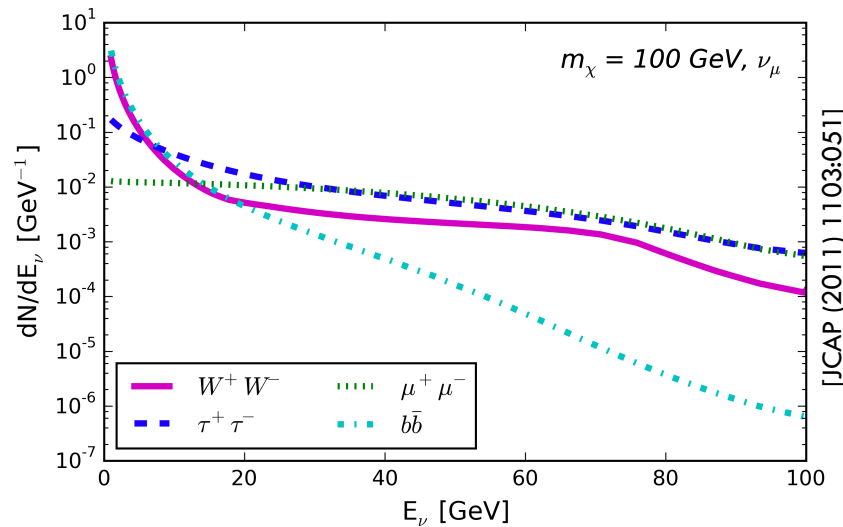
Astrophysics input
J-factor

Indirect Search in the Galactic Centre

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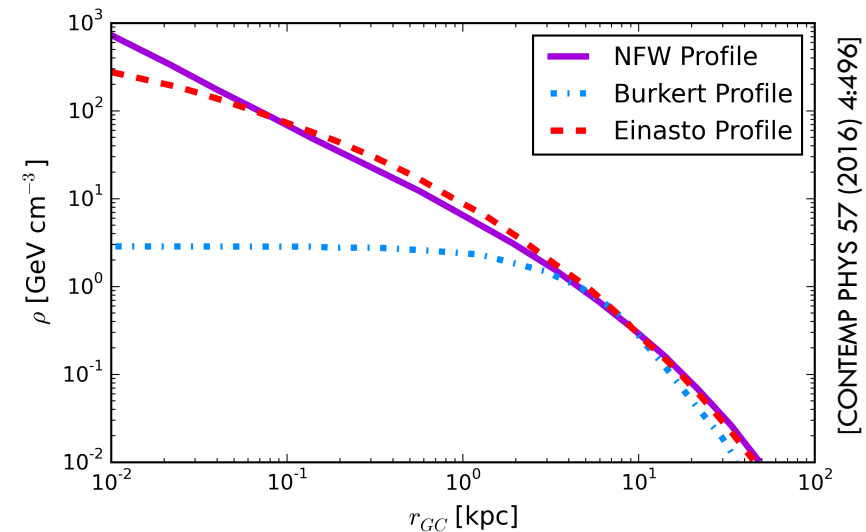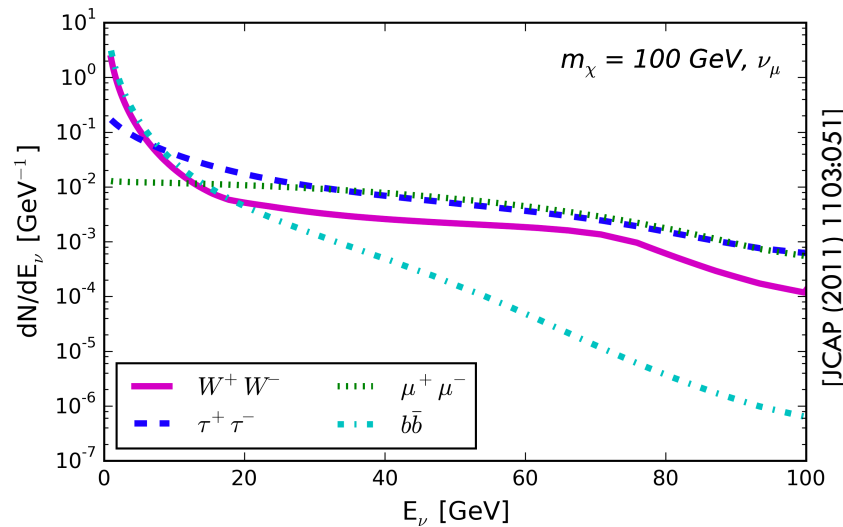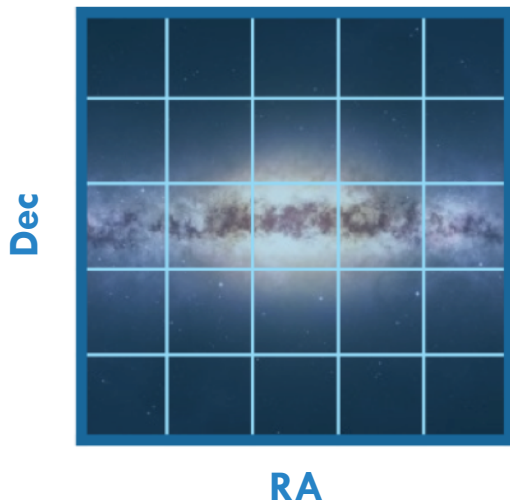
Theory input

Astrophysics input
J-factor

$m_\chi = 100\ GeV,\ \nu_\mu$

dN/dE_ν [GeV^{-1}]

E$_\nu$ [GeV]

- W^+W^-
- $\tau^+\tau^-$
- $\mu^+\mu^-$
- $b\bar{b}$

[JCAP (2011) 1103:051]

ρ [GeV cm^{-3}]

r_{GC} [kpc]

- NFW Profile
- Burkert Profile
- Einasto Profile

[CONTEMP PHYS 57 (2016) 4:496]

Indirect Search in the Galactic Centre

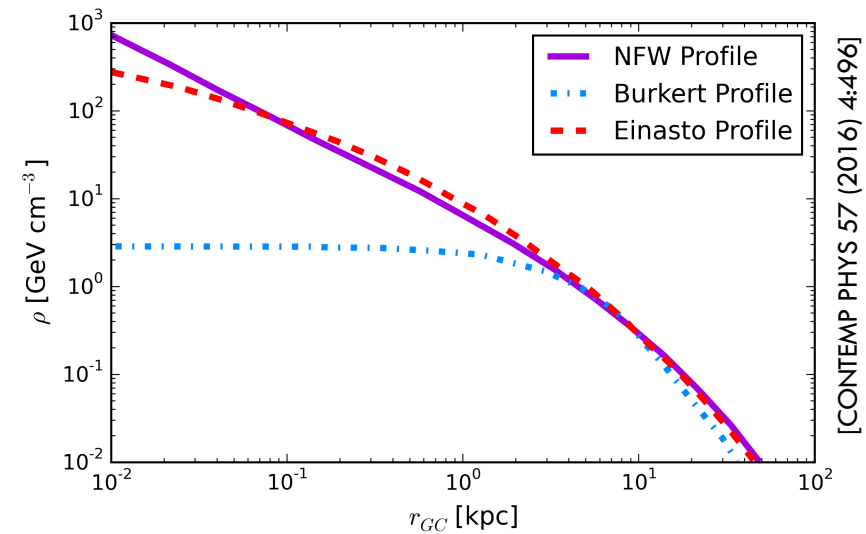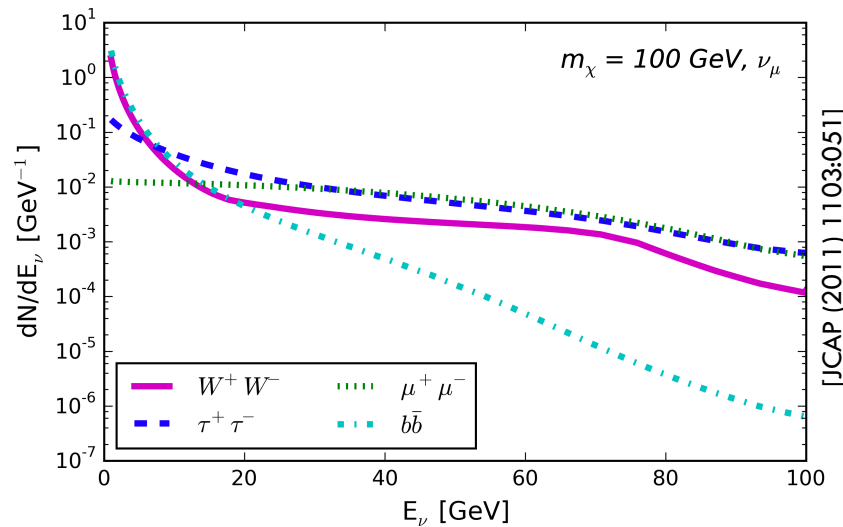$$\frac{\mathrm{d}\phi_\nu}{dE_\nu} = \frac{1}{2}\frac{\langle\sigma_A\nu\rangle}{4\pi\, m_\chi^2}\frac{dN_\nu}{dE_\nu}\int_0^{\Delta\Omega}d\Omega\int_{l.o.s}\rho_\chi^2(r(s,\Psi,\theta))ds$$

Measurements

Theory input

Astrophysics input
J-factor

Dec / RA

$m_\chi = 100$ GeV, ν_μ

dN/dE_ν [GeV^{-1}]

E_ν [GeV]

W^+W^- $\mu^+\mu^-$
$\tau^+\tau^-$ $b\bar{b}$

[JCAP (2011) 1103:051]

NFW Profile
Burkert Profile
Einasto Profile

ρ [GeV cm^{-3}]

r_{GC} [kpc]

[CONTEMP PHYS 57 (2016) 4:496]

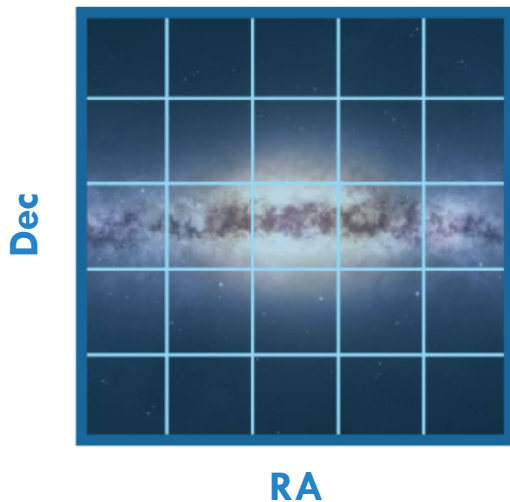# Indirect Search in the Galactic Centre

Constrain

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

Measurements

Theory input

Astrophysics input
J-factor

J-factor

Profiles used:

$$\rho_{NFW}(r) = \frac{\rho_0}{\frac{r}{r_s}\left(1 + \frac{r}{r_s}\right)^2}$$

$$\rho_{Burkert}(r) = \frac{\rho_0}{\left(1 + \frac{r}{r_s}\right)\left(1 + \left(\frac{r}{r_s}\right)^2\right)}$$

Model Parameters from:

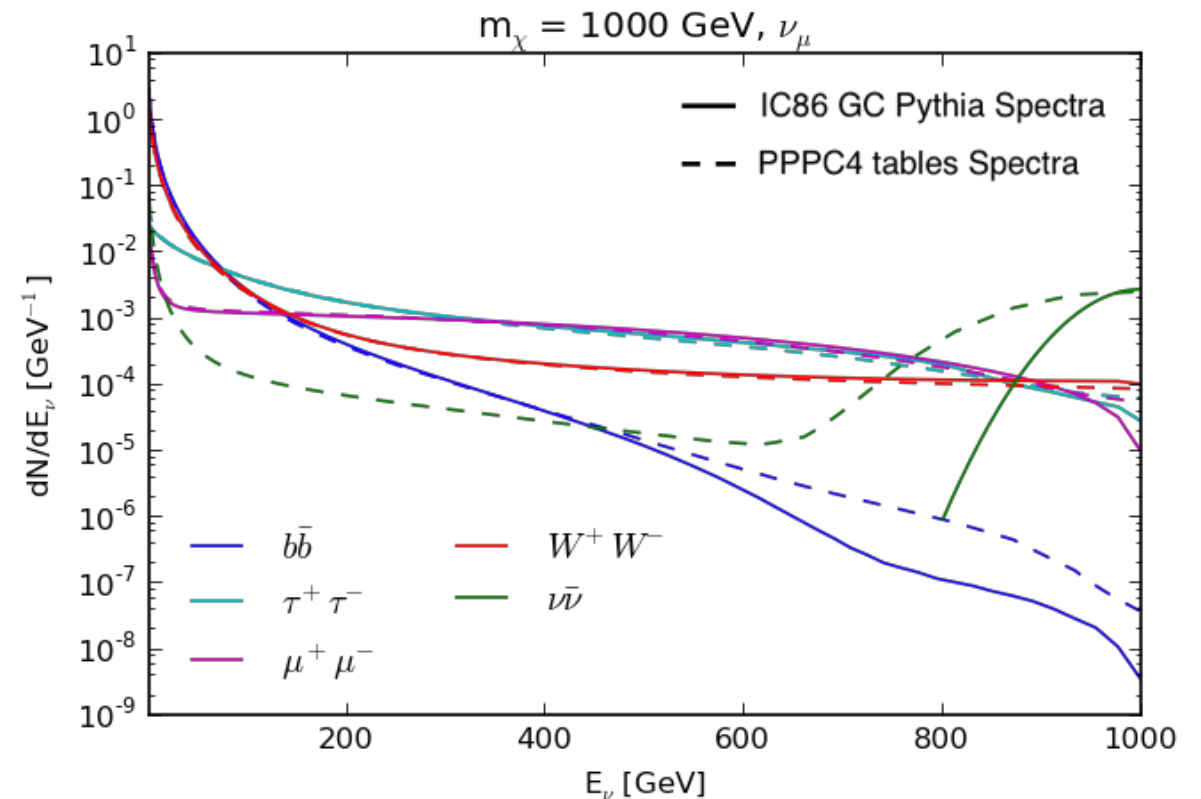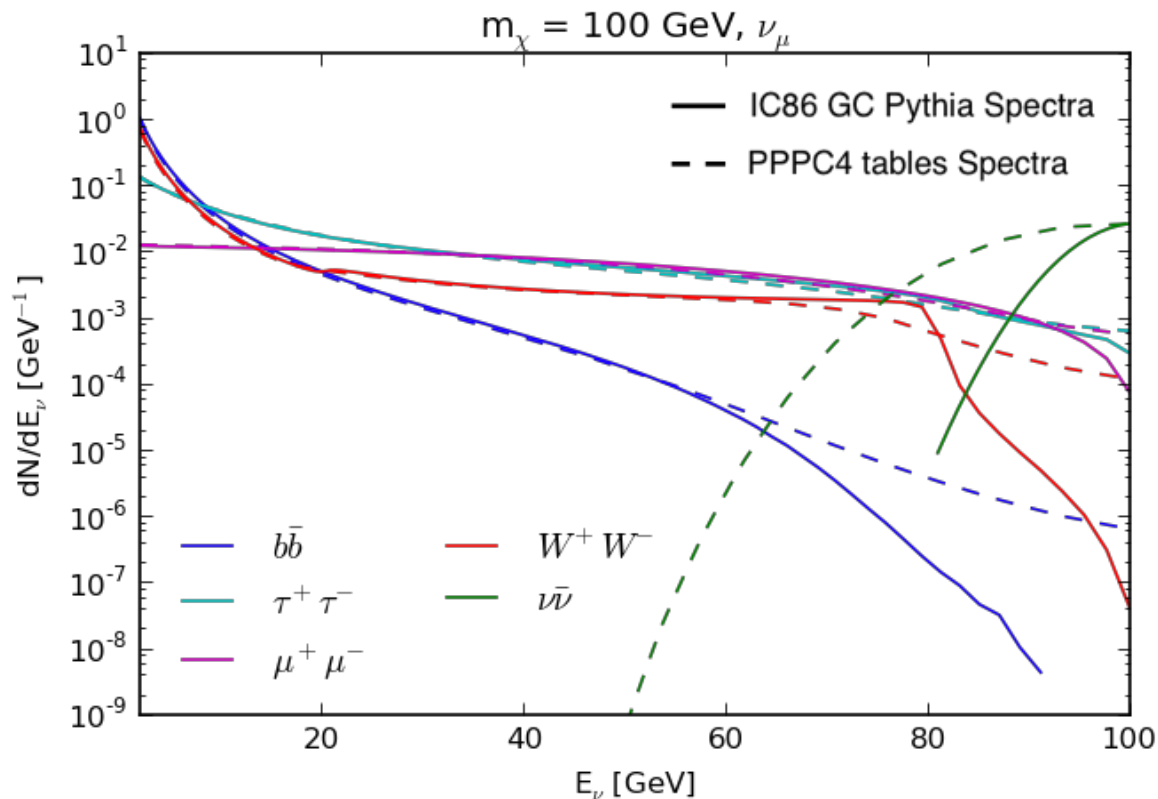Nesti & Salucci - JCAP 1307 (2013) 016

ANTARES: computed with Clumpy

IceCube: DMHaloModels project was used

Parameter	Units	NFW	Burkert
ρ_0	$10^7 M_\odot/kpc^3$	$1.40^{+2.9}_{0.93}$	$4.13^{+6.2}_{-1.6}$
r_s	kpc	$16.1^{+17}_{-7.8}$	$9.26^{+5.6}_{-4.2}$
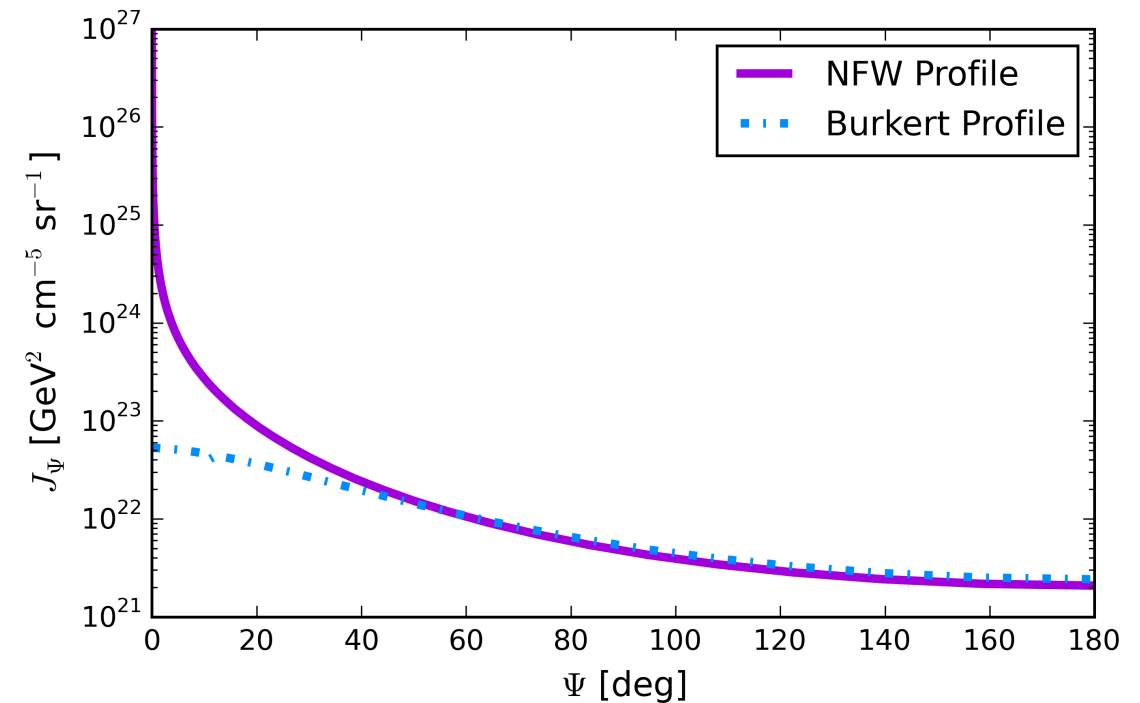
Spectra Investigation

- **ANTARES:** PPPC4 Spectra including EW corrections [JCAP 1103 (2011) 051]

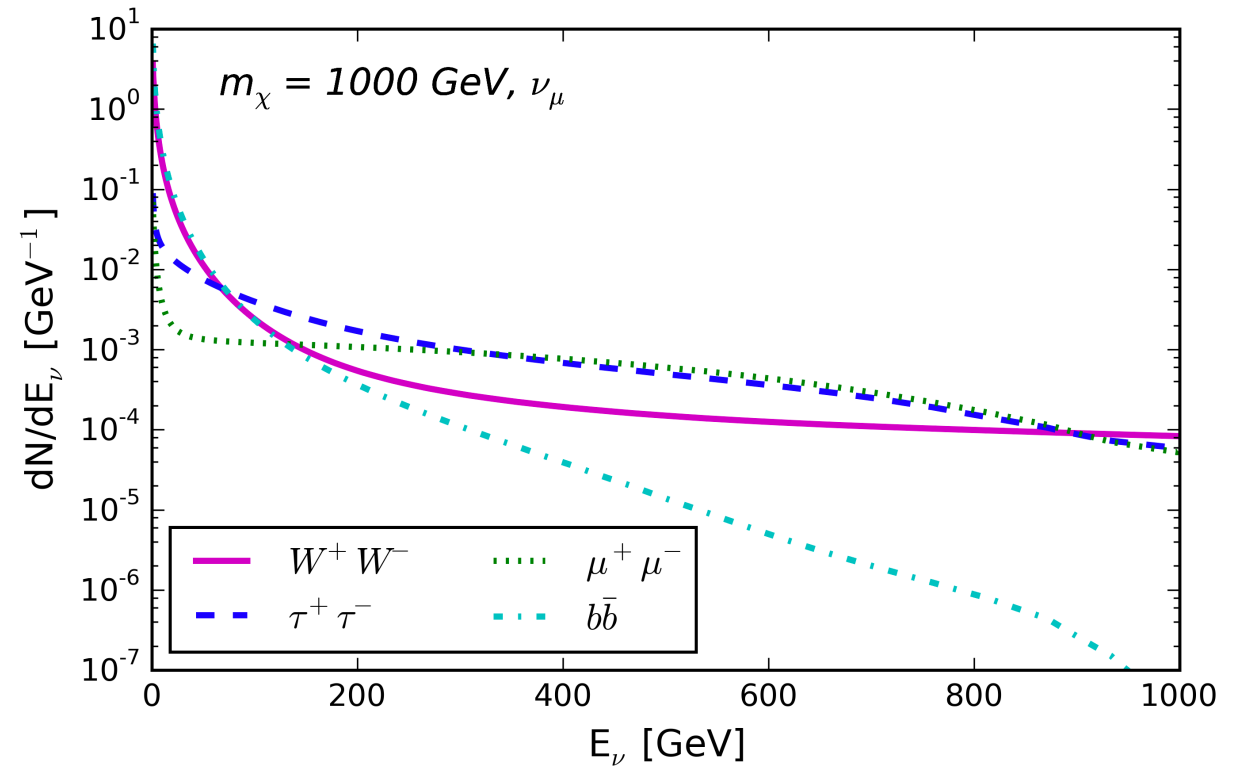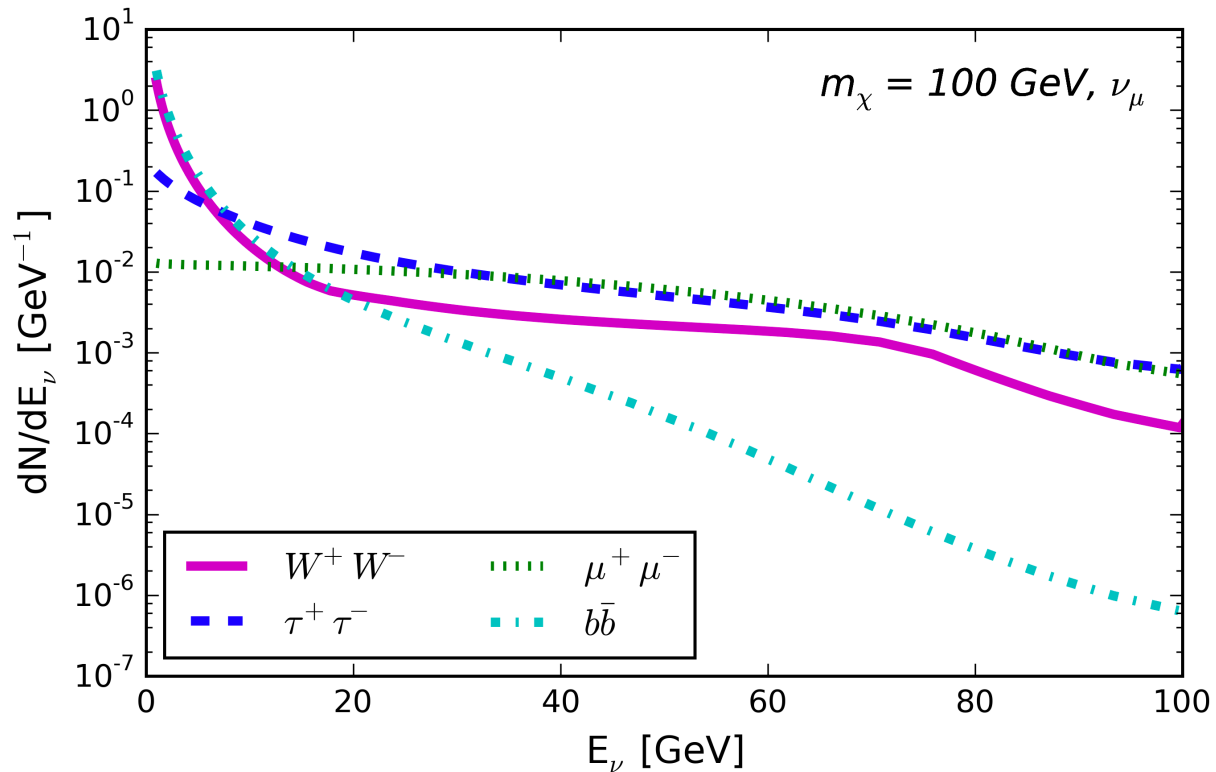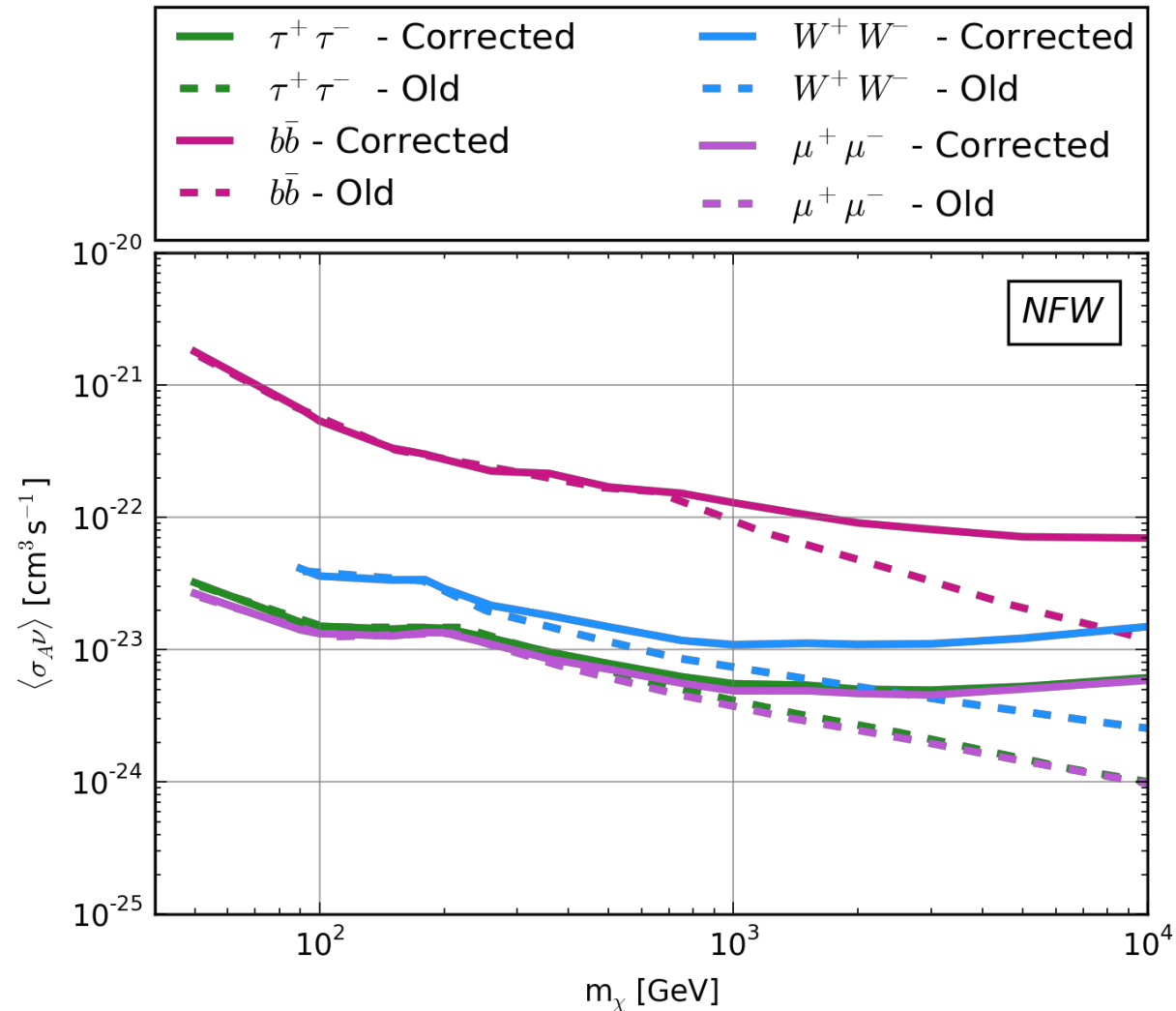- **IceCube:** Spectra produced with Pythia for the IC86 GC Analysis [arXiv:1705.08103]
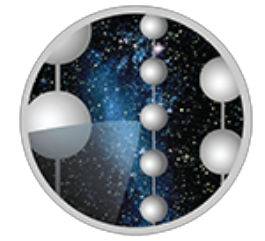
Spectra Investigation

Unification of the spectra

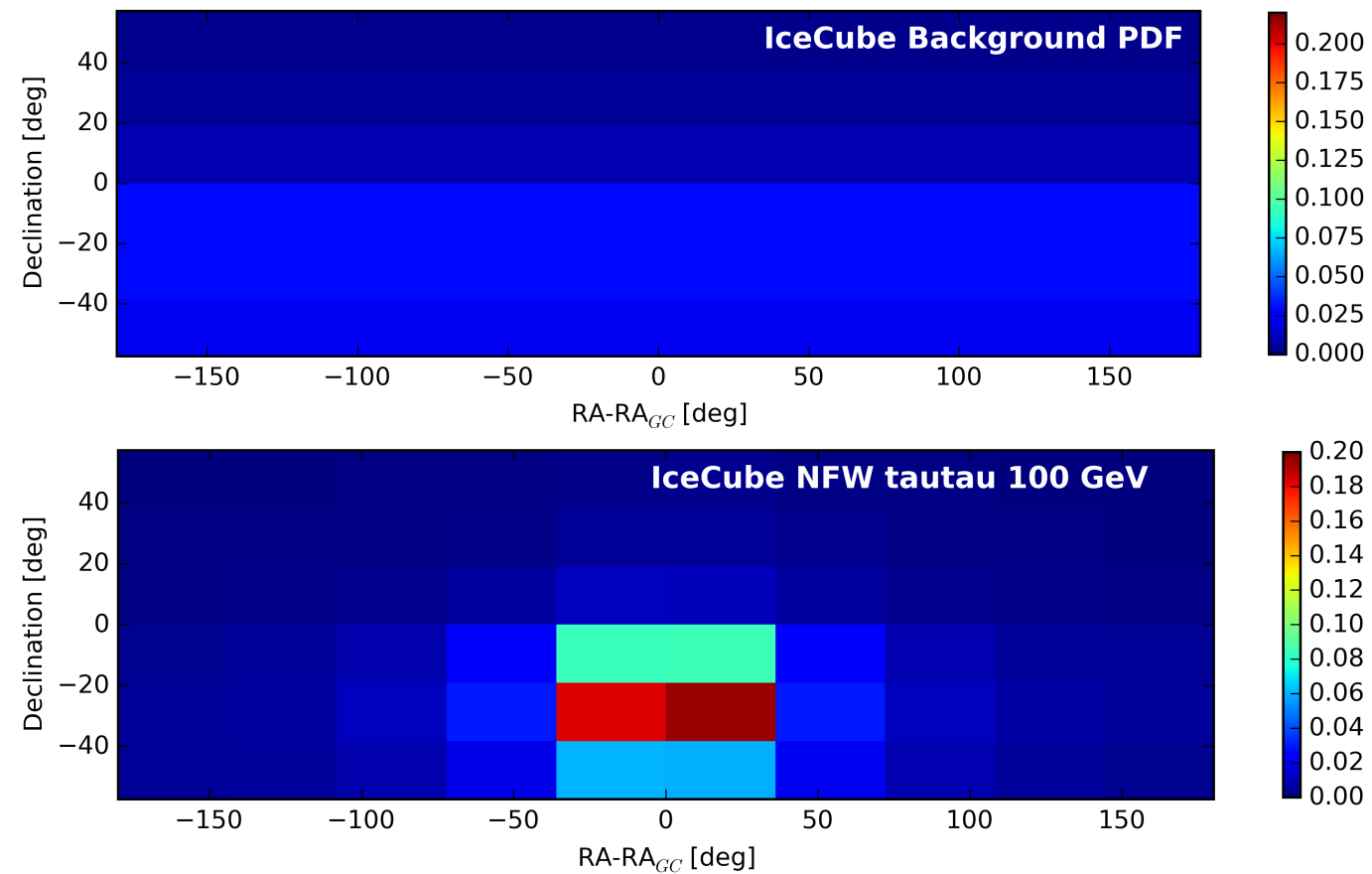→ Use of spectra from JCAP 1103 (2011) 051
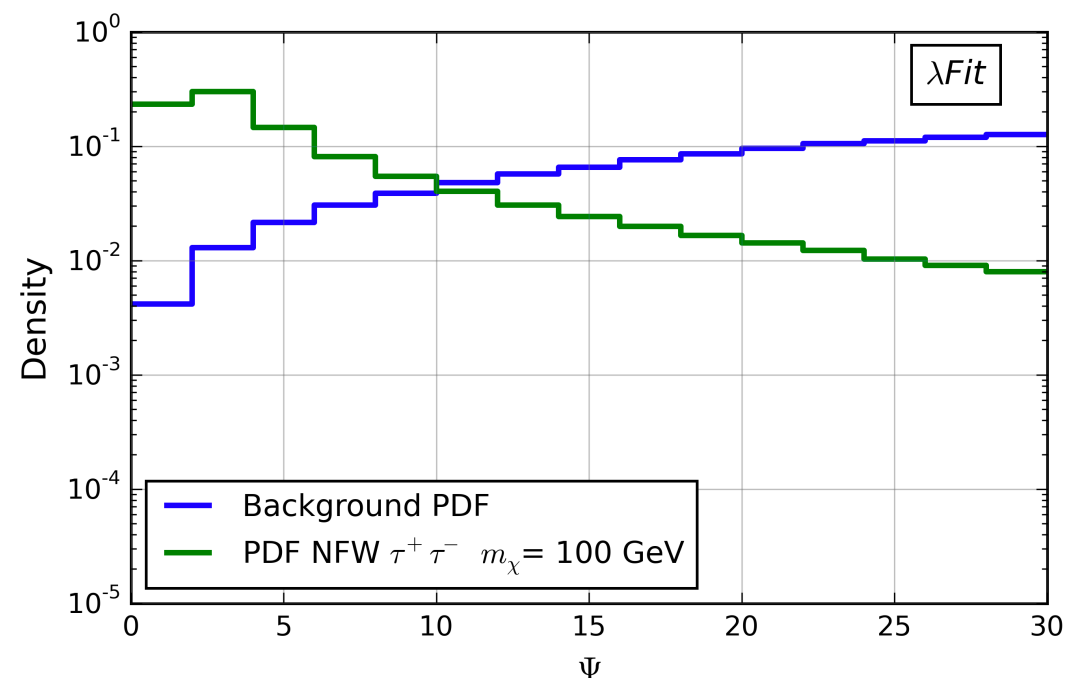
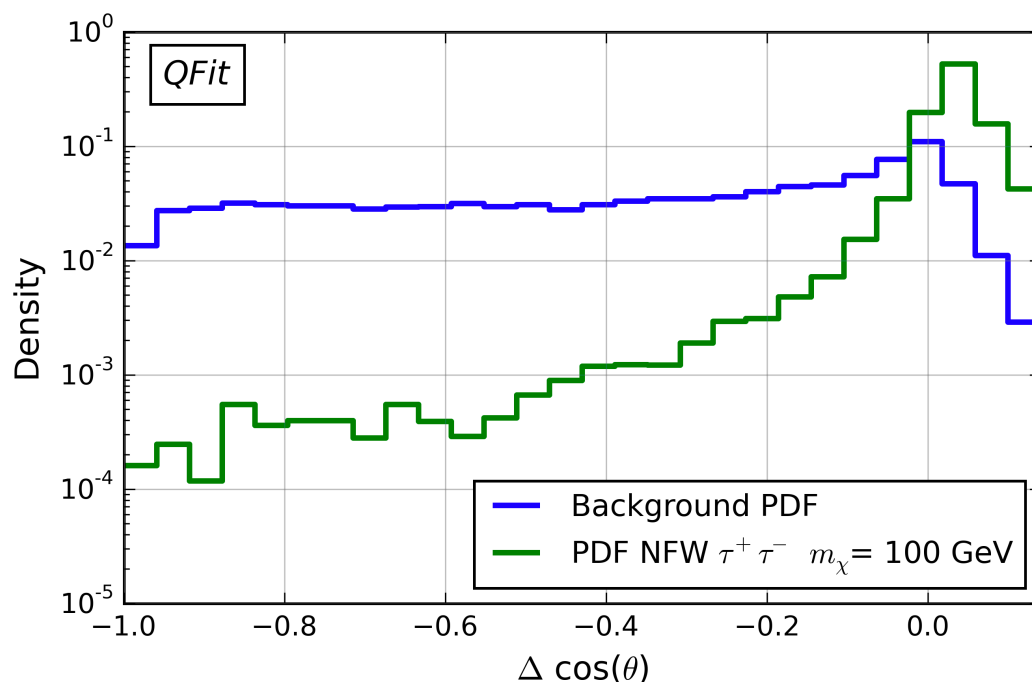# Erratum on ANTARES limits

IceCube PDFs

- **Right ascension:** 10 bins from $-\pi$ to π
- **Declination:** 6 bins from -1 to 1 rad
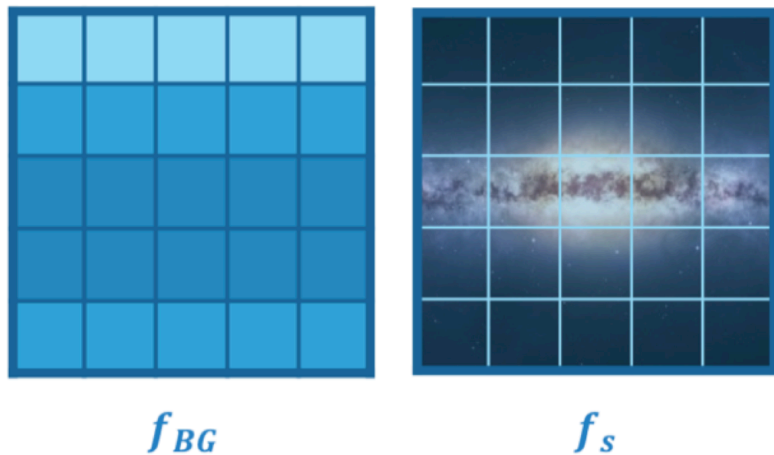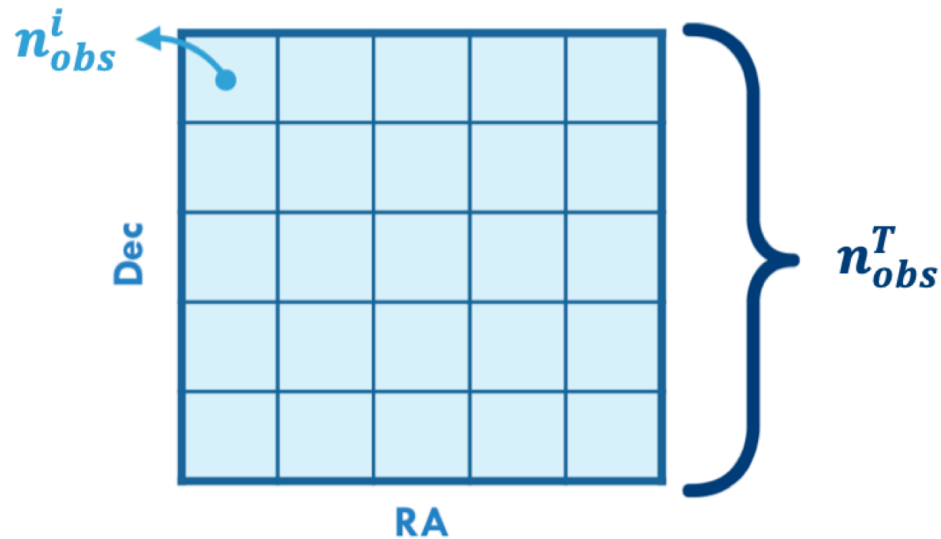
ANTARES PDFs

- **QFit:** 28 bins from $-1 < \Delta\cos(\theta) < 0.14$
  where $\Delta\cos(\theta) = \cos(\theta_{GC}) - \cos(\theta_{event})$ and θ is the zenith

- **λFit:** 15 bins from $0 < \Psi < 30°$
  where Ψ is the opening angle to the GC

Statistical Analysis: Binned Method

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

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

Likelihoods of each experiments combined:

$$\mathcal{L}_{comb}(\mu) = \prod_k^{A,I} \mathcal{L}_k(\mu_k)$$

➤ Obtain $\boldsymbol{\mu}_{\text{best}}$ by maximising the likelihood $\boldsymbol{\mathcal{L}(\mu)}$

➤ Compute $\boldsymbol{\mu_{90\%}}$ using the Feldman-Cousins method

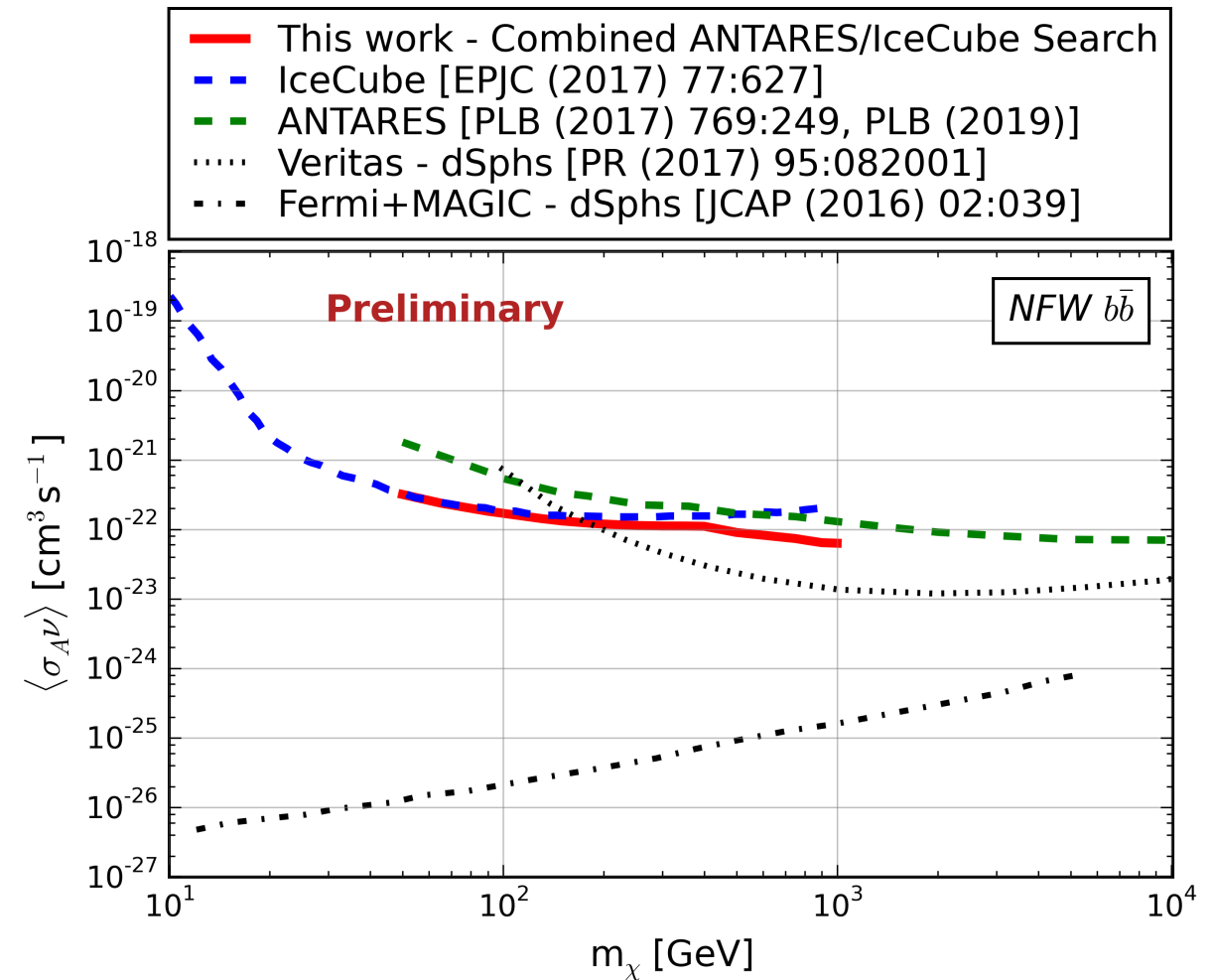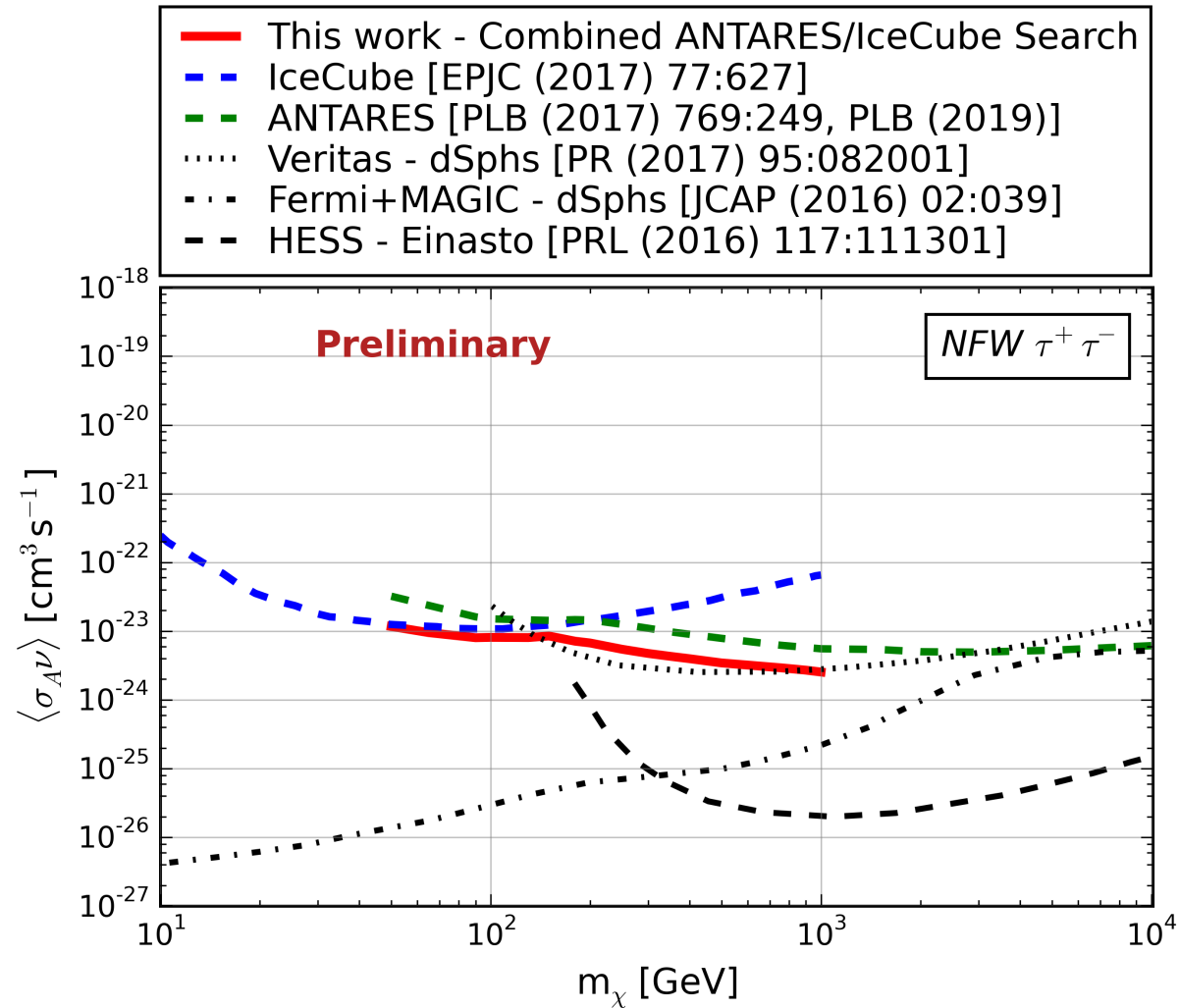➤ Limit on $\langle \boldsymbol{\sigma_A v} \rangle$ deduced from the signal fraction

Results

- No excess of signal neutrino seen in the direction of the Galactic Centre

- Limits on the thermally-averaged self-annihilation cross section $\langle \sigma_A v \rangle$
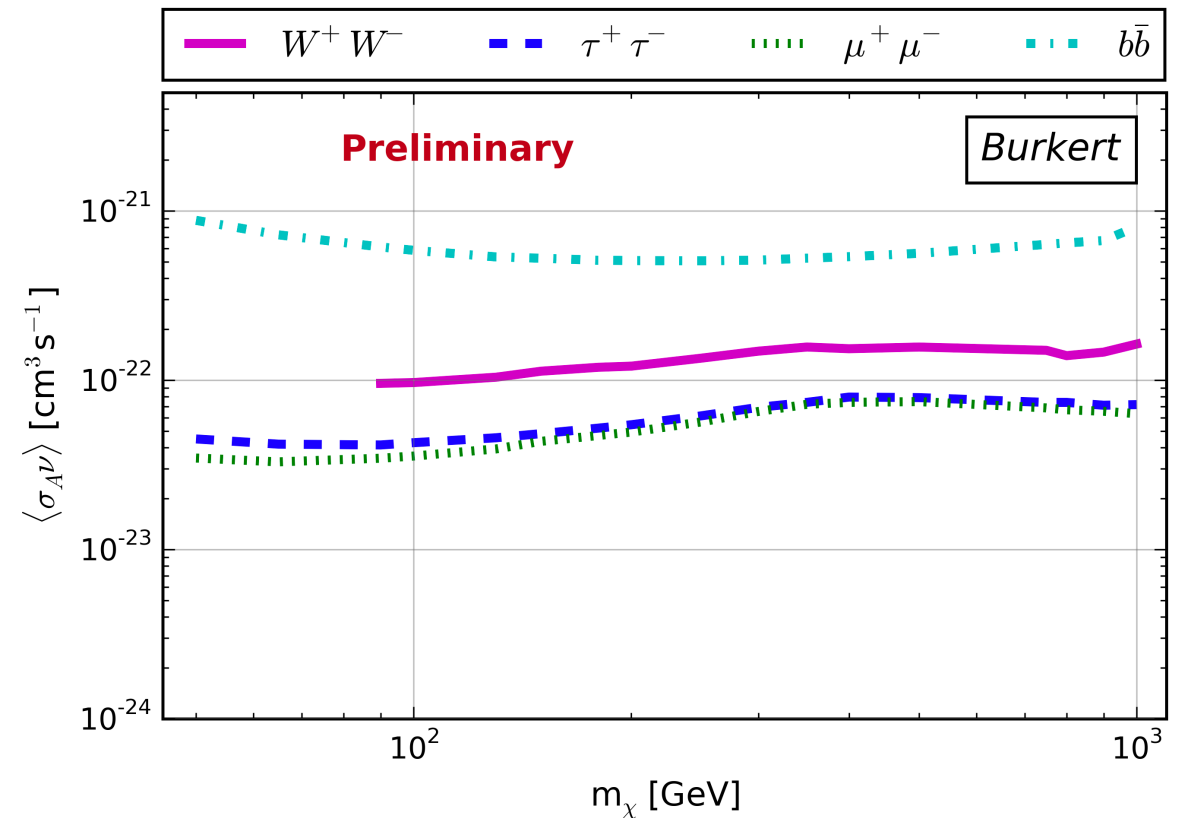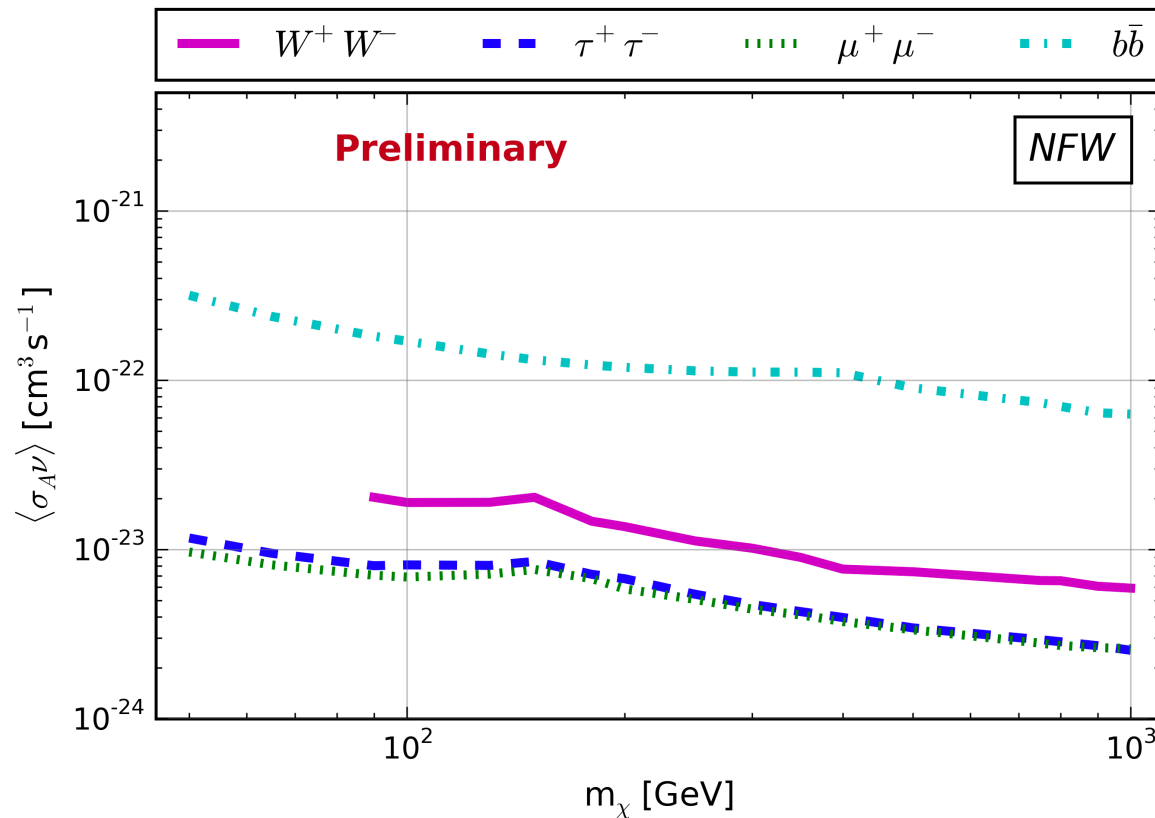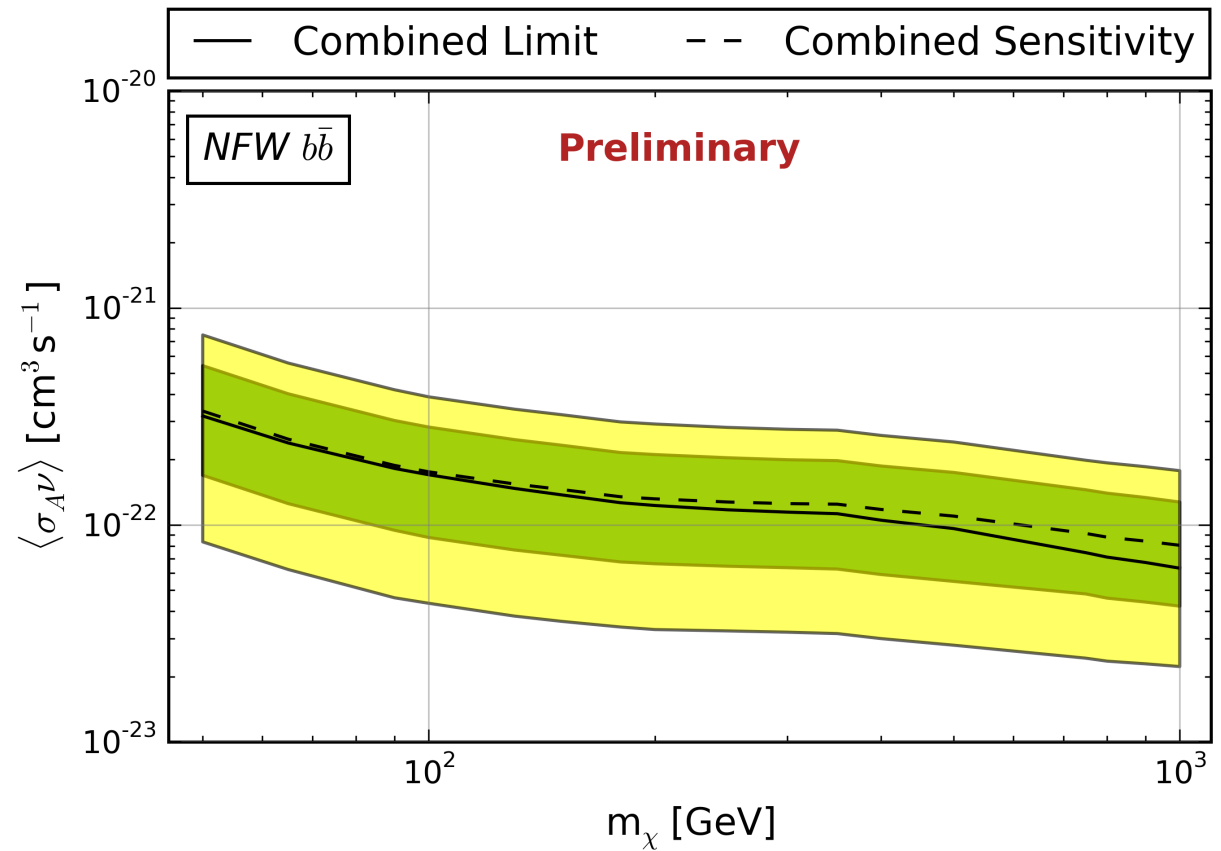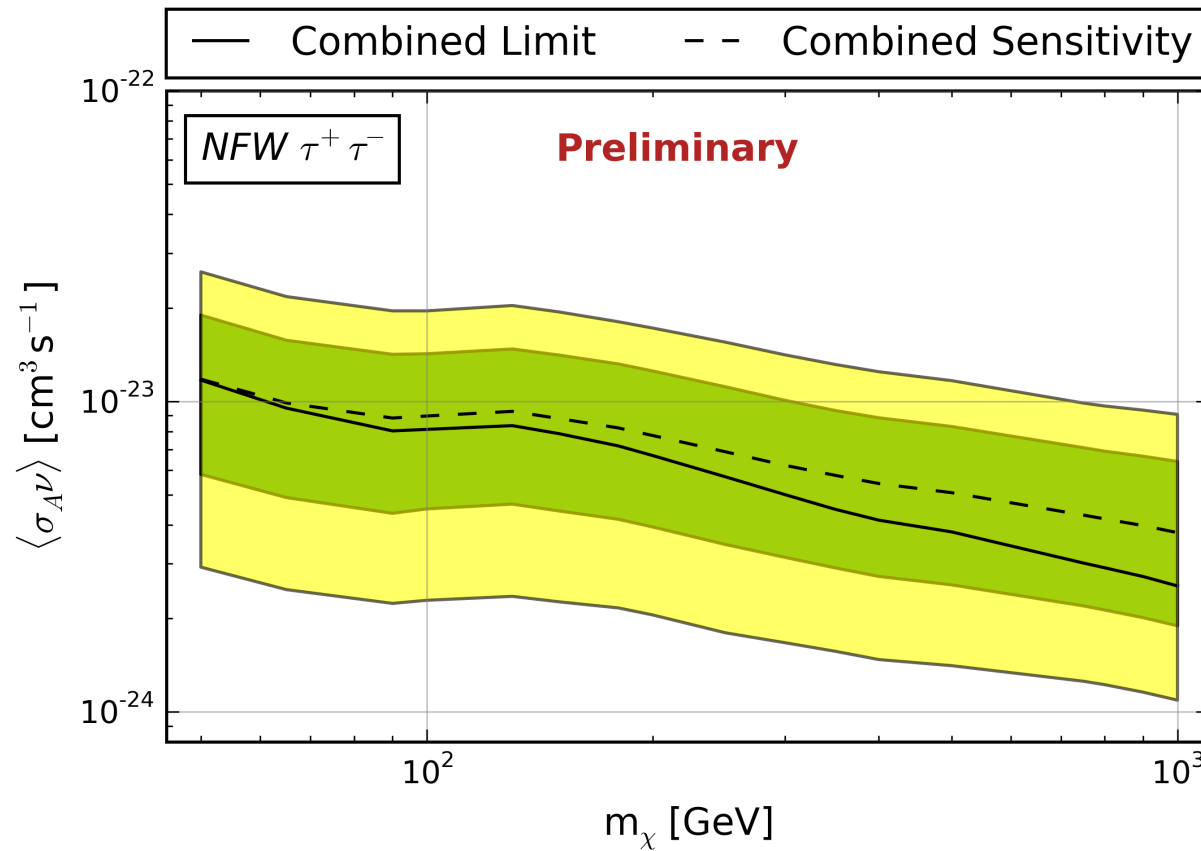
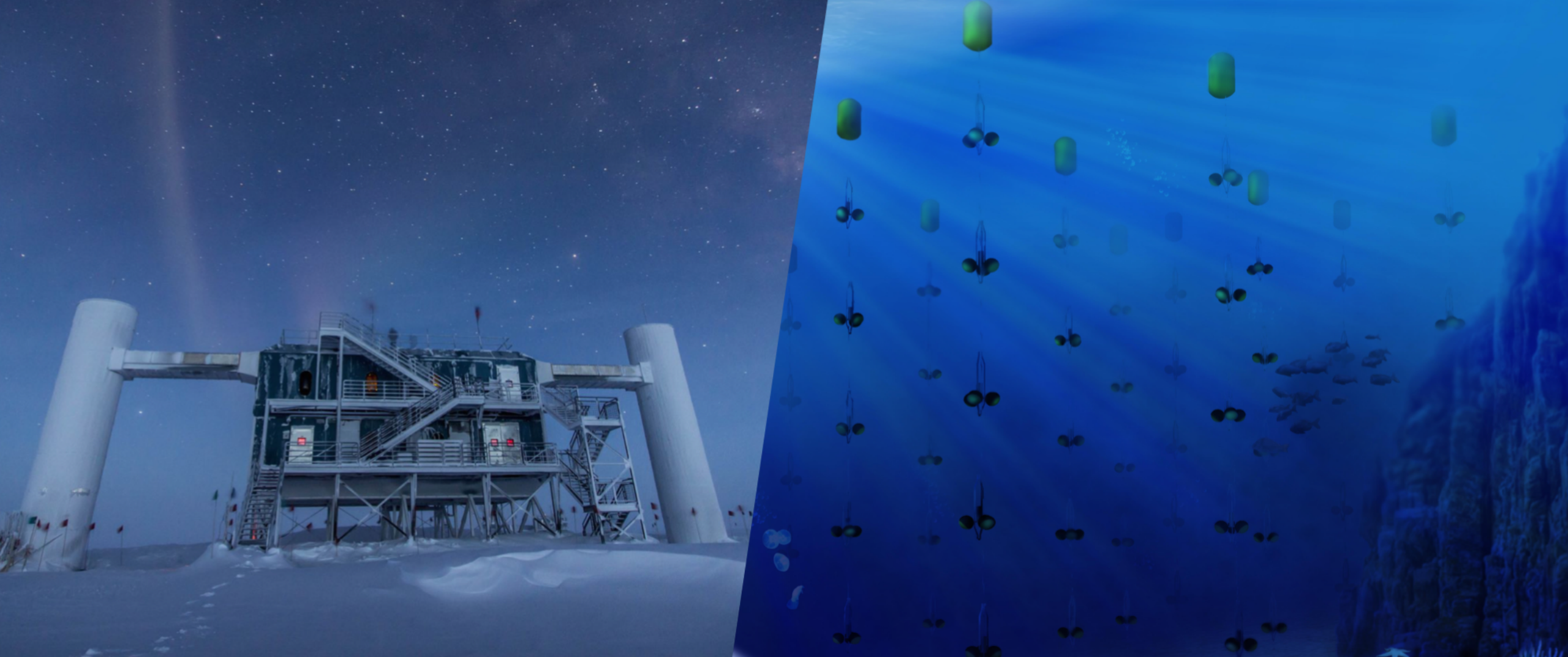# Limits Comparison

Limits for NFW

Conclusion

- Unification of ANTARES and IceCube analysis

    → Likelihood method

    → WIMP masses, DM halo density profiles and spectra

- Combined limits show improvement compared to the individual limits
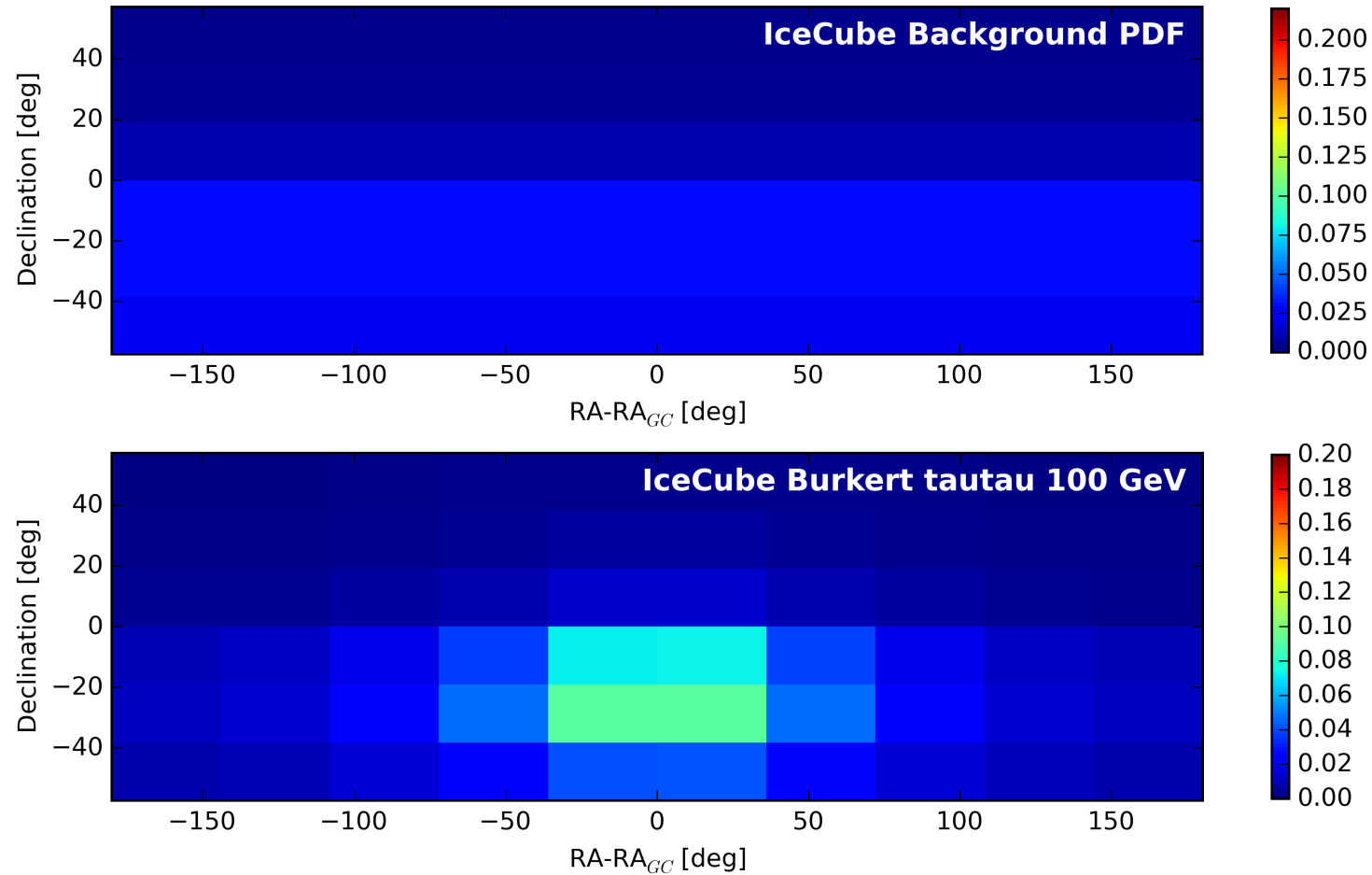
- Paper in progress

Outlooks:

- Extend analysis to more years of data

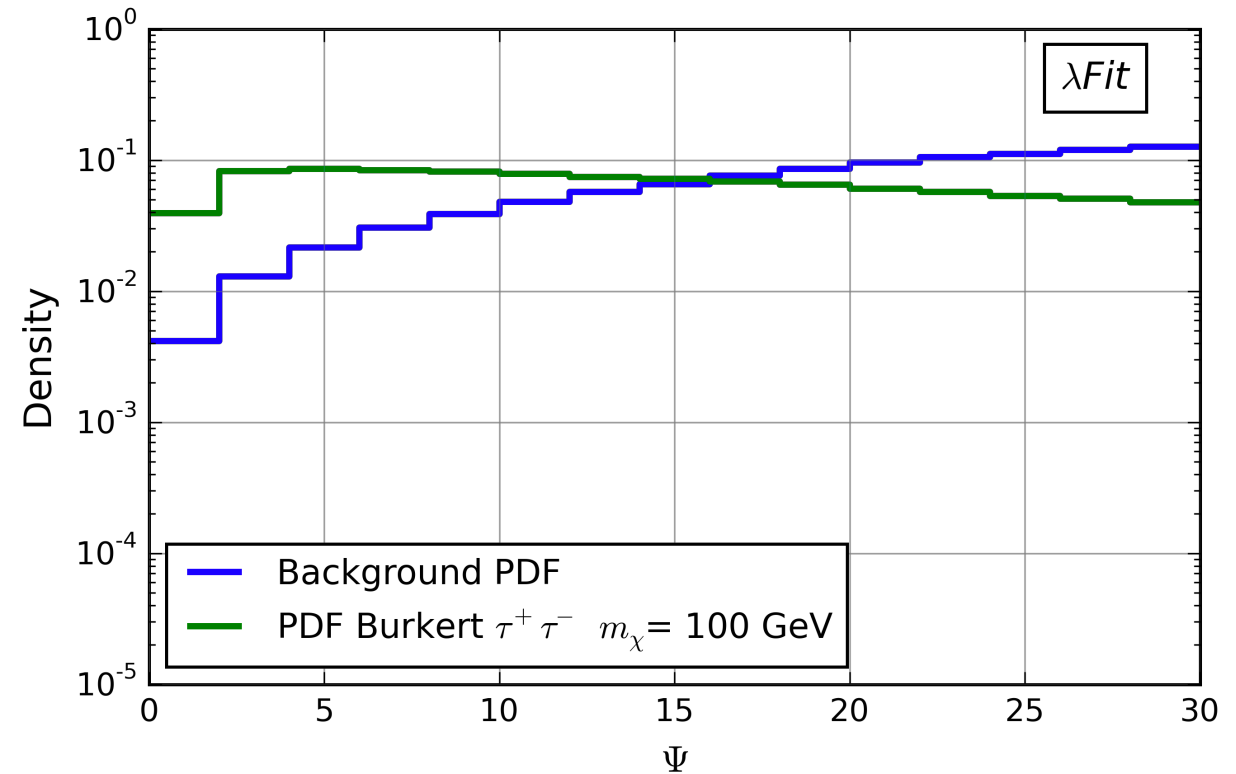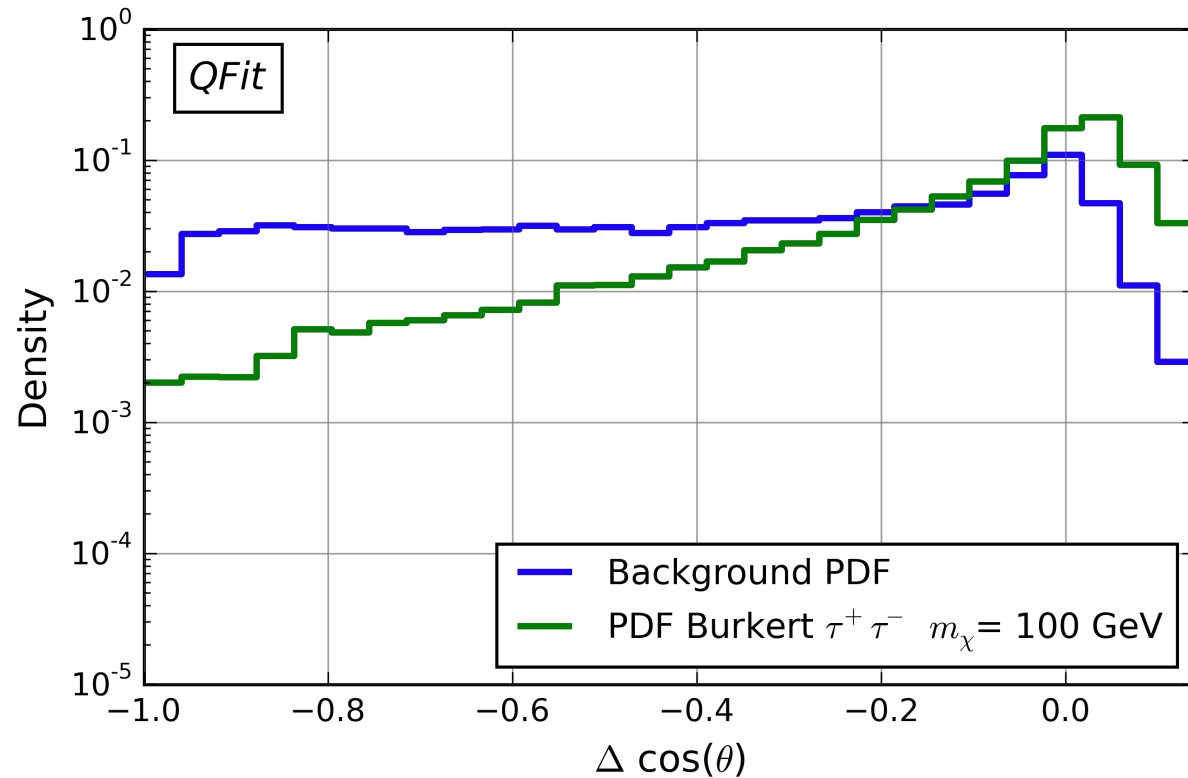- Use new events selections

Backup Slides

PDFs Burkert profile

PDFs Burkert profile

Combined Likelihood

Once computed for both ANTARES and IceCube, likelihoods are combined:

$$\mathcal{L}_{comb}(\mu) = \prod_{k}^{A,I} \mathcal{L}_k(\mu_k)$$

where we are **minimising** the combined signal fraction $\boldsymbol{\mu}$ which can be written as:

$$\mu = \frac{n_{sig}}{n_{tot}} = \frac{n_{sig}^A + n_{sig}^I}{n_{tot}^A + n_{tot}^I} = \frac{n_{sig}(s_A + s_I)}{n_{tot}(b_A + b_I)}$$

Relative signal efficiency

Relative background efficiency

$$\mu_k = \frac{n_{sig}^k}{n_{tot}^k} = \frac{s_k \, n_{sig}}{b_k \, n_{tot}} = w_k \, \mu$$
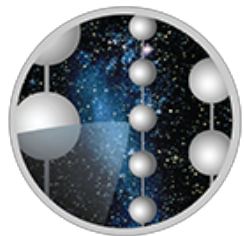
Weighting of Signal Simulation

Integrated Weight:

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

Sum of Each Event Weight:

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