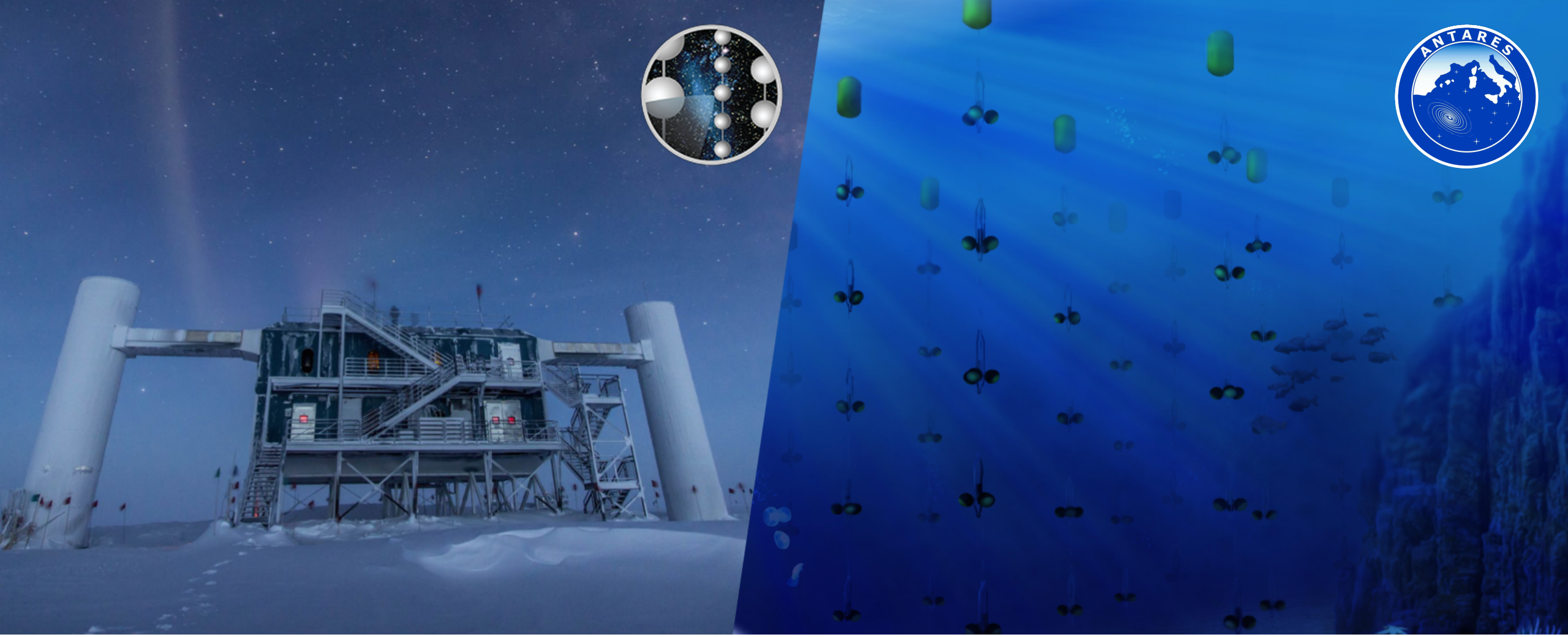


Combined Search for Neutrinos from Dark Matter Annihilation in the Galactic Centre using ANTARES and IceCube

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

Motivations

Physical Goals:

- Improve the detection potential in the region where the two telescopes are comparable

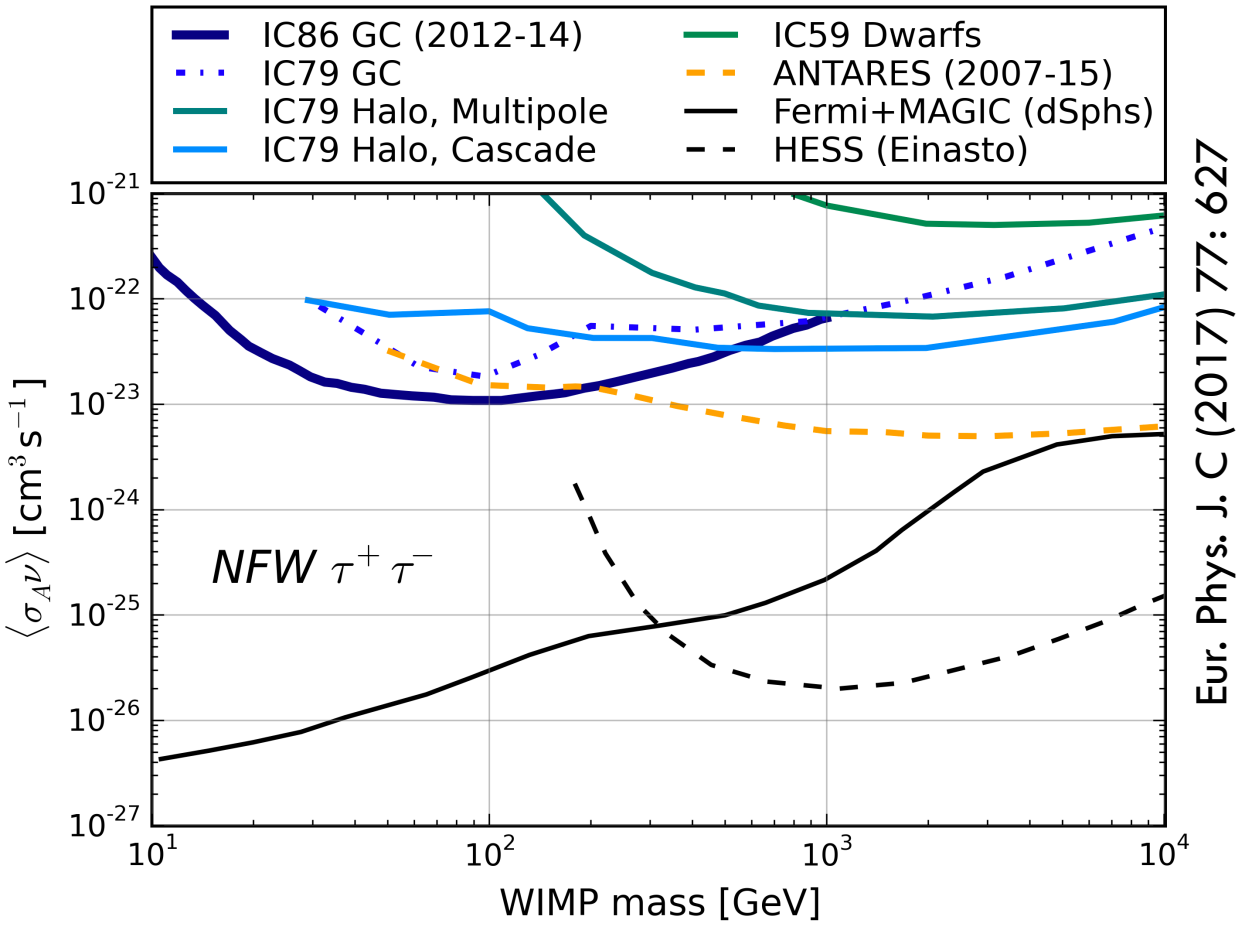
  → Between 50 and 1000 GeV

Further Goal:

- Unify the analyses done by both detectors

  → Model parameters

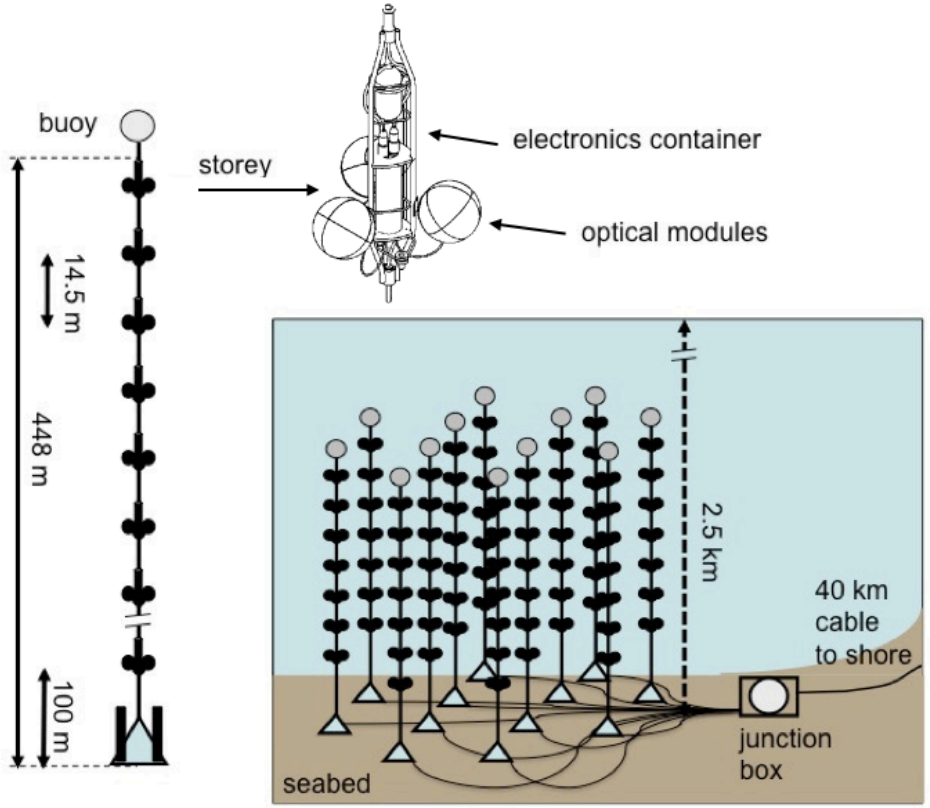
  → Analysis method



Detectors

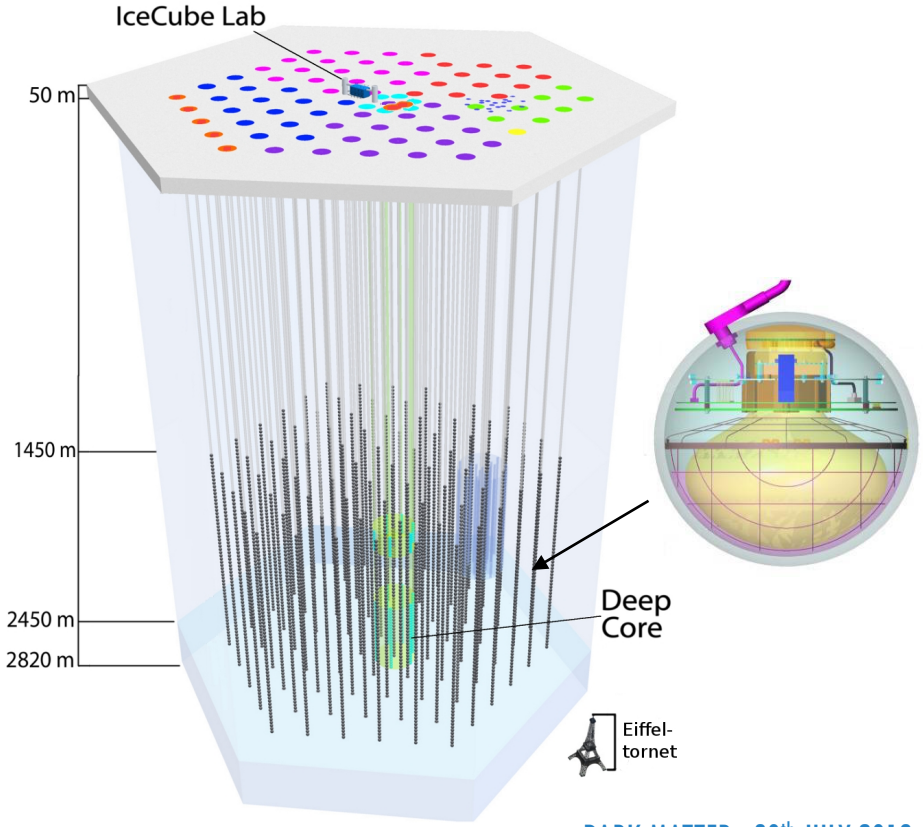
ANTARES

→ 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

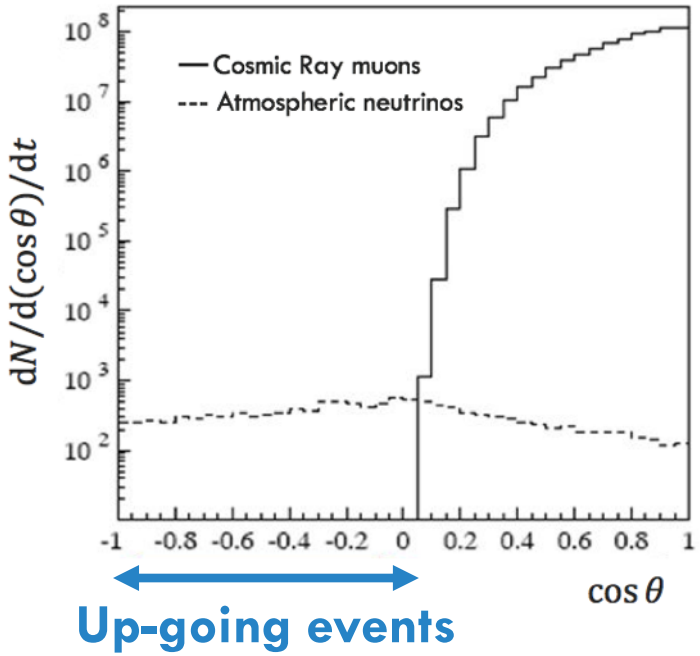


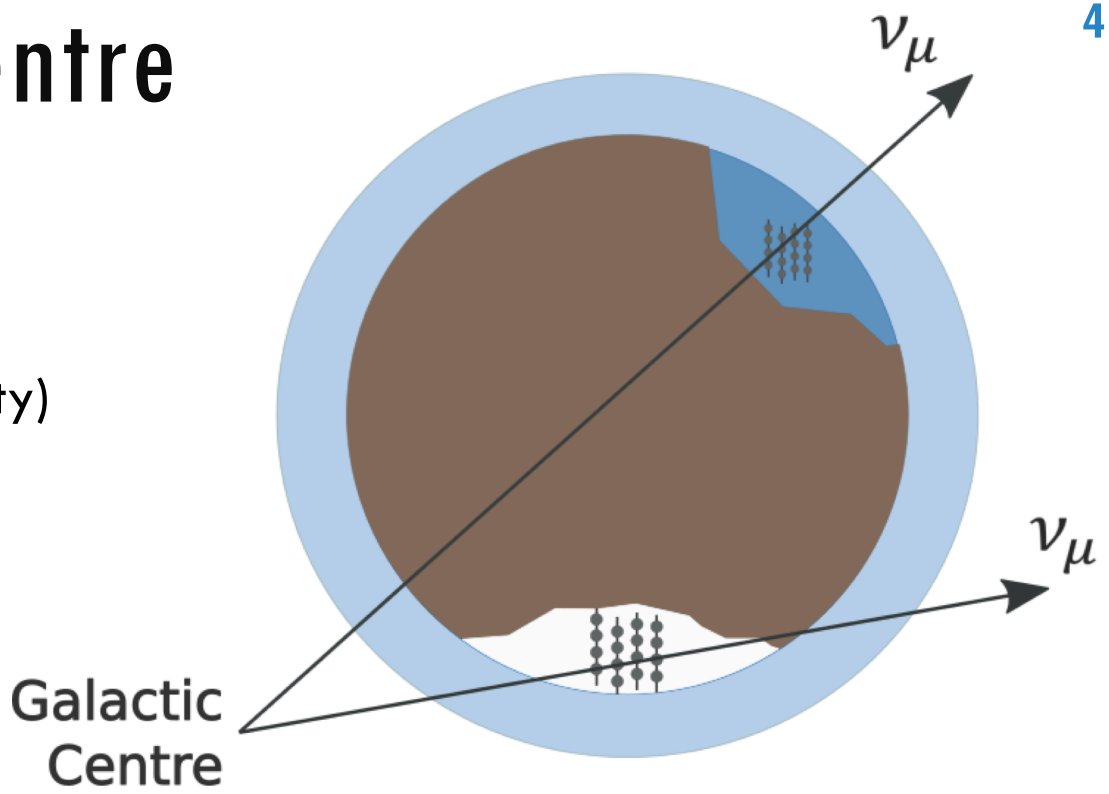
Coverage of the Galactic Centre

Galactic Centre located at dec ~−29.01°

→ Neutrinos coming from the GC are seen as

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





Background of both experiments:

Dominated by atmospheric muons and neutrinos

For **up-going** events:

The Earth acts as a shield against atmospheric muons

Indirect Search in the Galactic Centre

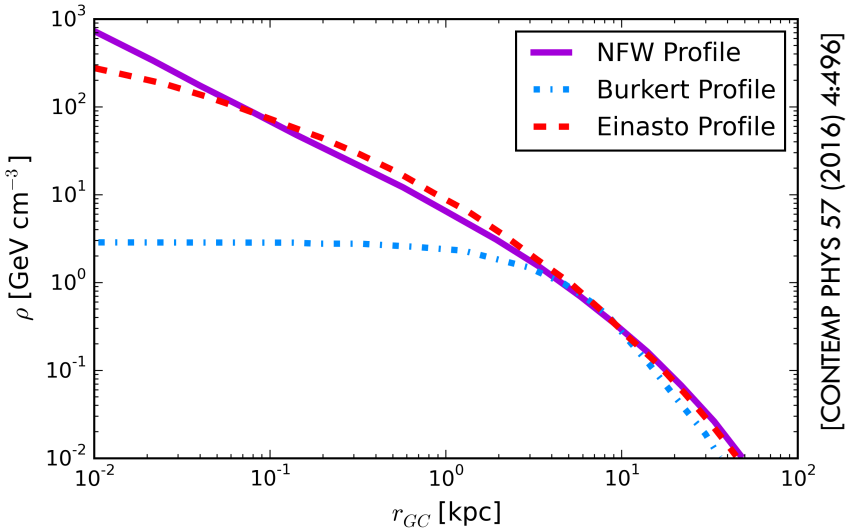
$$\frac{\mathrm{d}\phi_\nu}{dE_\nu} = \frac{1}{2}\frac{\langle\sigma_A\nu\rangle}{4\pi\, m_\chi^2}\frac{dN_\nu}{dE_\nu}\int_0^{\Delta\Omega} d\Omega \int_{l.o.s}\rho_\chi^2(r(s,\Psi,\theta))ds$$

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



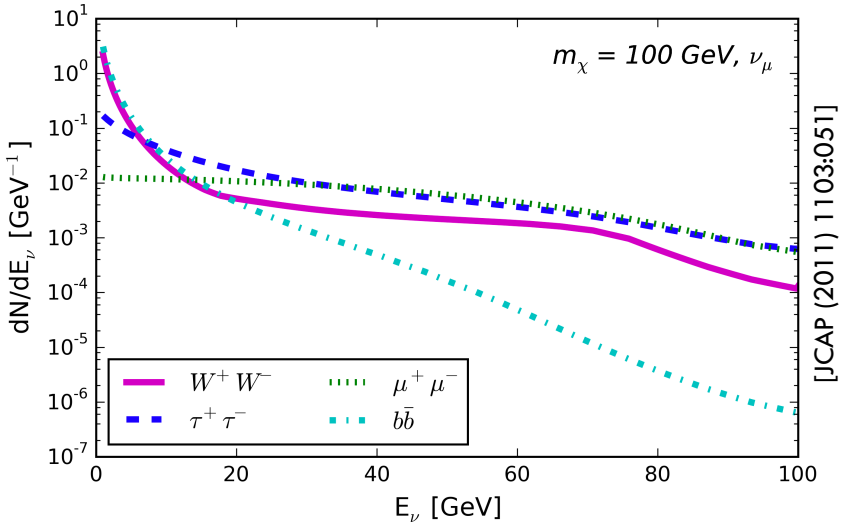
Indirect Search in the Galactic Centre

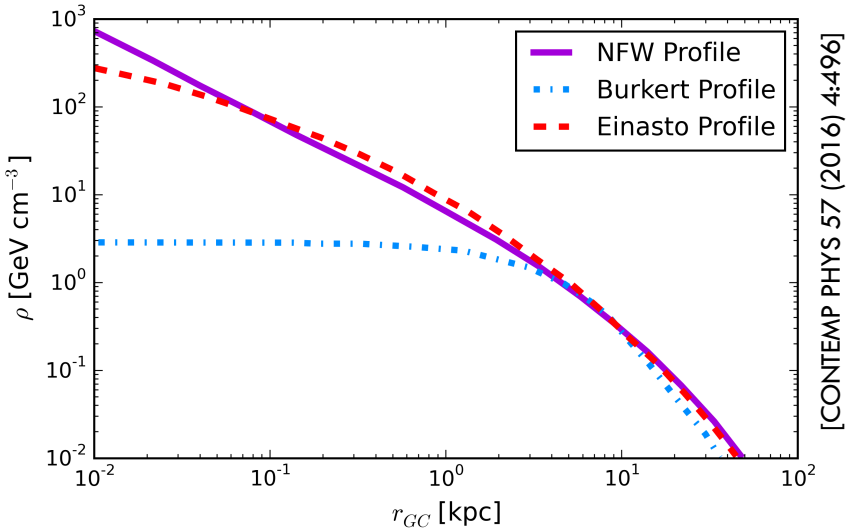
$$\frac{\mathrm{d}\phi_\nu}{dE_\nu} = \frac{1}{2}\frac{\langle\sigma_A v\rangle}{4\pi m_\chi^2}\frac{dN_\nu}{dE_\nu}\int_0^{\Delta\Omega} d\Omega \int_{l.o.s} \rho_\chi^2(r(s,\Psi,\theta))ds$$

Theory input

Astrophysics input

J-factor





Indirect Search in the Galactic Centre

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

Measurement

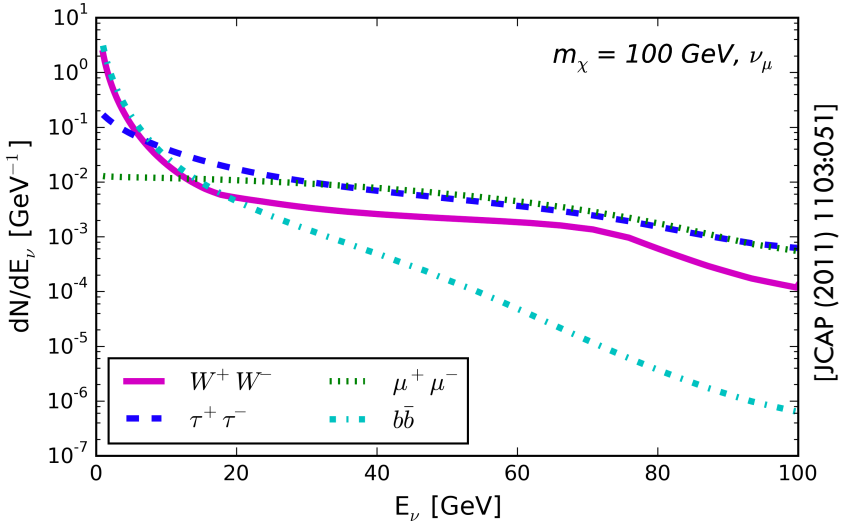
Theory input

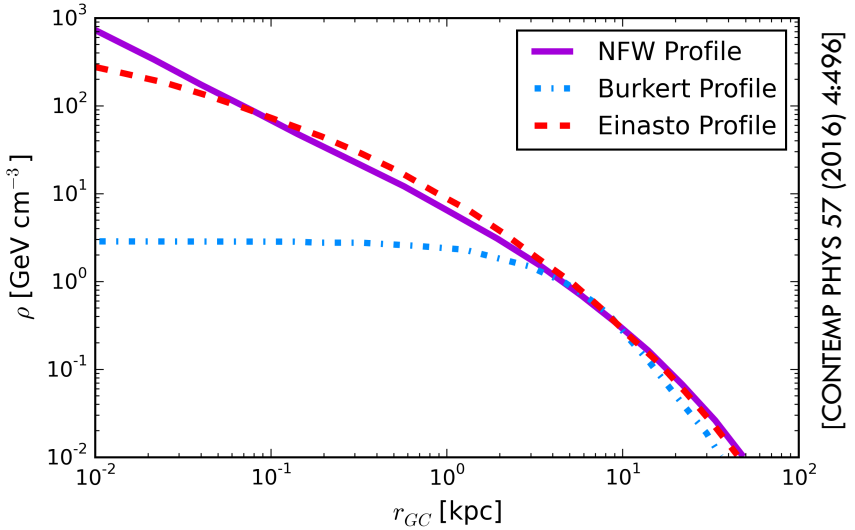
Astrophysics input

J-factor

Dec

RA





Indirect Search in the Galactic Centre

Constrain

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

Measurement

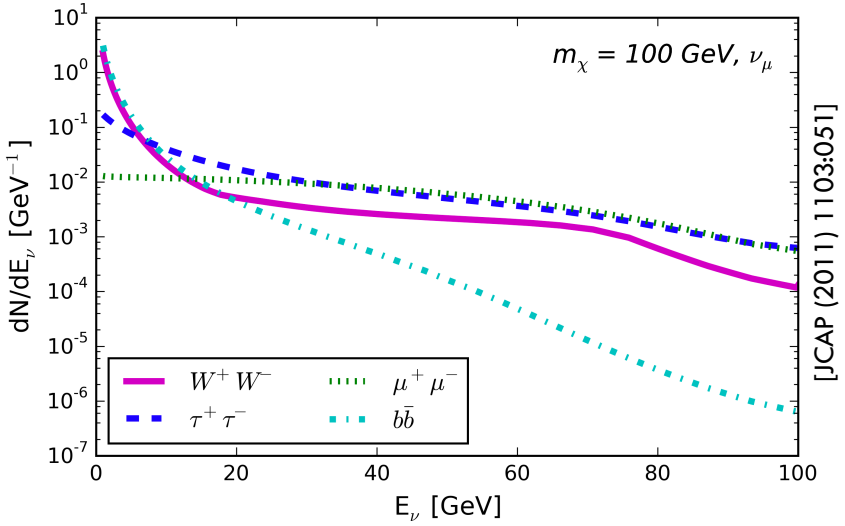
Theory input

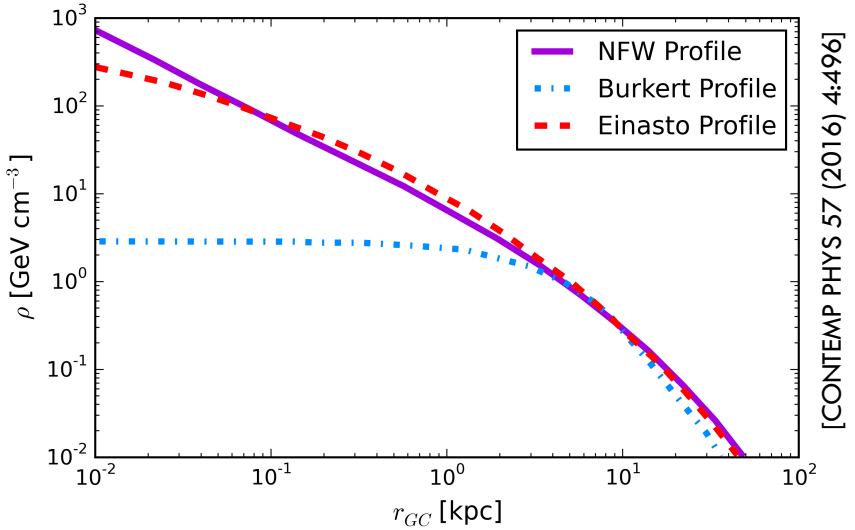
Astrophysics input

J-factor

Dec

RA



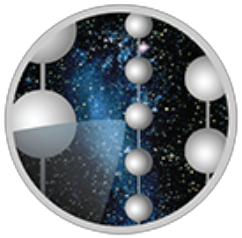


Weighting of Signal Simulation

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:



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

Weighting of Signal Simulation

Integrated Weight:

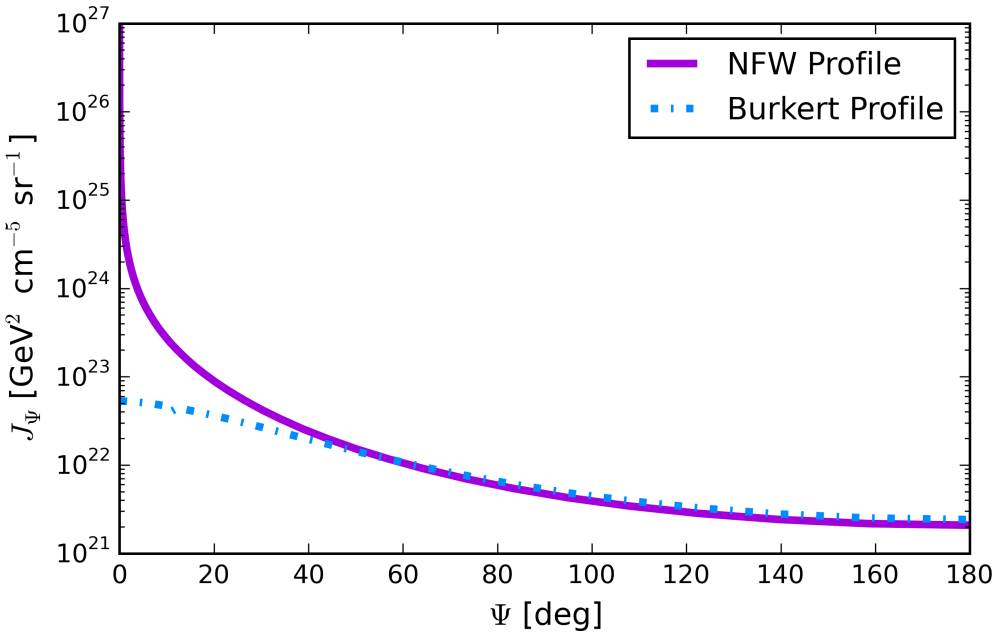
J-factor
Computed using CLUMPY

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

Sum of Each Event Weight:

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

Model Parameters from:
JCAP 1307 (2013) 016



Weighting of Signal Simulation

Integrated Weight:

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

J-factor
Computed using CLUMPY

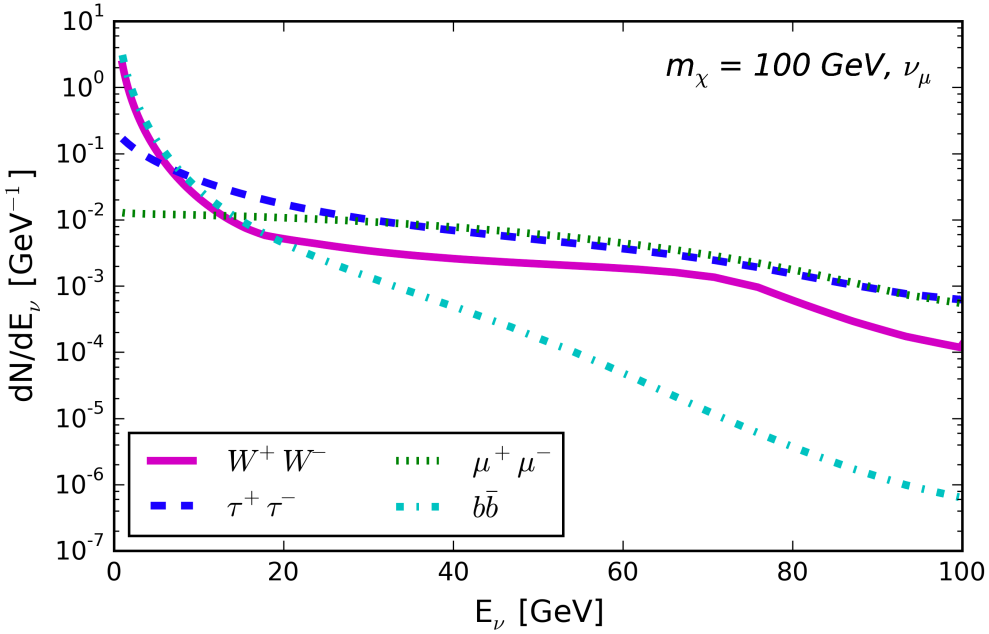
Spectra from:
JCAP 1103 (2011) 051

PPPC4 spectra

Sum of Each Event Weight:

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

Model Parameters from:
JCAP 1307 (2013) 016



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:

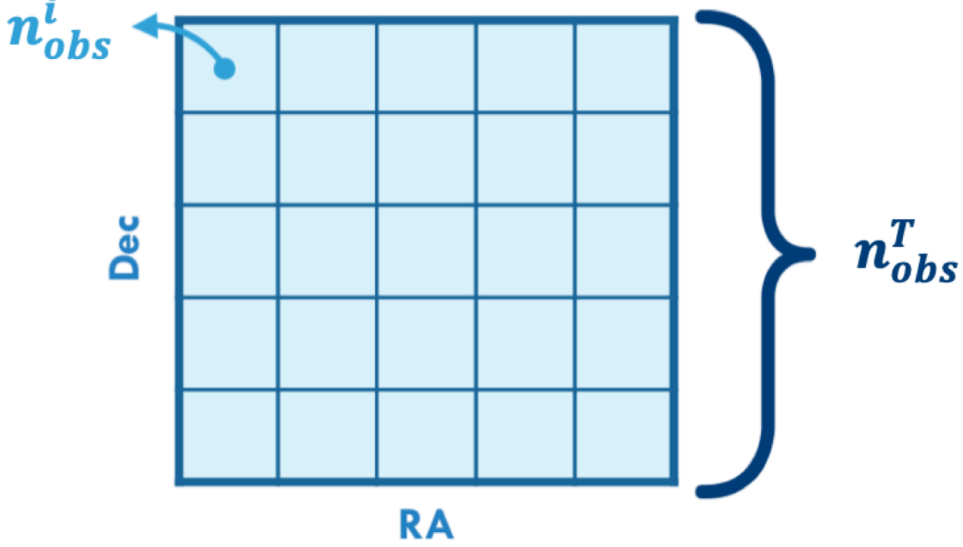
- Single-Line reconstruction (QFit)
  → Reconstruct only zenith
- Multi-Line reconstruction (λFit)

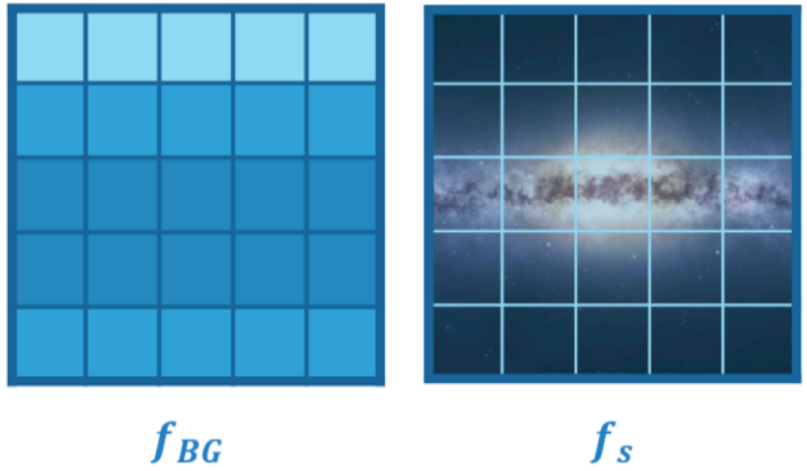
Lifetime: 1006 days from May 2012 to May 2015

Data from ***IceCube 3 years DM Milky Way Search*** [Eur. Phys. J. C (2017) 77: 627]

Taken with the IC86 configuration

Statistical Analysis: Binned Method





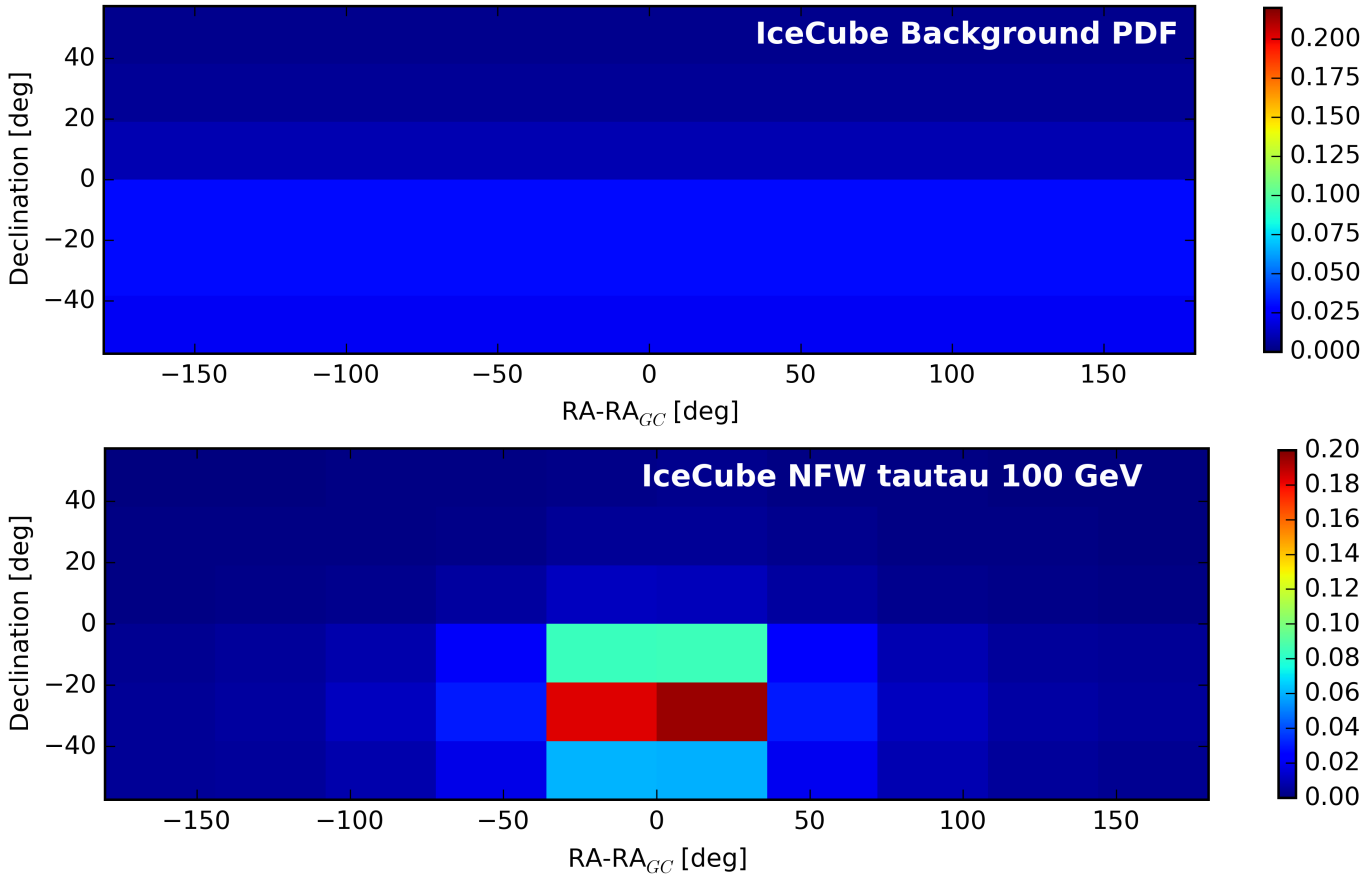
$$\mathcal{L}(\mu) = \prod_i^{N_{bins}} \text{Poisson}\left(n^i_{obs}\,; n^T_{obs}\, f(i\,;\mu)\right)$$

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

- Obtain best estimate on the signal fraction $\boldsymbol{\mu}$ by maximising the likelihood $\boldsymbol{\mathcal{L}(\mu)}$
- Upper limit on the signal fraction $\boldsymbol{\mu_{90\%}}$ using the Feldman-Cousins method
- Limit on $\boldsymbol{\langle \sigma_A v \rangle}$ deduced from the signal fraction using the number of expected signal events

IceCube PDFs

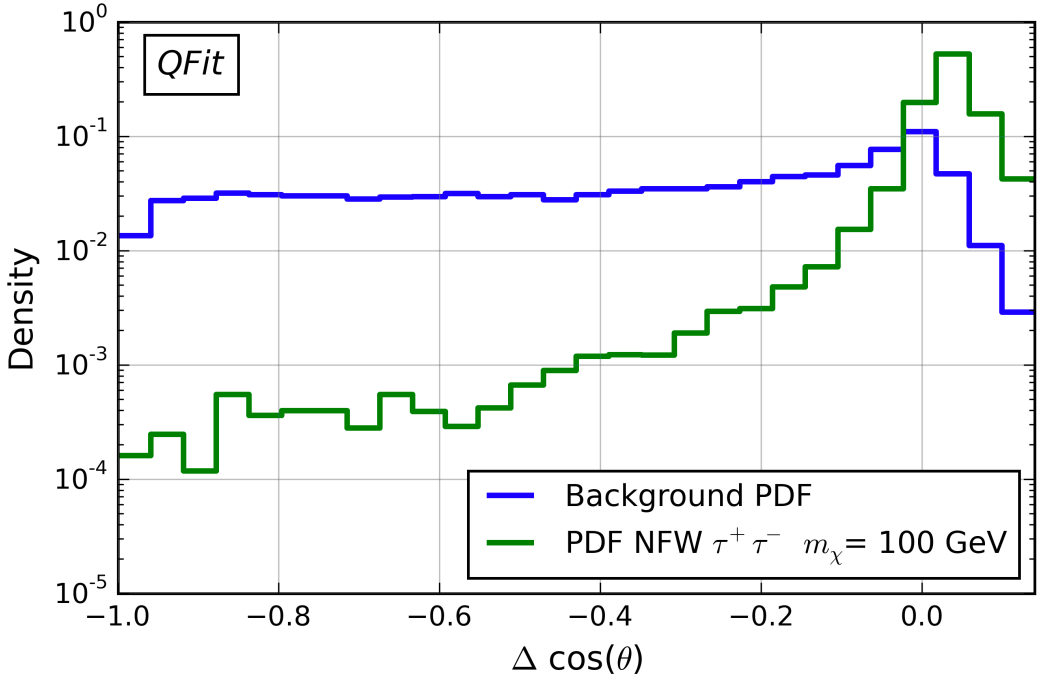
- **Right ascension:** 10 bins from $-\pi$ to π
- **Declination:** 6 bins from -1 to 1 rad

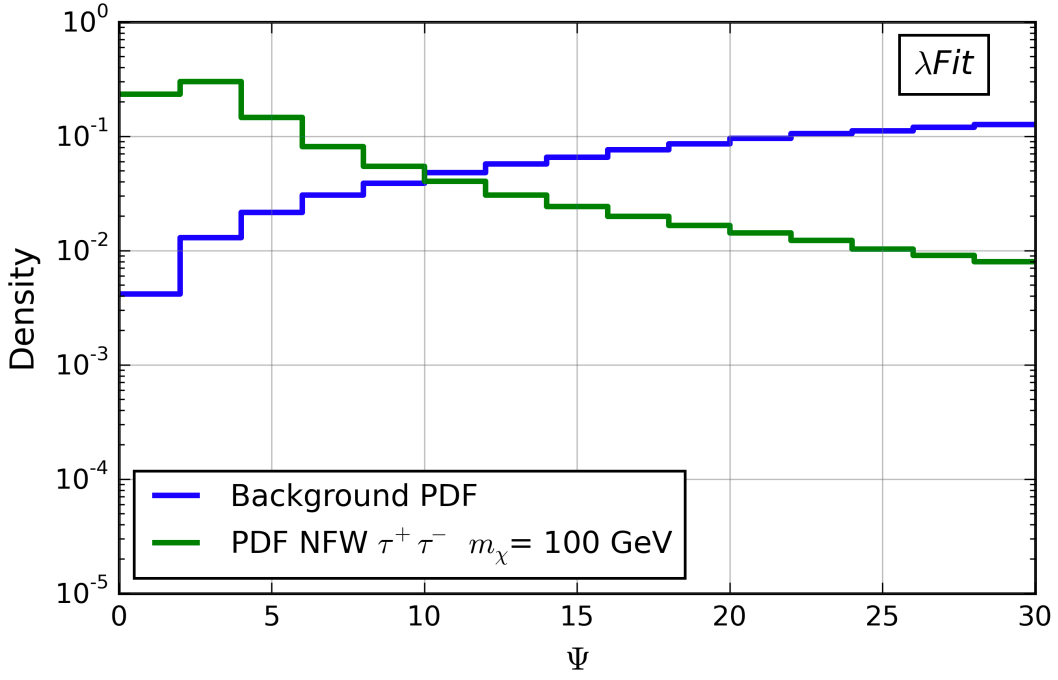


ANTARES PDFs

- **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





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 μ which can be written as:

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

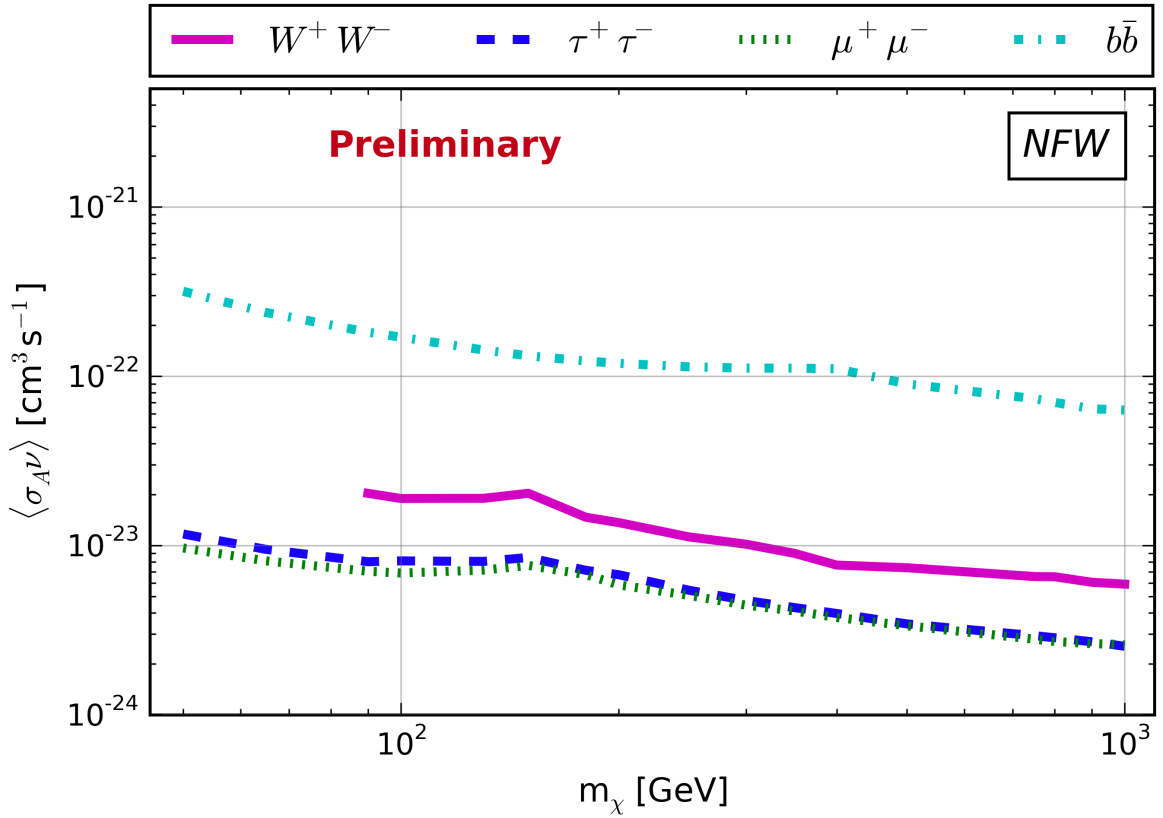
Relative signal efficiency

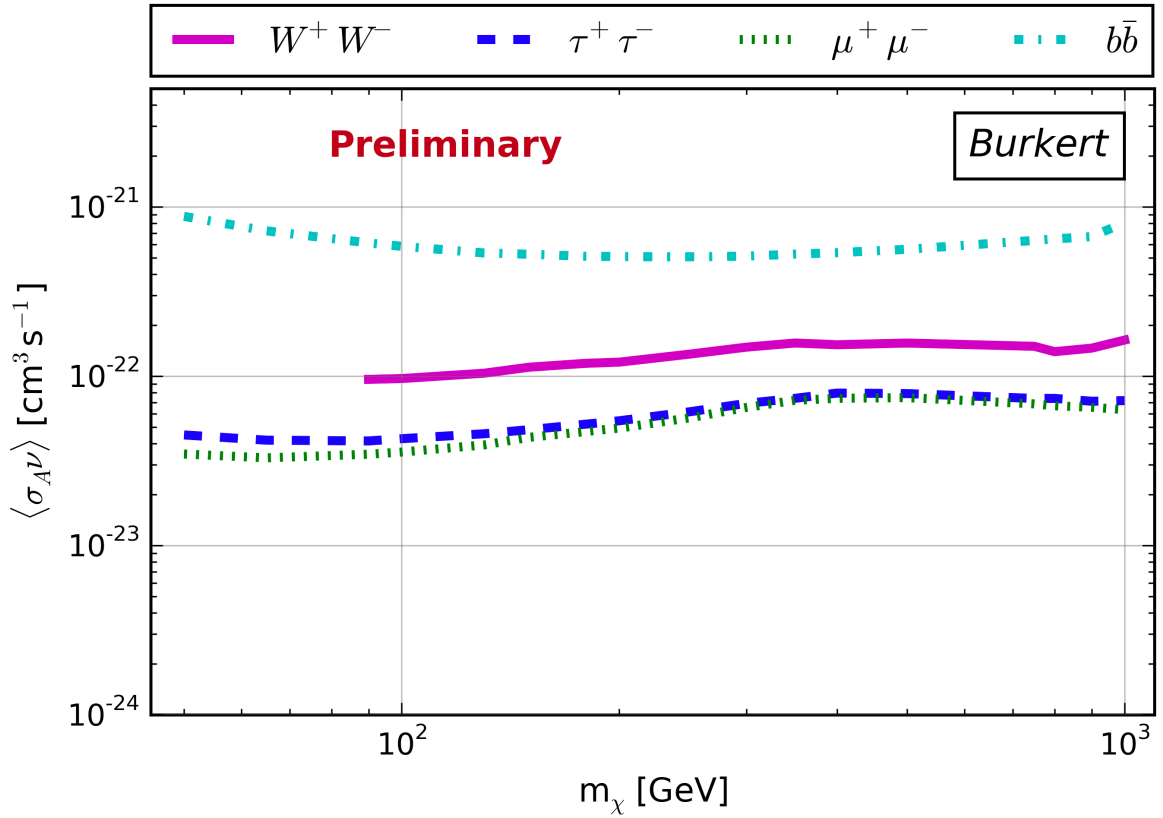
Relative background efficiency

$$\mu_k = \frac{n_{sig}^{k}}{n_{tot}^{k}} = \frac{s_k \; n_{sig}}{b_k \;\; n_{tot}} = w_k \; \mu$$

Results

- No excess of signal neutrino seen in the direction of the Galactic Centre
- Limits on the thermally-averaged self-annihilation cross section $\langle \sigma_A v \rangle$



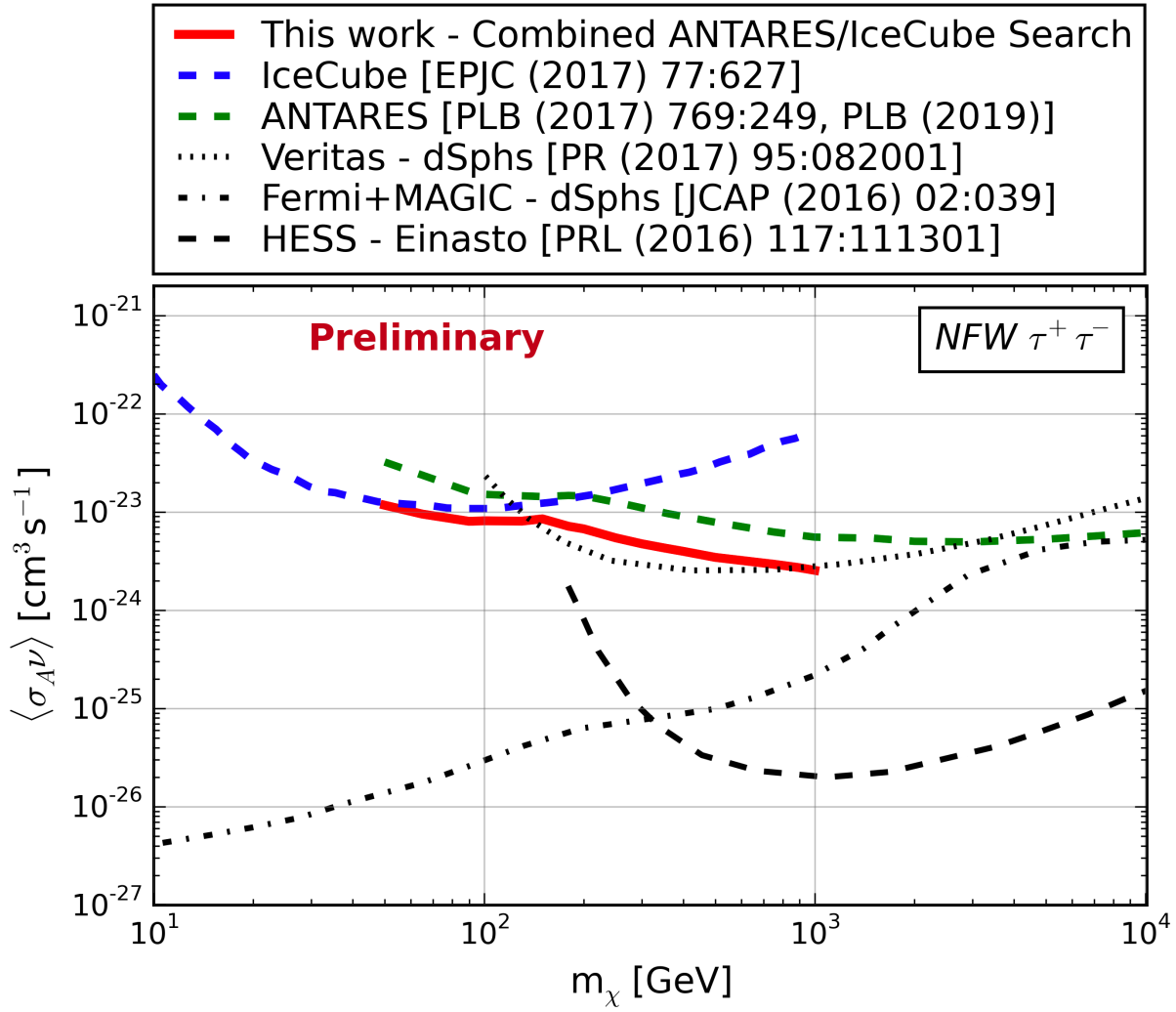


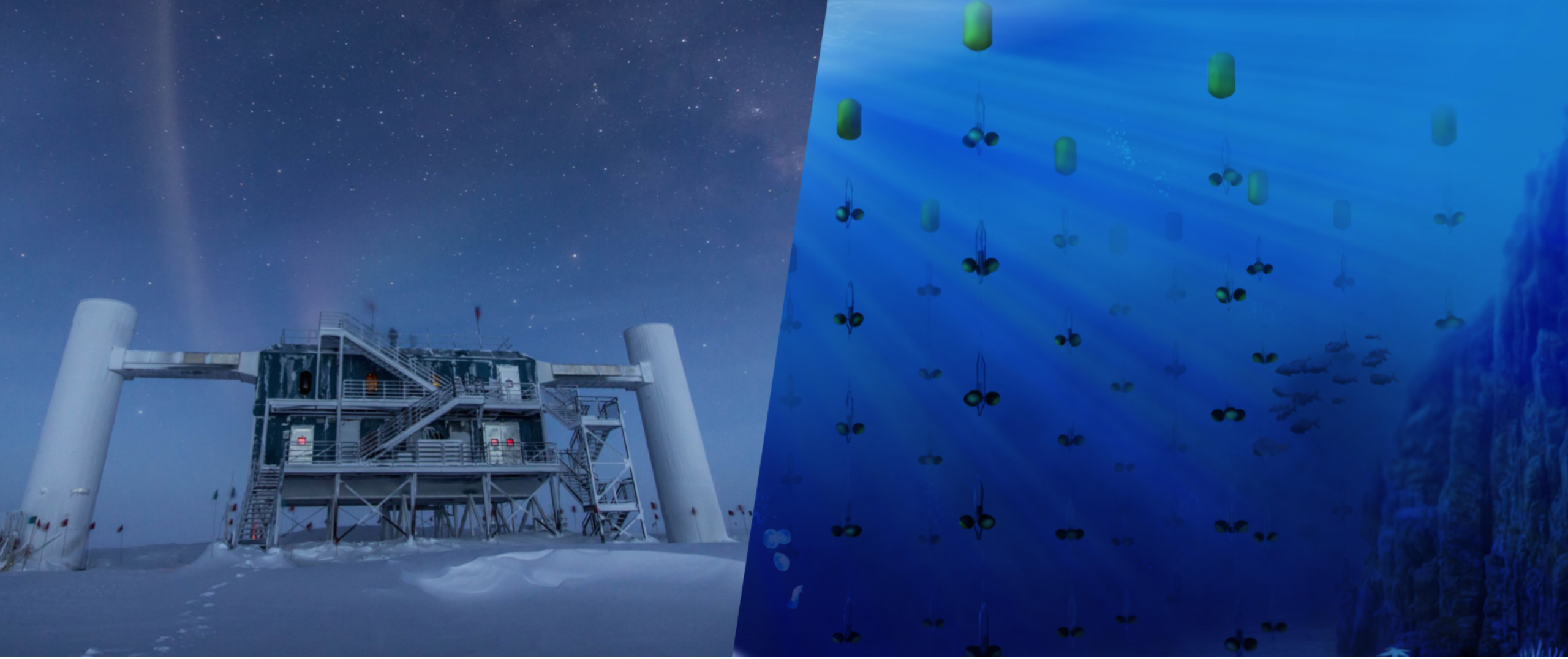
Conclusion

- Unification of ANTARES and IceCube analysis
  - → Likelihood method
  - → Model parameters
- Improvement of the sensitivities for the WIMP mass range considered

Outlooks:

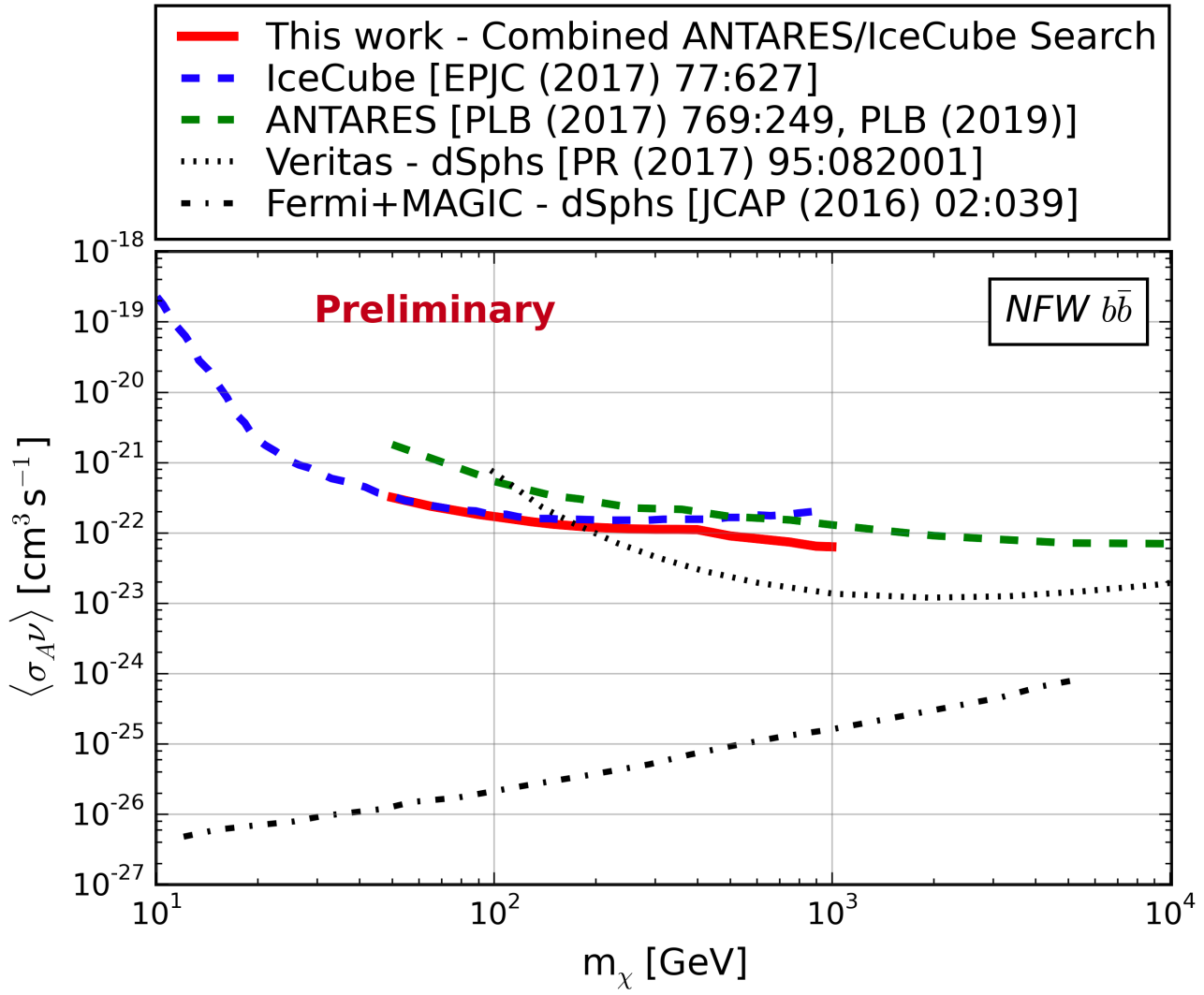
- Extend analysis to more years of data
- Use new events selections
- Use an unbinned likelihood method



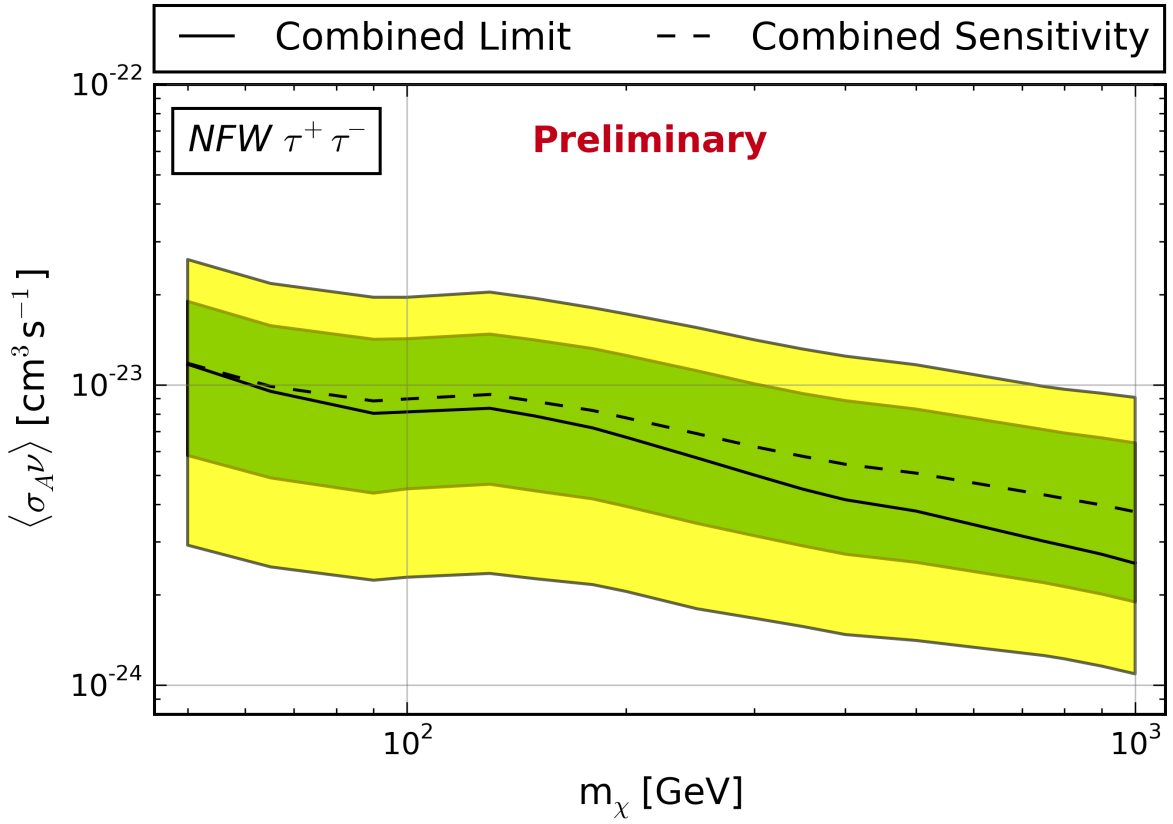


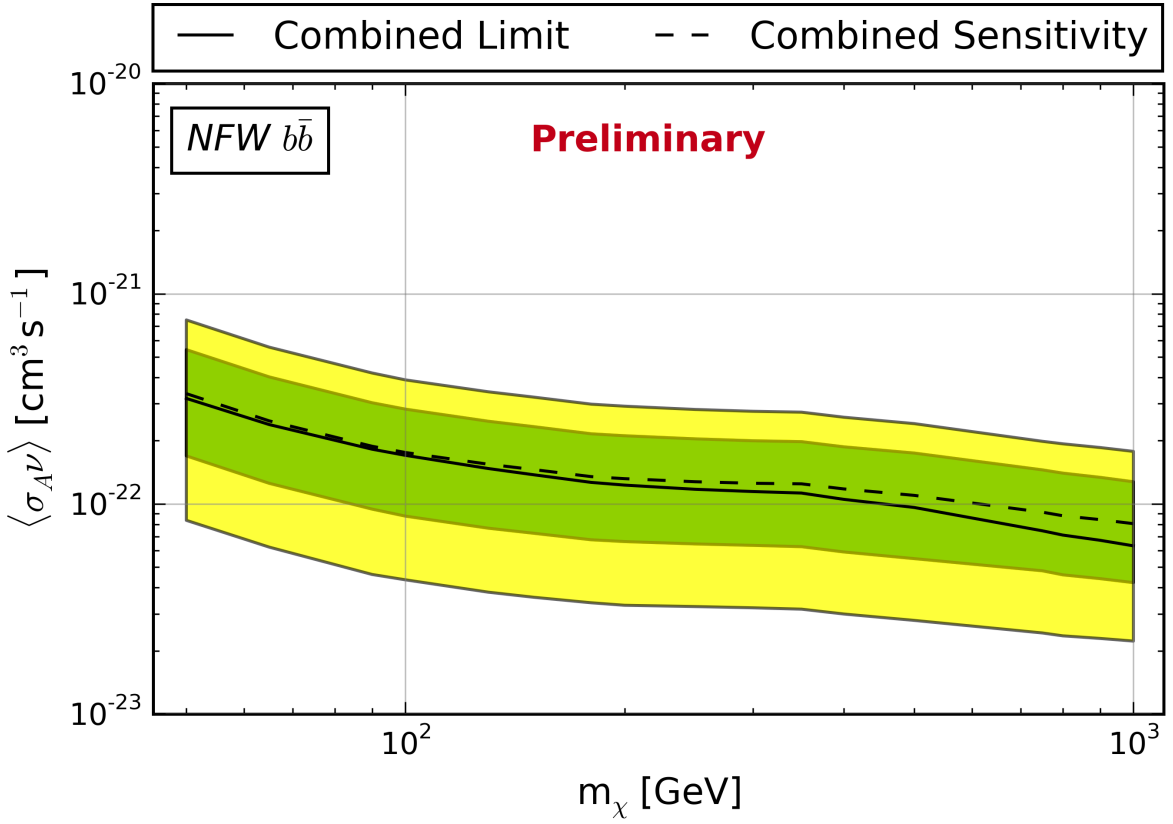
Backup Slides

Limits for NFW $b\bar{b}$

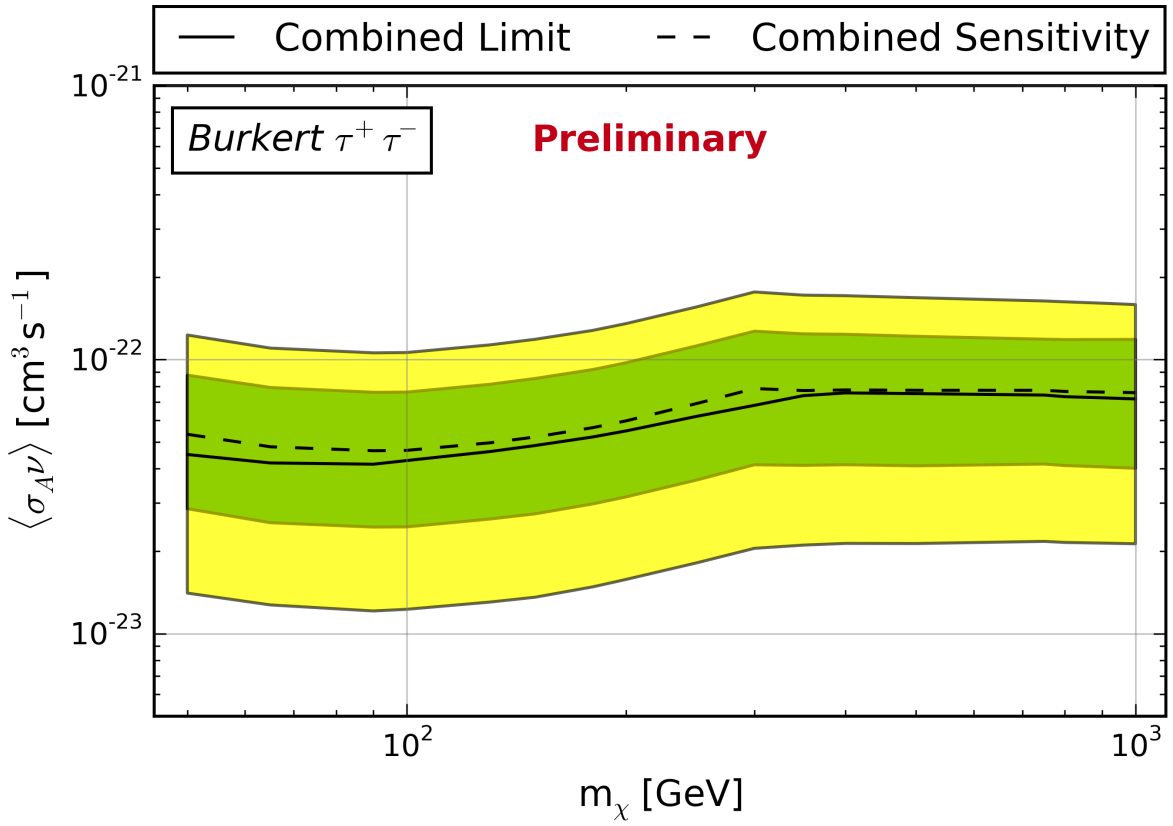


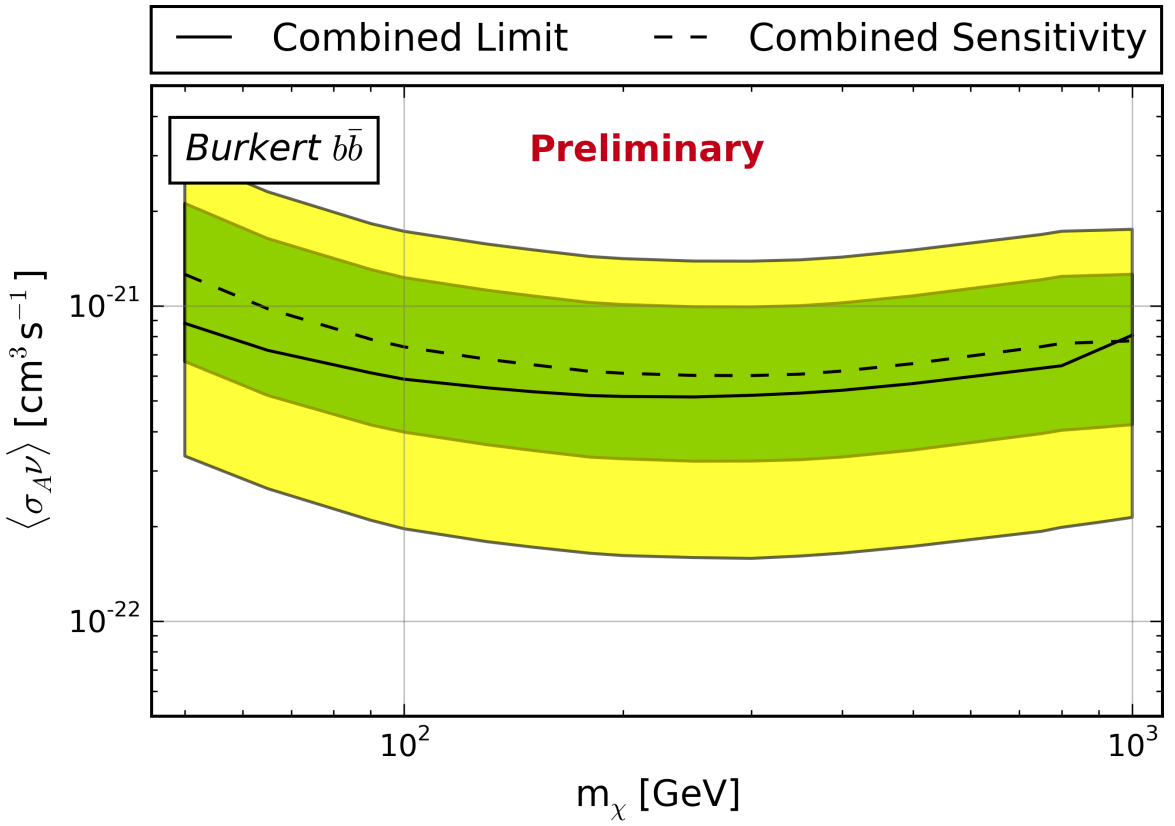
Limits for NFW



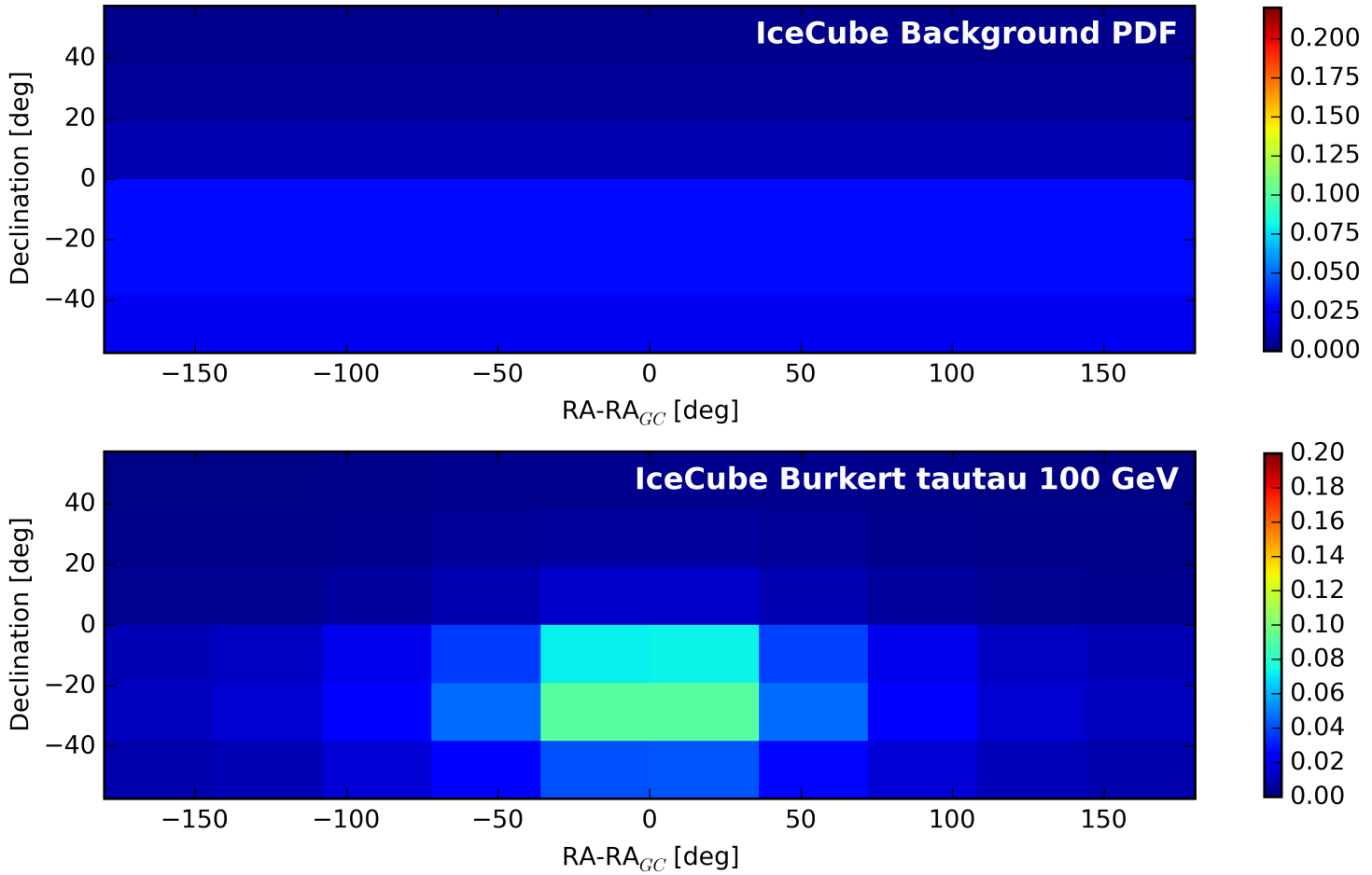


Limits for Burkert





PDFs Burkert profile



PDFs Burkert profile