A search for neutrinos from dark matter in the Galactic Centre with IceCube

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on behalf of the IceCube Collaboration

TeV Particle Astrophysics (TeVPA)
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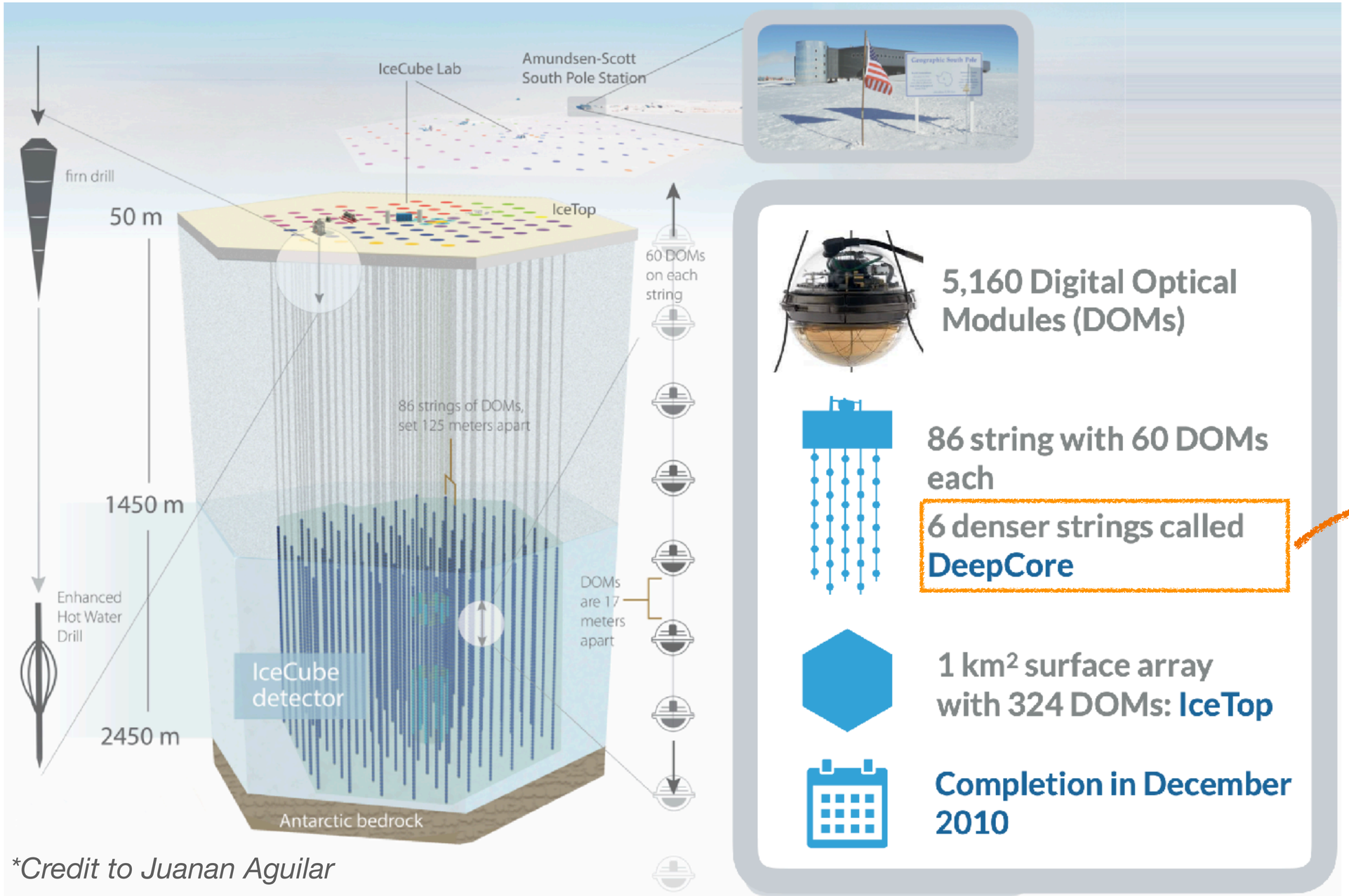
The IceCube Neutrino Observatory

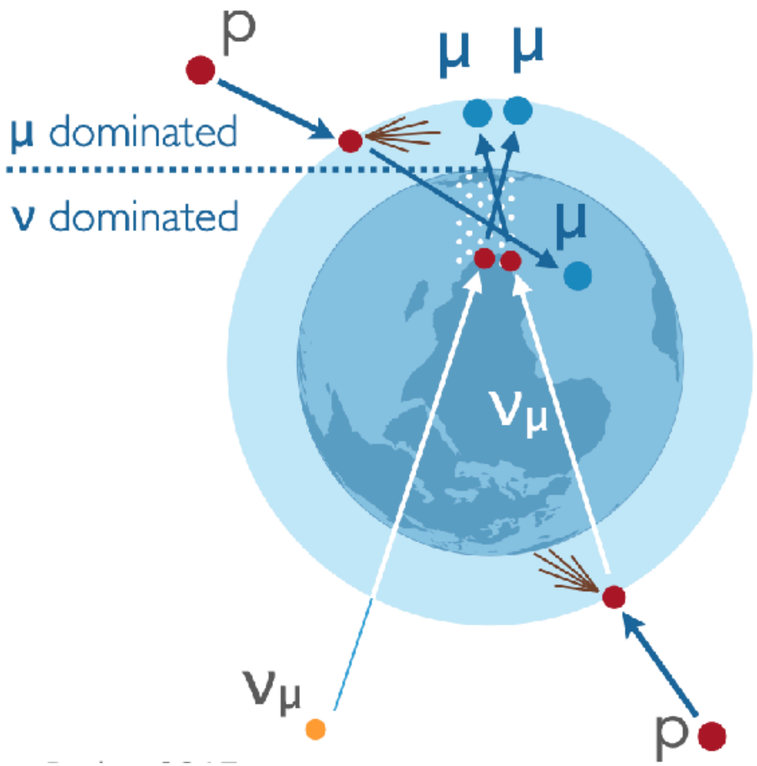


Down to GeV-scale

*Credit to Juanan Aguilar

Rejection of atmospheric muons

Earth as a shield against up-going atm. muons



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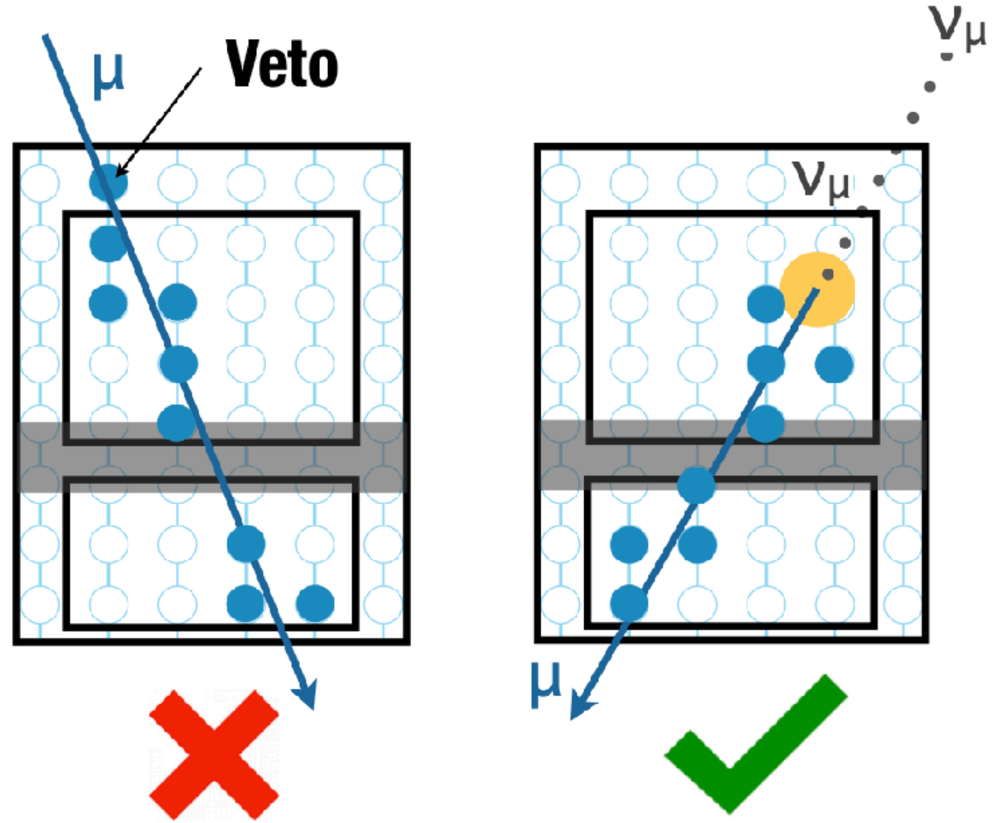
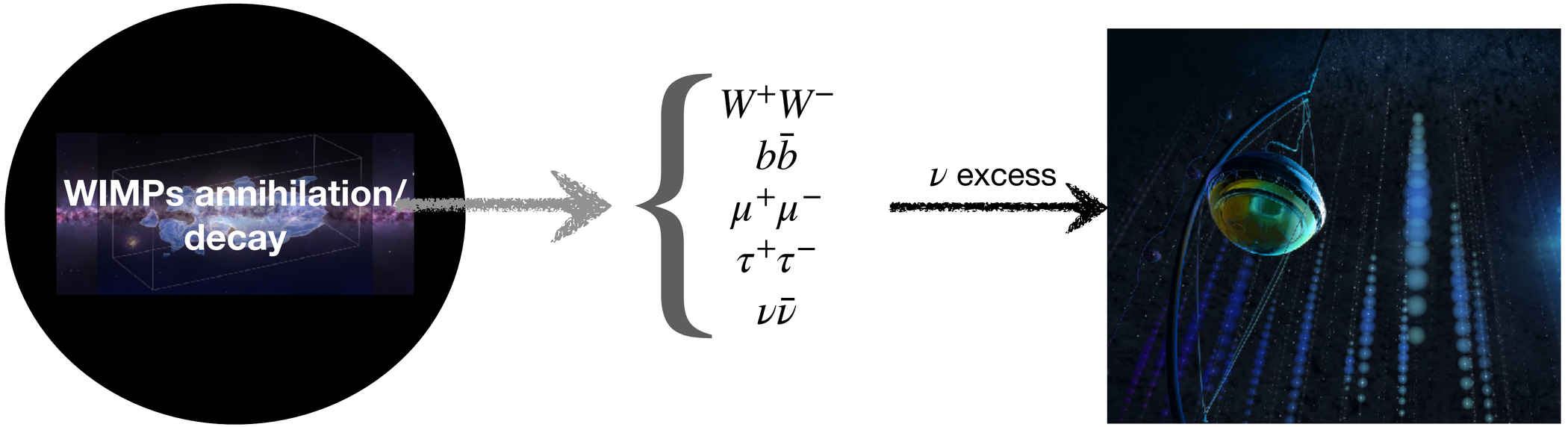
For down-going: Outer layer as an active veto for selecting starting events

→ necessary as Galactic Centre in the southern sky



This analysis

- Search for neutrino signal due to **Dark Matter annihilation/decay in the Galactic Center (Halo)**



- High statistic sample of the **oscNext event selection** (Optimized for oscillation studies) arXiv:2304.12236

  ~9.3 years of DeepCore data

- Targeting **low energy search (DM mass up to 8 TeV)** of dark matter annihilation/decay

Incoming Signal flux

Particle physics

Astrophysical input
Density profile of the source

$$\frac{d\phi_{\nu_\alpha}}{dEd\Omega} = \frac{1}{4\pi}\frac{\langle\sigma_a v\rangle}{2m_{\rm DM}^2}\frac{dN_{\nu_\alpha}}{dE}\int_{l.o.s}\rho^2(\vec{r})ds \quad \text{Annihilation}$$

$$\frac{1}{4\pi}\frac{1}{m_{\rm DM}\tau}\frac{dN_{\nu_\alpha}}{dE}\int_{l.o.s}\rho(\vec{r})ds \quad \text{Decay}$$

Measurement

Constraint parameters
Converted from signal fraction

Incoming Signal flux

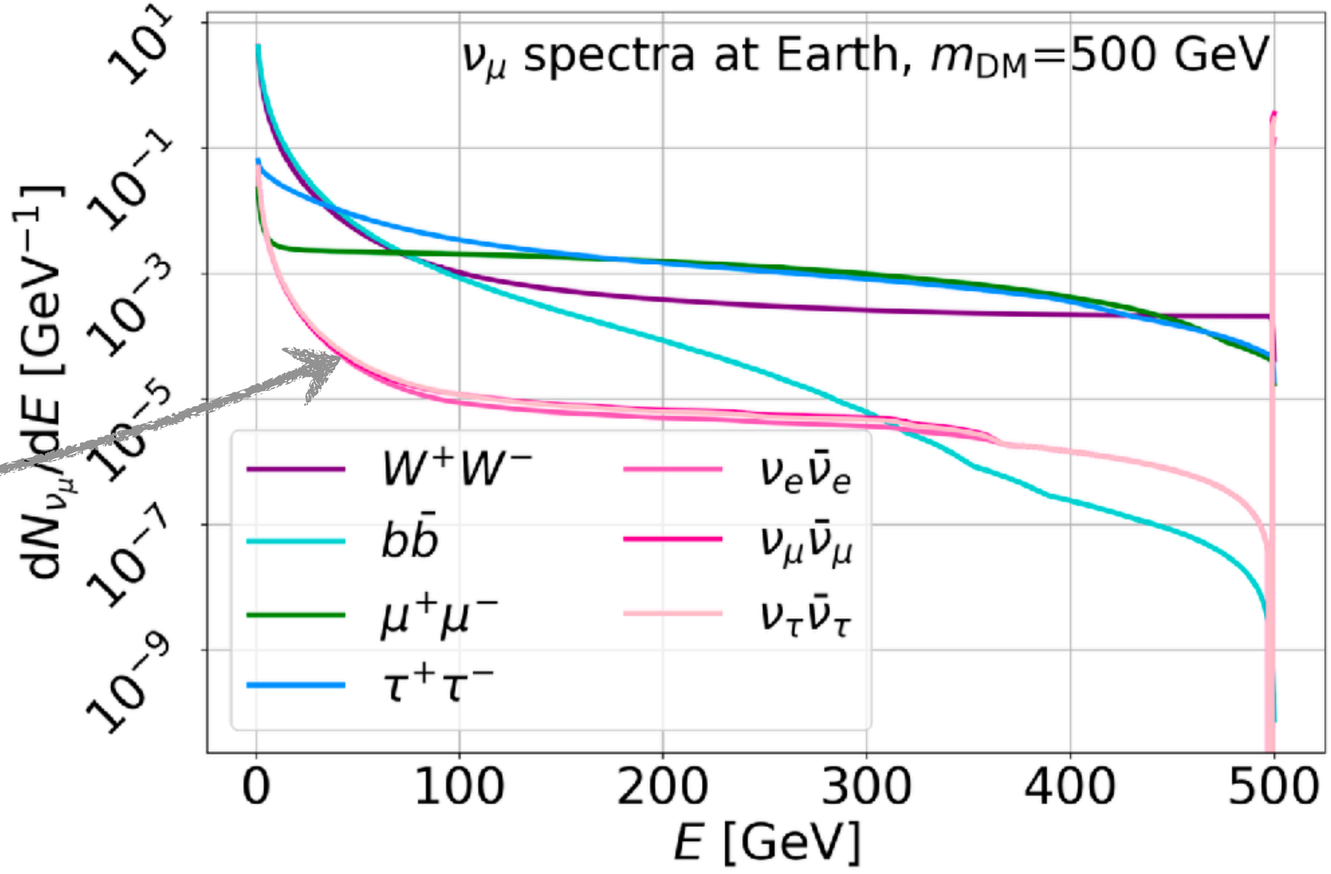
$$\frac{d\phi_{\nu_\alpha}}{dEd\Omega} = \frac{1}{4\pi}\frac{\langle\sigma_a v\rangle}{2m_{\rm DM}^2}\frac{{\rm d}N_{\nu_\alpha}}{{\rm d}E}\int_{l.o.s}\rho^2(\vec{r})ds$$

- Spectra computed with $\chi arov$

  arXiv:2007.15010v2

➡Couple Pythia with the state-of-the-art EW correction - JHEP 06 (2021) 121

- Propagate to the Earth assuming averaged oscillation



Incoming Signal flux

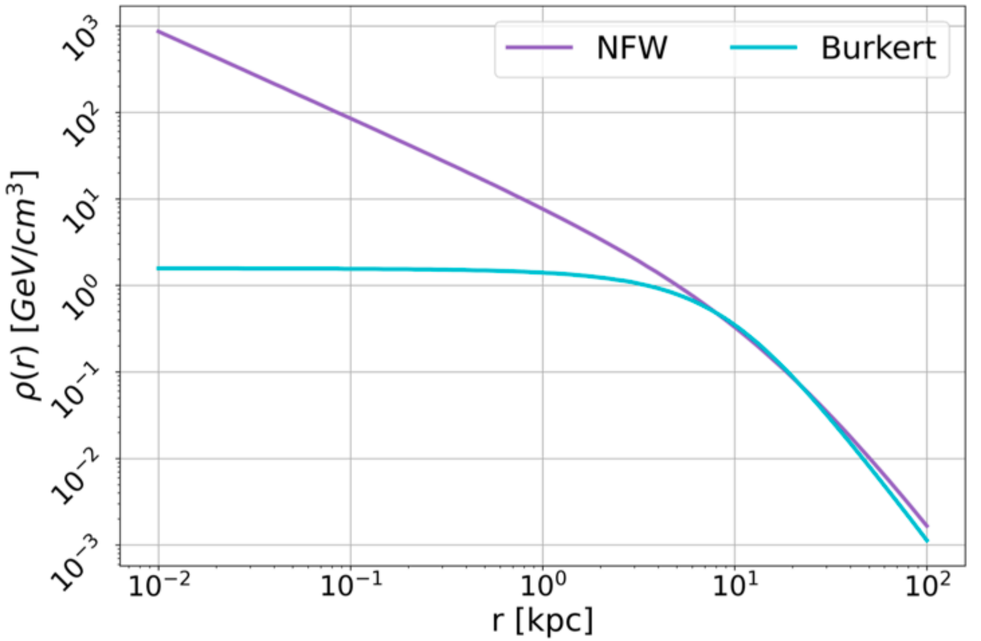
$$\frac{d\phi_{\nu_\alpha}}{dEd\Omega} = \frac{1}{4\pi} \frac{\langle \sigma_a v \rangle}{2m_{\mathrm{DM}}^2} \frac{\mathrm{d}N_{\nu_\alpha}}{\mathrm{d}E} \int_{l.o.s} \rho^2(\vec{r}) ds$$

- **J-factor**: Integration of DM profile along the line-of-sight

$$J(\Psi) = \int_{\Delta\Omega} \mathrm{d}\Omega(\Psi) \int_0^{l_{max}} \rho^2_{\mathrm{DM}}(r(l,\Psi))\, dl$$

- Computed with **Clumpy** (arXiv:1806.08639) for 2 profiles: **NFW** and **Burkert**

- Parameter values for the Milky Way taken from Nesti&Salucci (arXiv:1304.5127)



Signal PDFs

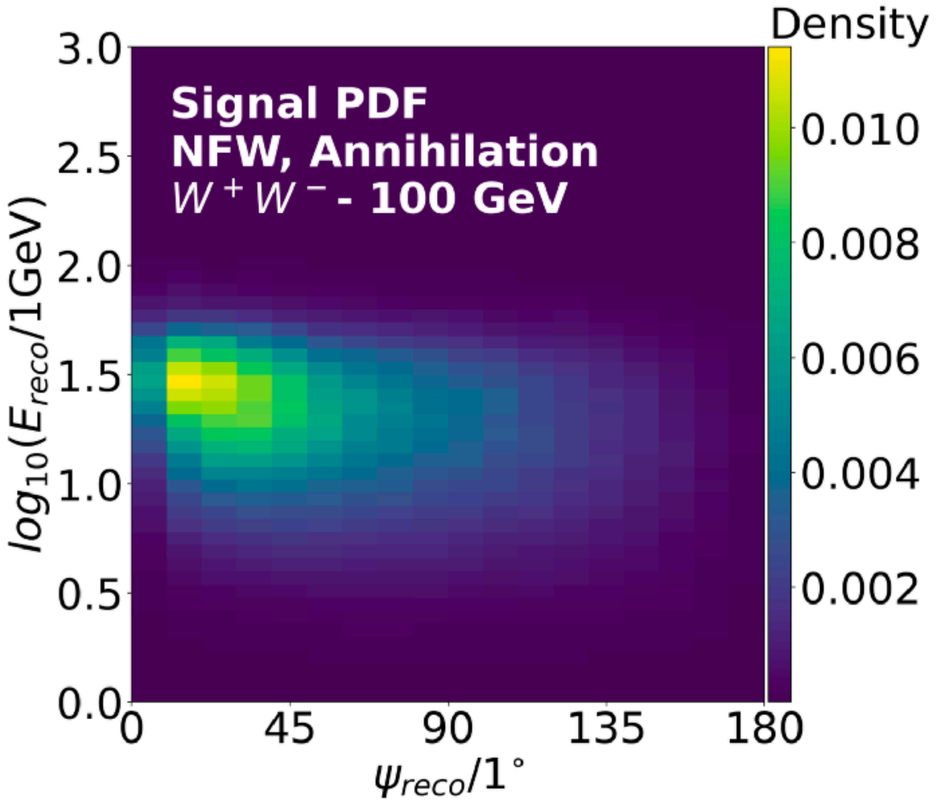
- Expected event distribution:

$$\propto EffectiveArea(E_{true}, \psi_{true}) \times Resolution(E_{true}, \psi_{true}, E_{reco}, \psi_{reco})$$

$$N_{reco}(E_{reco}, \psi_{reco}) = \sum_{\nu_\alpha, E_{true}, \psi_{true}} \left[\frac{1}{2} \frac{\langle \sigma_a v \rangle}{4\pi m_{\mathrm{DM}}^2} \frac{\mathrm{d}N_{\nu_\alpha}}{\mathrm{d}E}(E_{true})\, J_\Psi(\psi_{true}) \right] \left[R^{\nu_\alpha}(E_{true}, \psi_{true}; E_{reco}, \psi_{reco}) \right] T_{livetime}$$

Spectra (Charon) x Jfactor (Clumpy) $[GeV^{-1} cm^{-2} sec^{-1} sr^{-1}]$

Detector response built from MC + KDE $[GeV \cdot cm^2 \cdot sr]$



2 observables:

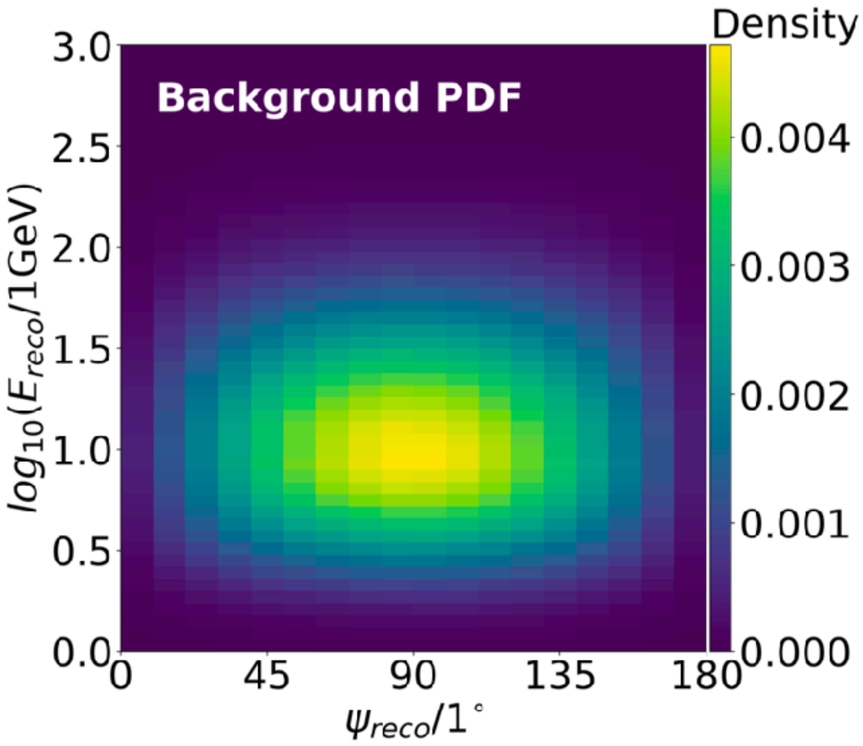
Energy (E)

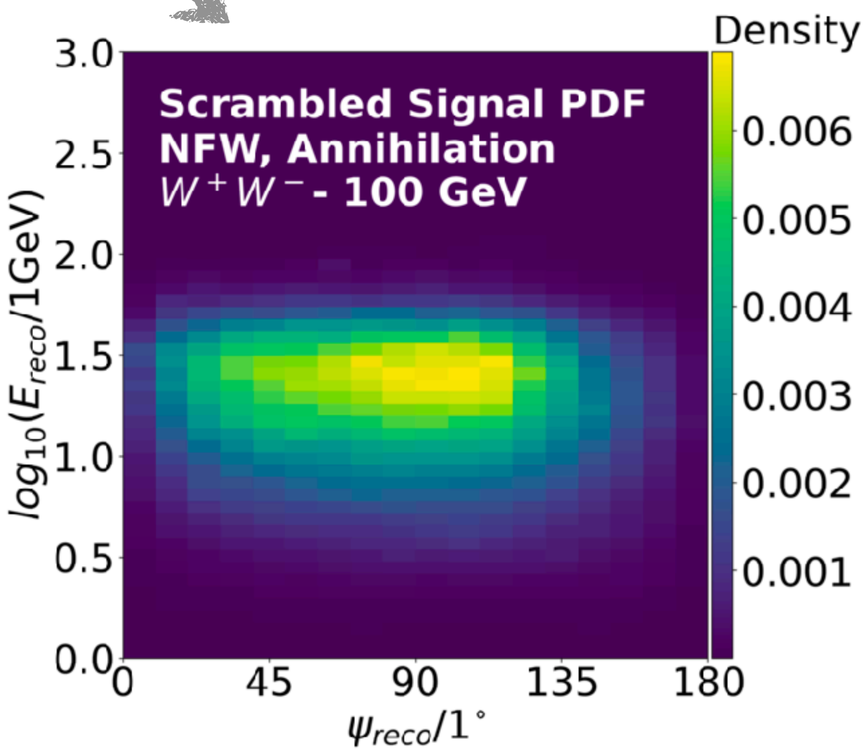
Open angle (ψ)

Background PDFs

- Background PDF estimated from RA scrambled data
- If signal in the data ⟶ need signal subtraction to correct for the contamination

$$\mathcal{B}_i = \frac{1}{1-\xi}(\mathcal{B}_i^{scr} - \xi \mathcal{S}_i^{scr})$$





Analysis method

- **Binned Poisson Likelihood**

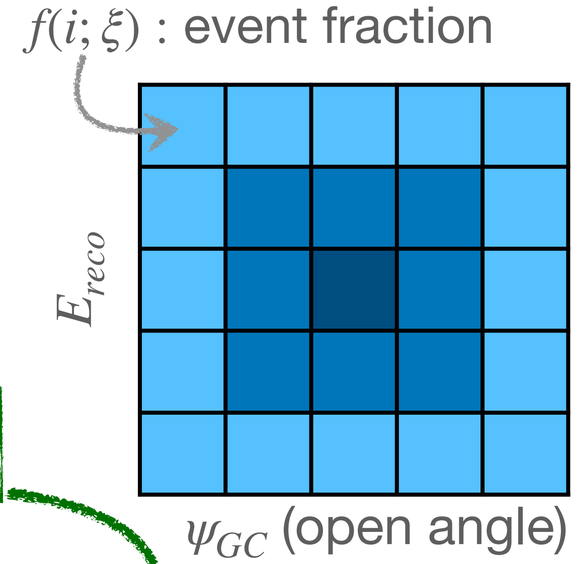
$$\mathscr{L}(\xi) = \prod_i Poisson(n^i_{obs}; n^{tot}_{obs} f(i, \xi))$$

$$f(i\,;\,\xi) = \xi\,\mathcal{S}_i + (1-\xi)\,\mathcal{B}_i, \qquad \mathcal{B}_i = \frac{1}{1-\xi}(\mathcal{B}^{scr}_i - \xi\mathcal{S}^{scr}_i)$$

Signal PDF (MC)

Background PDF as RA Scrambled data

Signal subtraction for correction of signal contamination

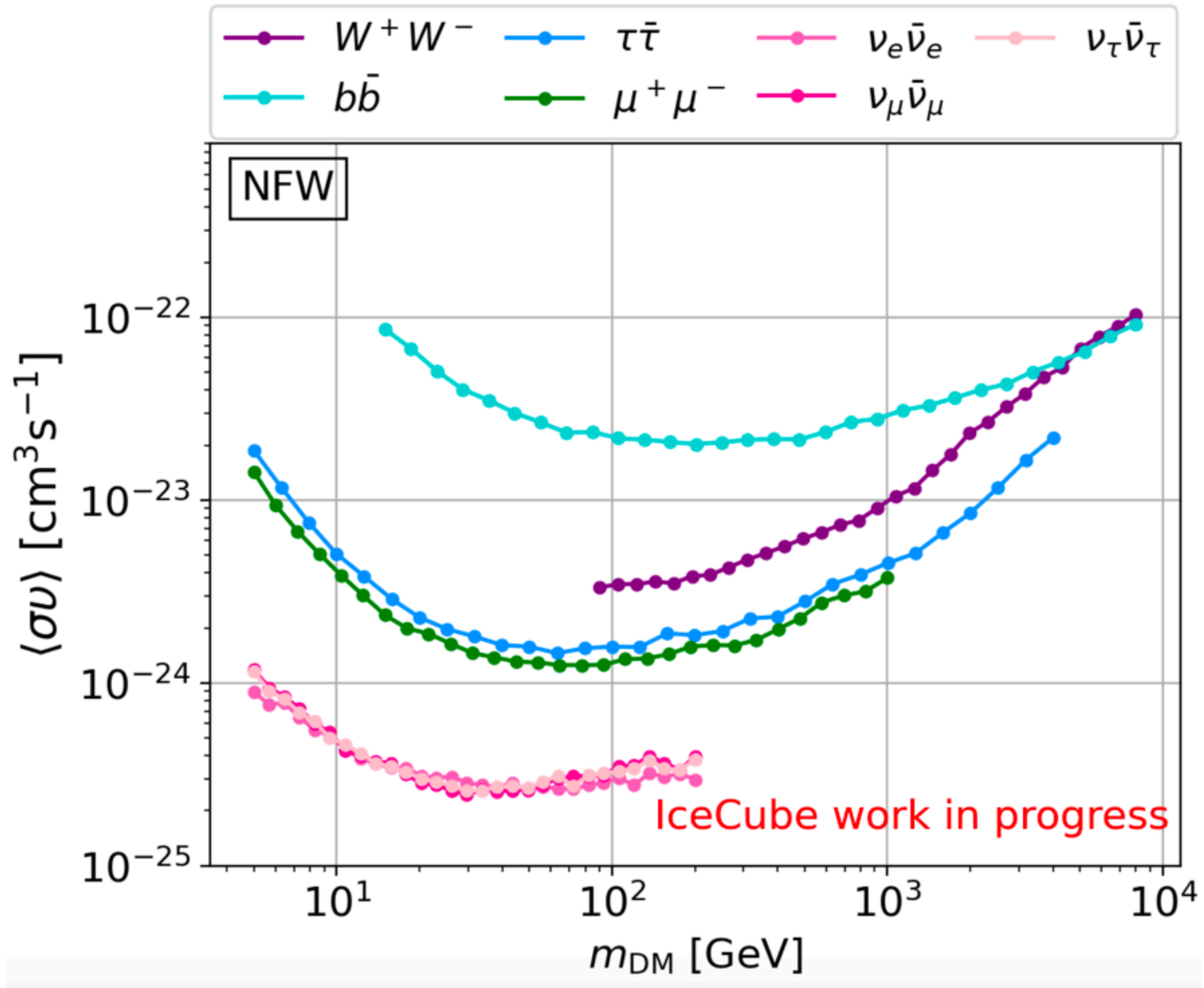


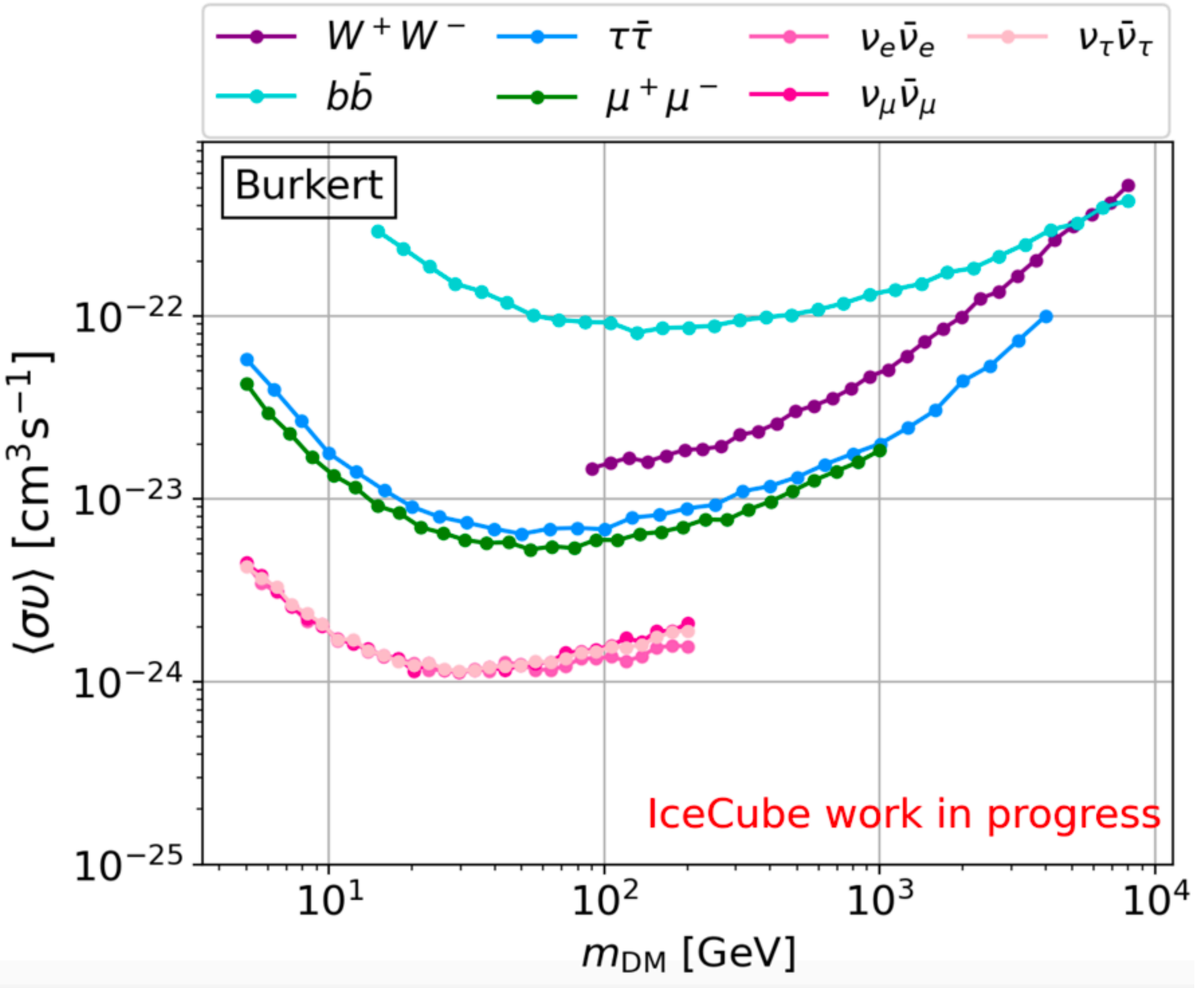
- **One parameter to fit: signal fraction** $\xi = \dfrac{n^{tot}_{signal}}{n^{tot}_{obs}}$ (→looking for possible excess)

- **Sensitivity evaluation with likelihood interval method**

Sensitivity for annihilation - 9 years

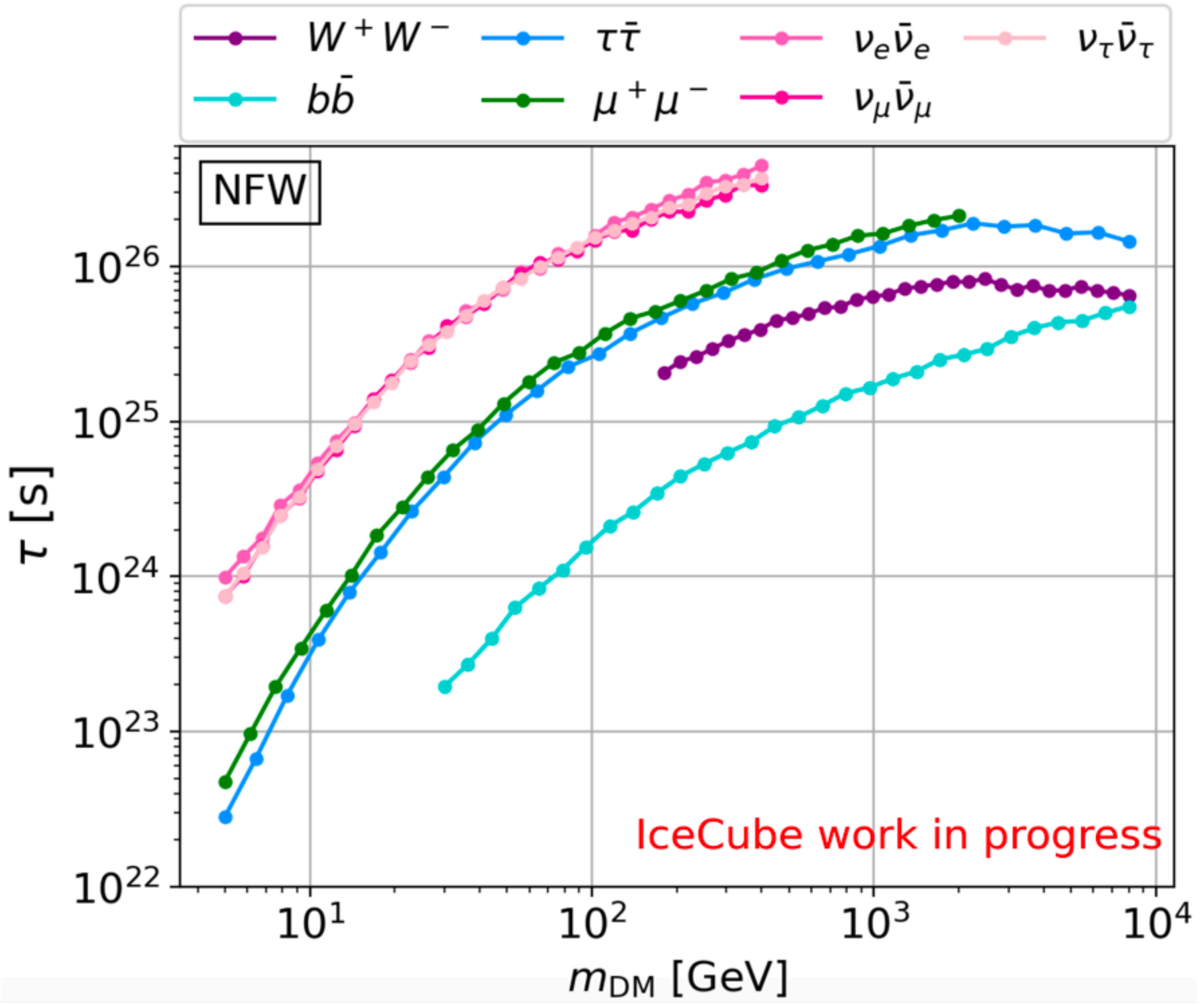
90% CL median (upper) limit

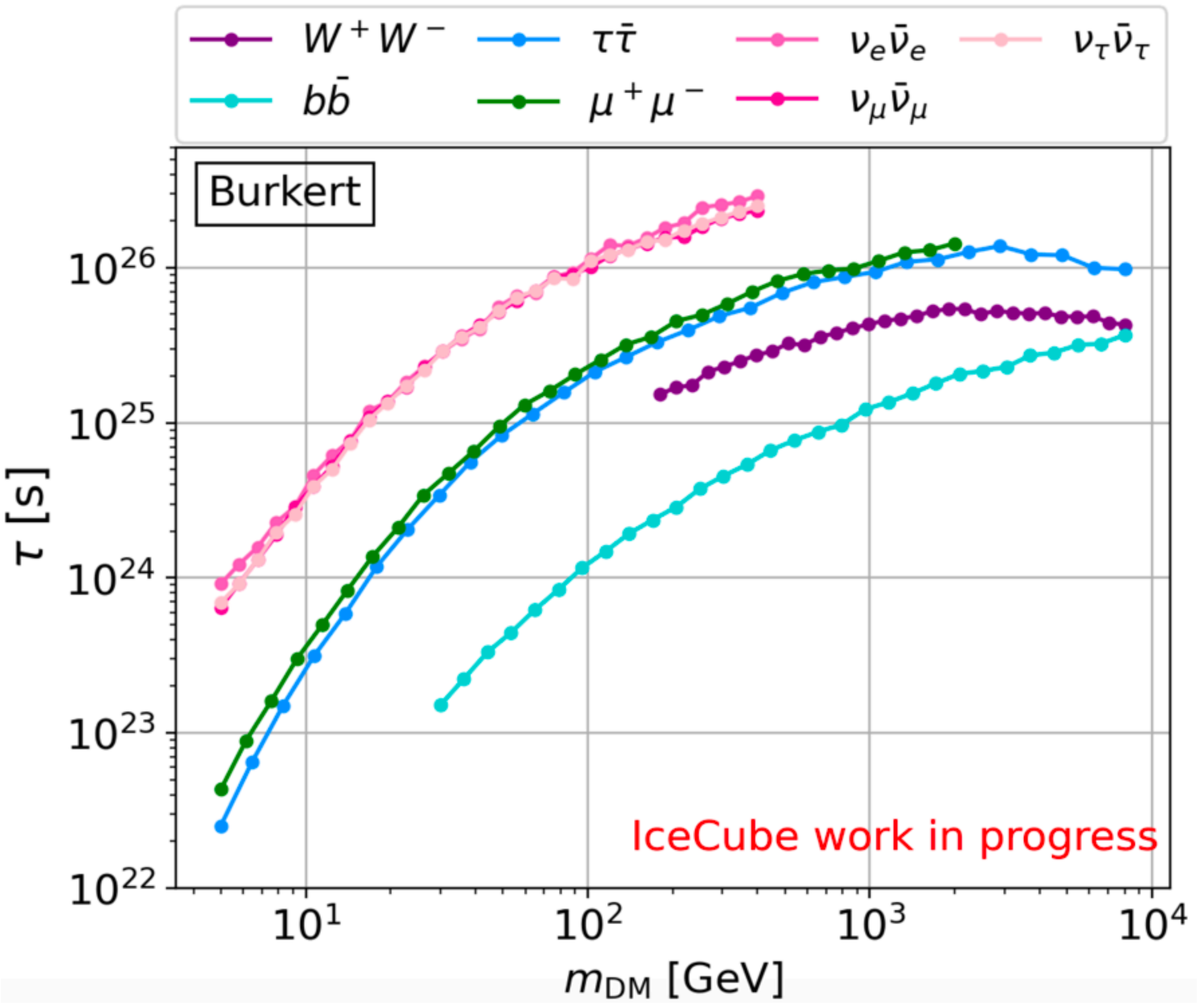




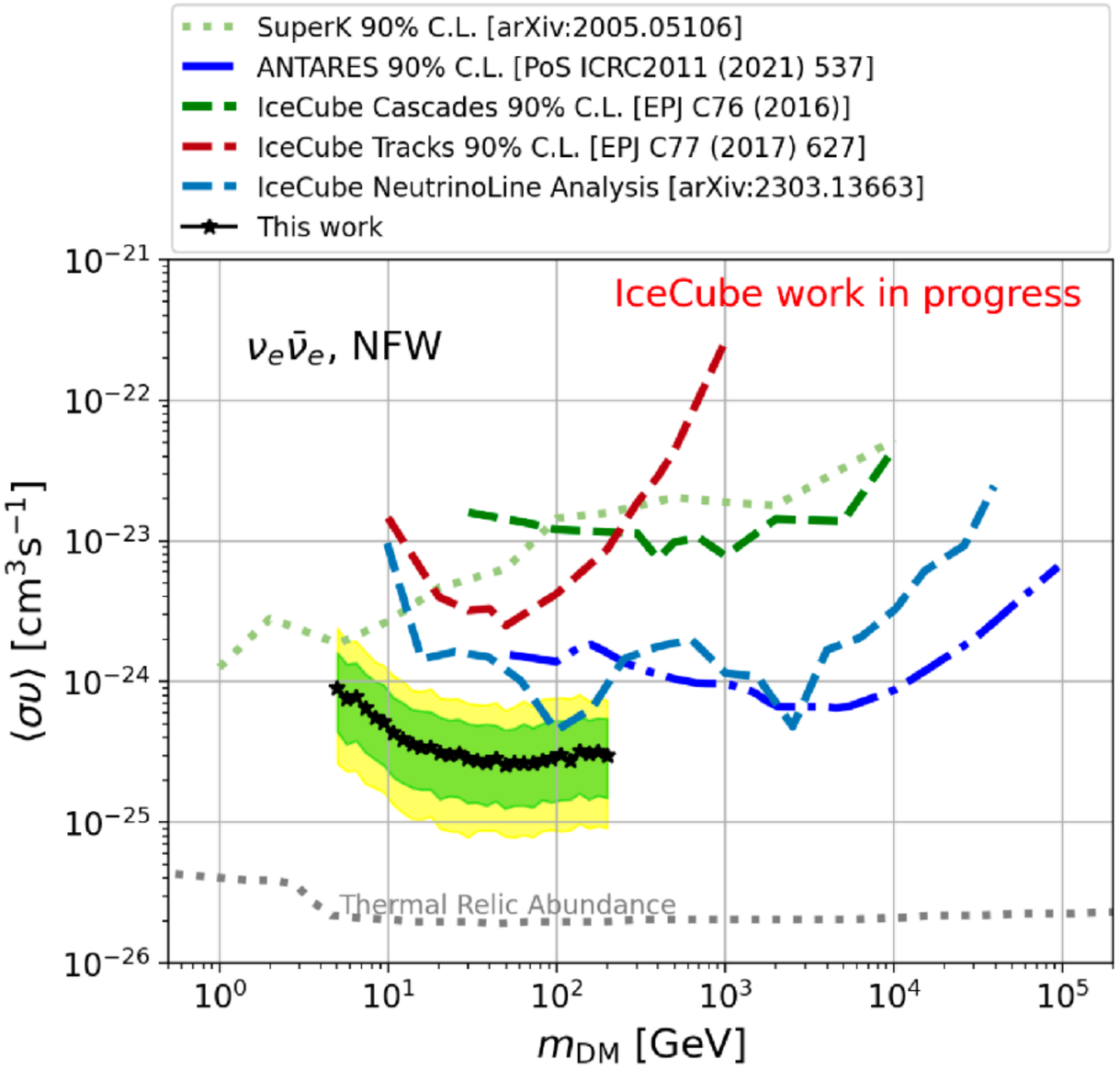
Sensitivity for decay - 9 years

90% CL median (lower) limit





Comparison to other analyses



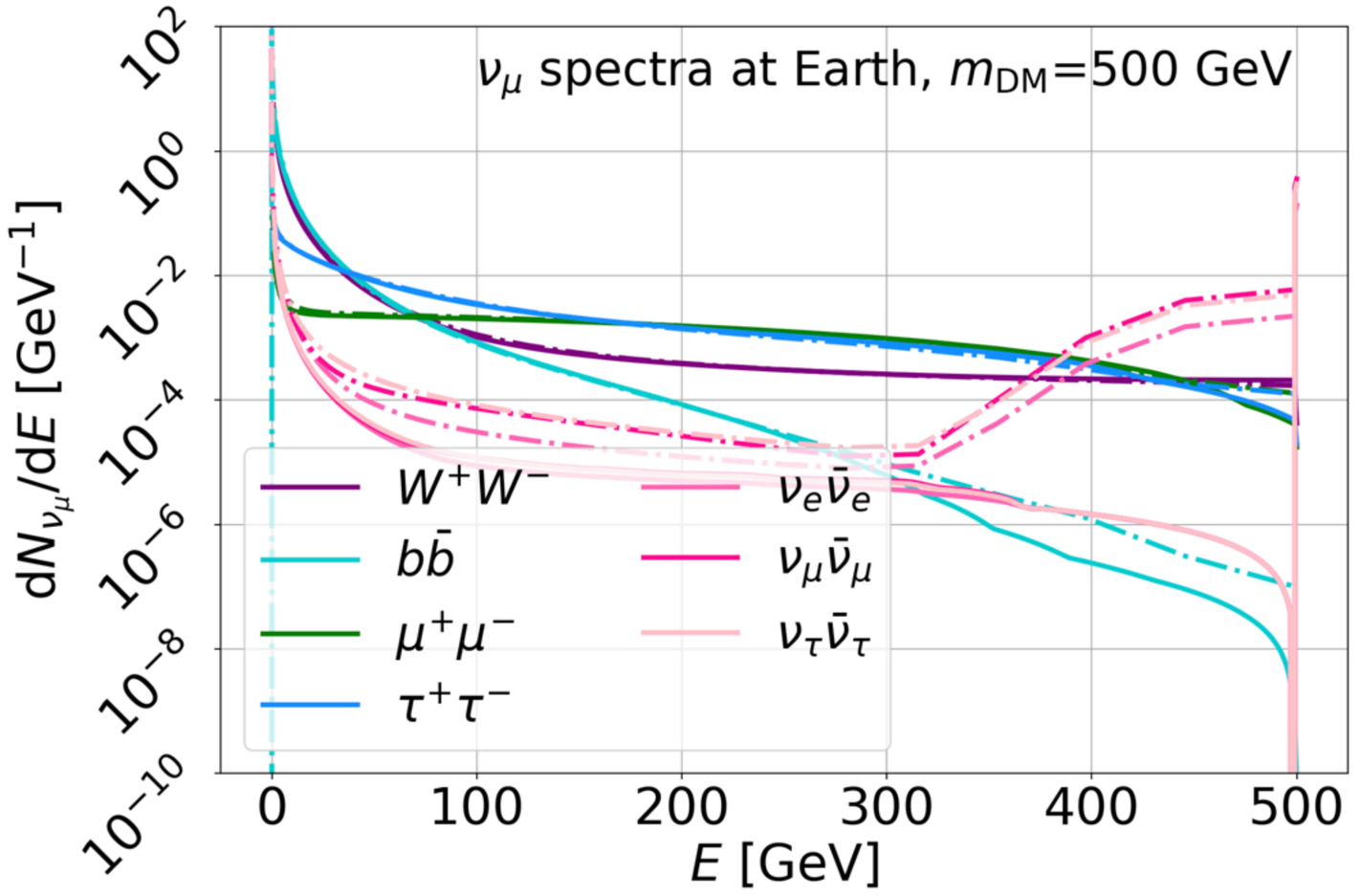
Summary

- Sub-TeV search for dark matter from Galactic Centre with 9 years of DeepCore data
- Binned likelihood method with interval likelihood construction for the limit
- Expected to improve the current IceCube limit for sub-TeV dark matter
- Results are coming soon, stay tuned!

Back up

Spectra

χαροv: solid
PPPC4: dash



Likelihood interval method

- Test statistics:

$$\lambda_\xi = 2\log\frac{\mathscr{L}(\hat{\xi})}{\mathscr{L}(\xi)} \text{ (for } \xi \leq \hat{\xi} \text{ , 0 otherwise)}$$

- $\xi_{90\%}$ defined as $median(f(\lambda_\xi|0)) = 1.64$

Since: $\int_{1.64}^{\infty} f(\lambda_\xi|\xi)d\lambda_\xi = 0.1$

- Require λ_ξ to asymptotically follows a χ^2 distribution

Effects of Galactic Plane

- Checking the GP's impact by modifying the likelihood:

$$\mathscr{L}(\xi) = \prod_i Poisson(n^i_{obs}; n^{tot}_{obs} f(i, \xi))$$

$$f(i;\xi) = \xi f_s(i) + n_{GP} f_{GP}(i) + f^{scr}_{BG} - \xi f^{scr}_s(i) - n_{GP} f^{scr}_{GP}(i)$$

- Test with **different combination of GP injection and assumption in the likelihood.**

➡ **Negligible impacts** on **signal recovery fit, TS distribution, sensitivity**