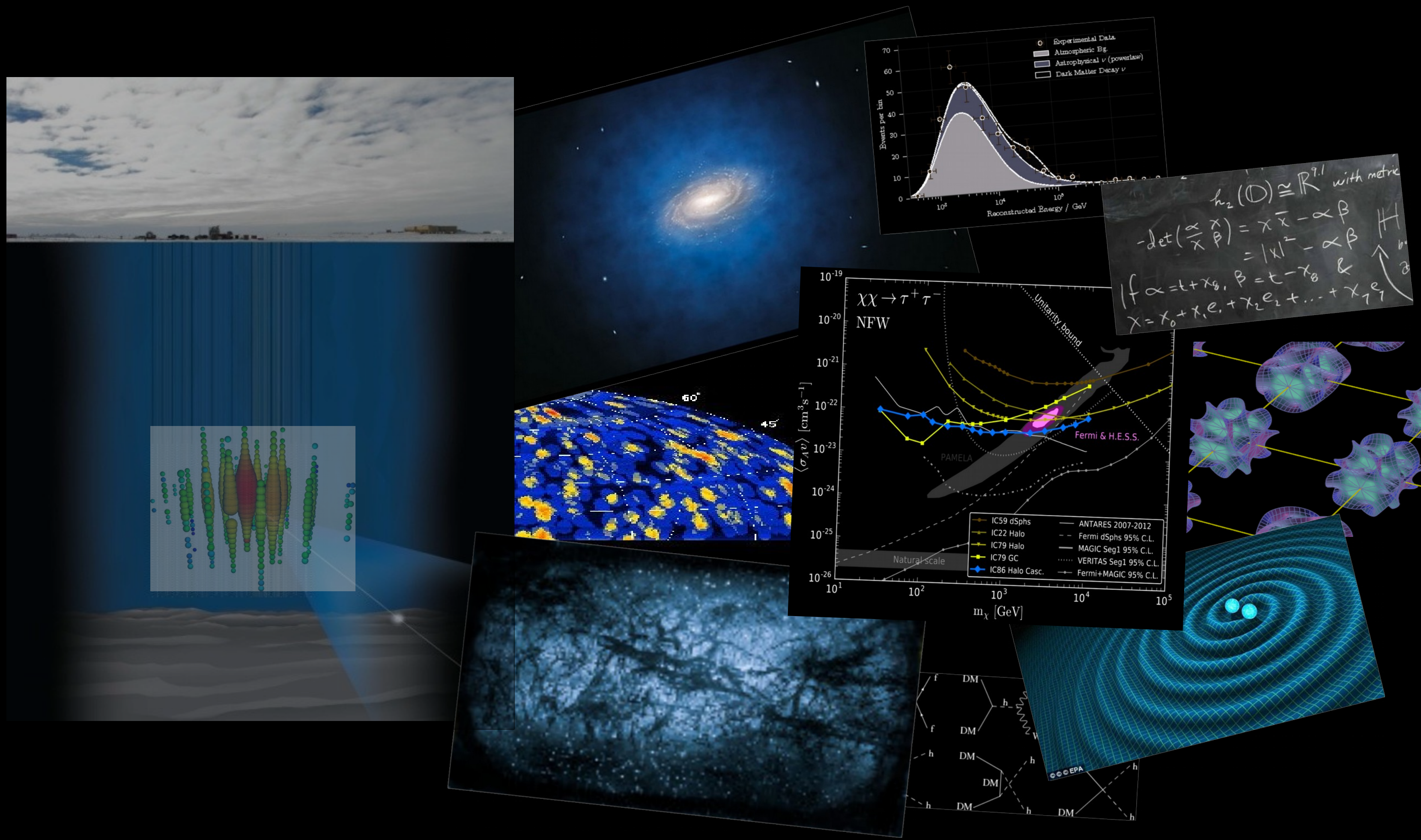
Recent results on Dark Matter searches with the IceCube neutrino telescope

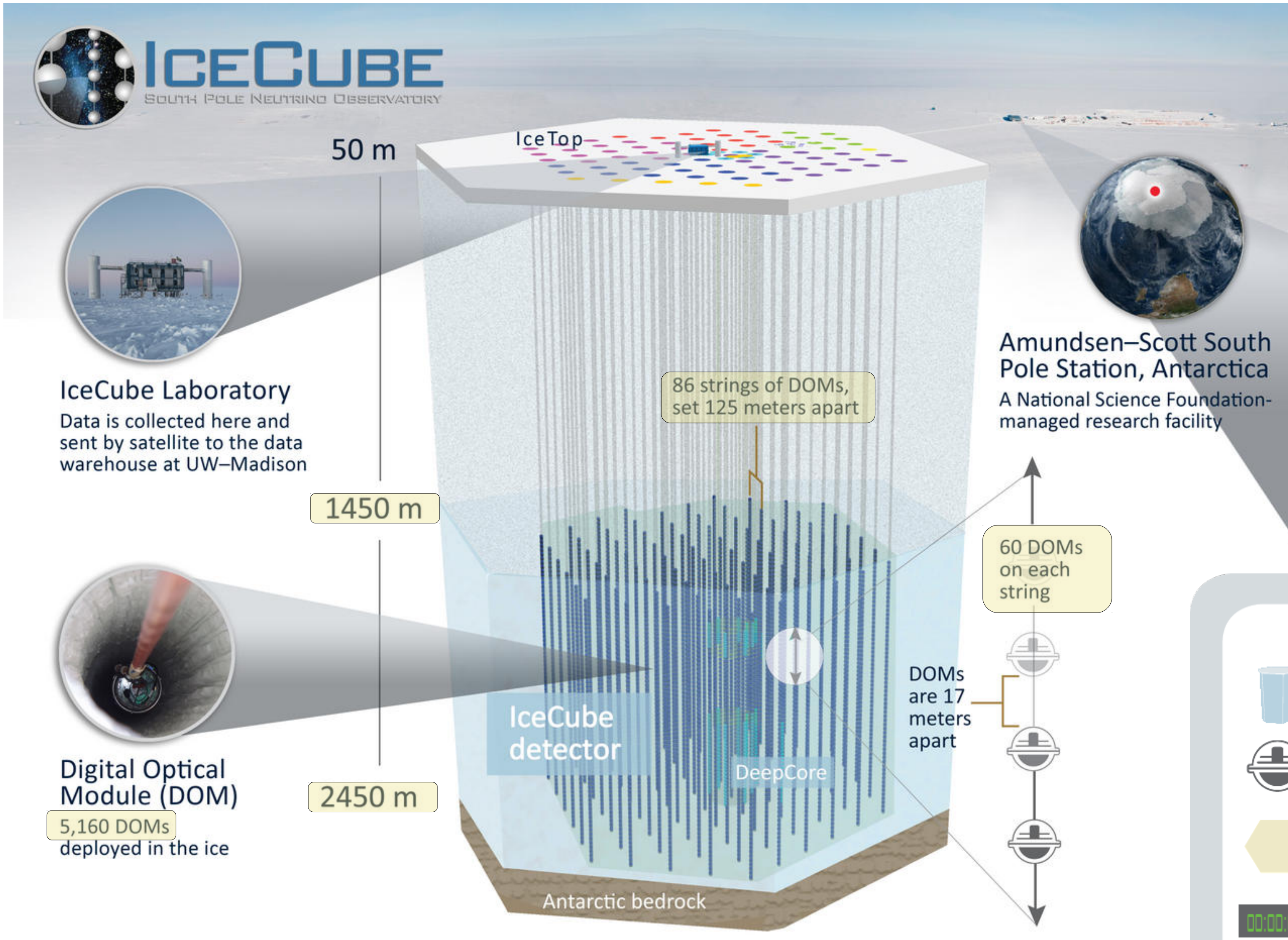


Carlos de los Heros

Uppsala University

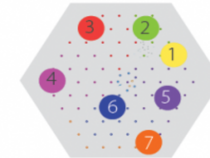
GEMMA Workshop, Lecce, June 4-7 2018.

the IceCube Neutrino Observatory



Detector Construction

7 seasons of construction, 2004-2011



28,000 person-days to complete construction, or 77 years of continuous work

2.1 million kilograms of cargo was shipped, 0.5 million of which was the drill

48 hours to drill and 11 hours to deploy sensors per hole

4.7 megawatts of drill thermal power with 760 liters of water per minute delivered at 88 °C and 7,600 kilopascals

Detector Design

1 gigaton of instrumented ice

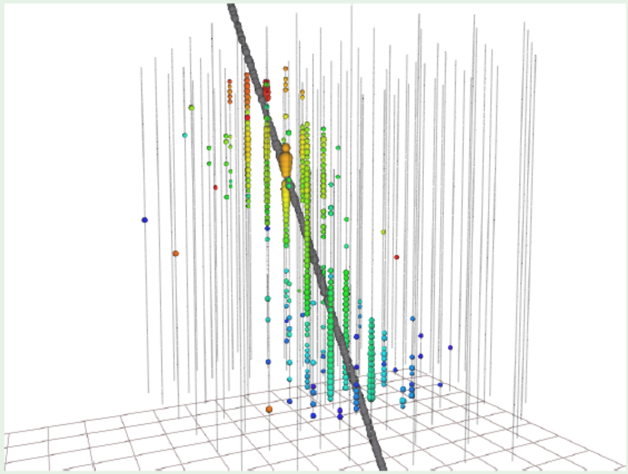
5,160 light sensors, or digital optical modules (DOMs), digitize and time-stamp signals

1 square kilometer surface array, IceTop, with 324 DOMs

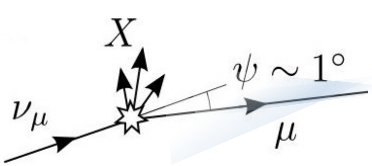
2 nanosecond time resolution

IceCube Lab (ICL) houses data processing and storage and sends 100 GB of data north by satellite daily

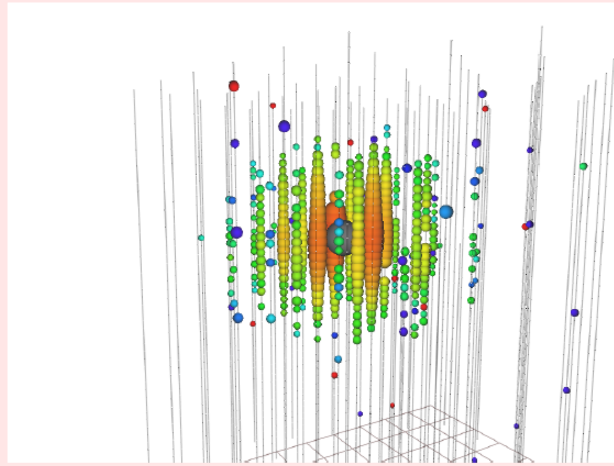
Track



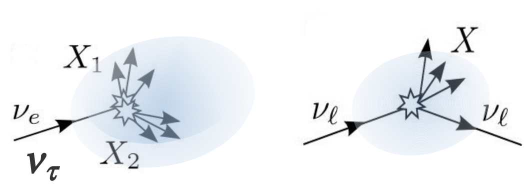
- Muon tracks (CC ν_μ)
- Resolution $< 1^\circ$
- Large energy uncertainties



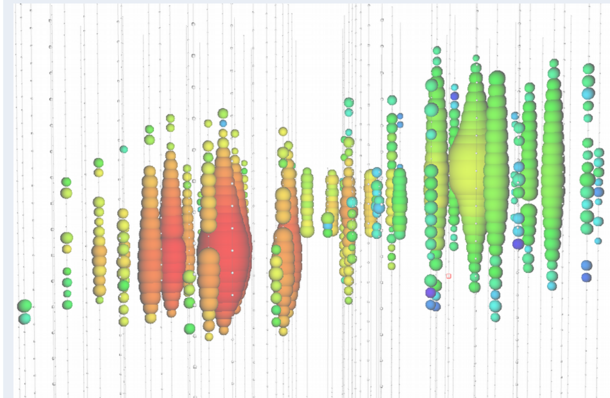
Cascade



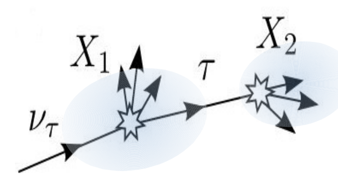
- NC or ν_e/ν_τ
- Resolution $\approx 15^\circ - 20^\circ$
- Energy resolution $\delta E/E \approx 15\%$

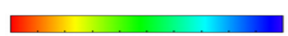


Double-bang



- High energy ν_τ (>100 TeV)
- Not observed yet



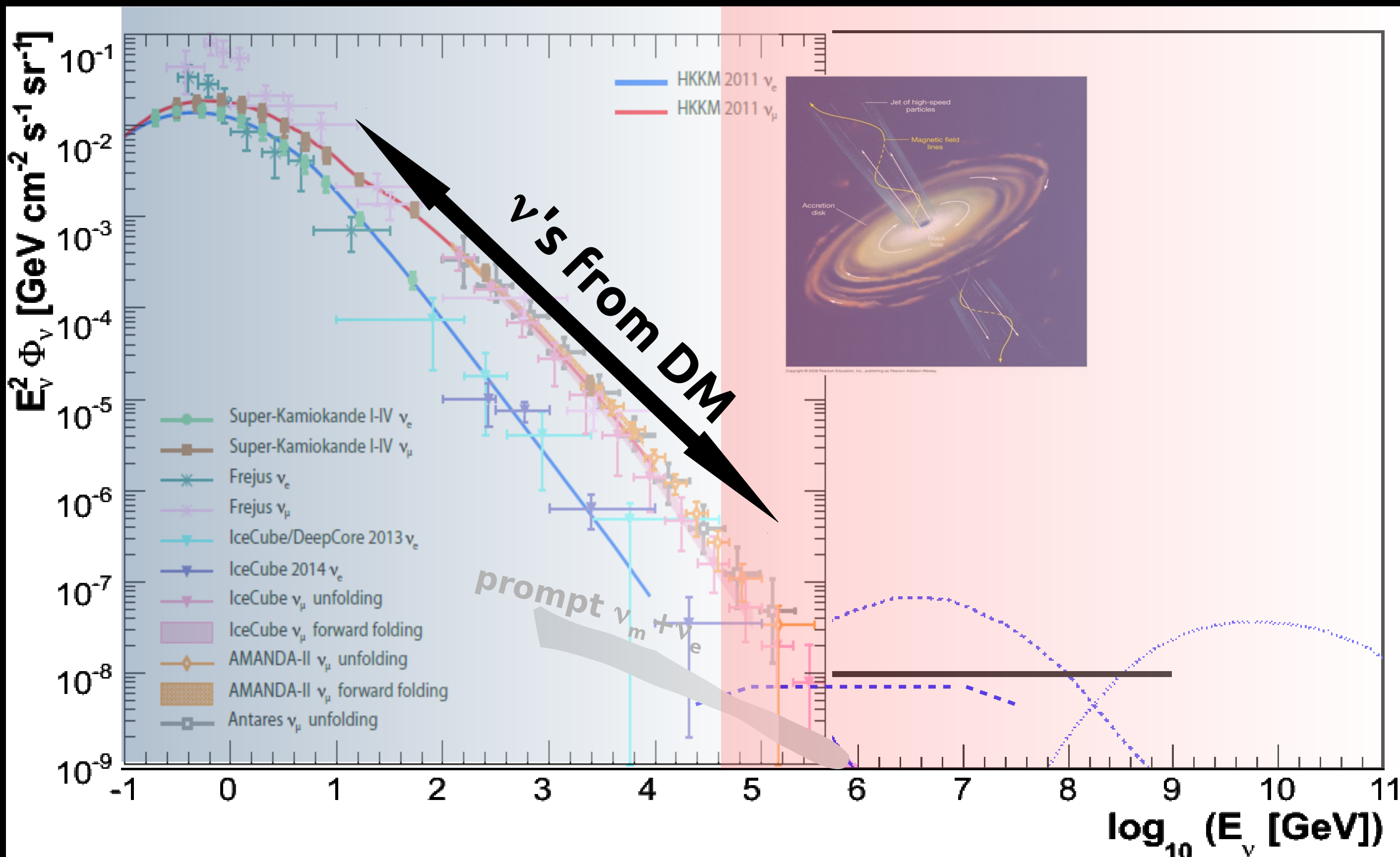
early  late

amount of light in detector ∝ ν energy

Atmospheric
Produced in cosmic-ray air showers

Astrophysical
Galactic and extra-Galactic sources

GZK νs
CRs on CMB photons



neutrino telescopes are subject to a high statistics (~100.000 /y km³), high-energy neutrino beam from the atmosphere

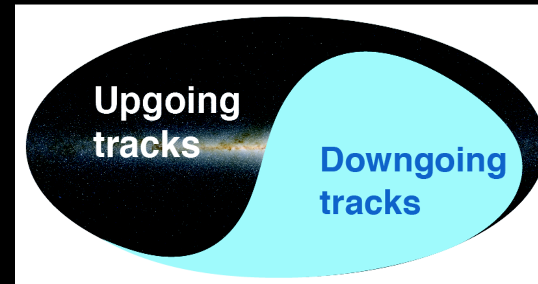
plus…

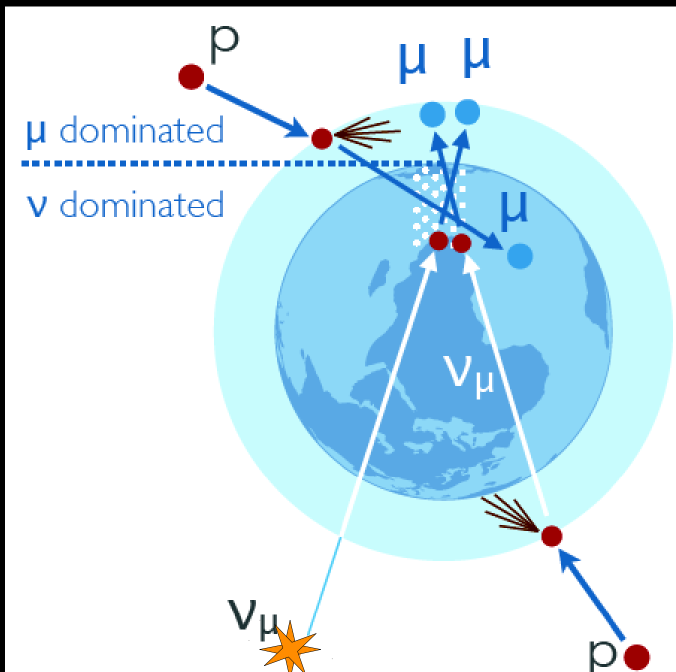
an even higher-energy astrophysical flux (~100 /y km³)

These are irreducible backgrounds for DM searches

background rejection

Southern Sky dominated by atmospheric muons

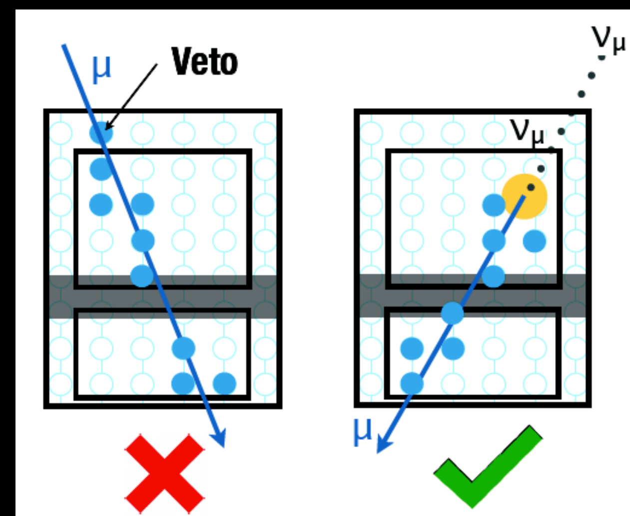




above horizon (Southern sky)

below horizon (Nothern sky)

use outer layers as a veto to select neutrino-induced starting events

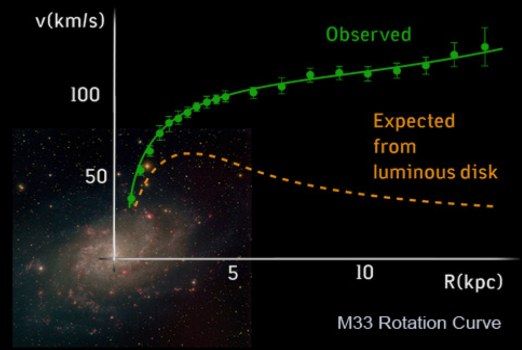


use Earth as a filter to reject atmospheric muons from Northern Sky

detector becomes 4π, sensitive to **Galactic Center and Southern sky**

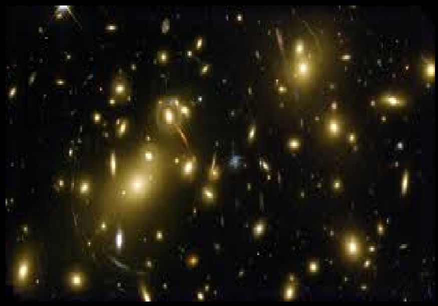
evidence for dark matter

galaxy clusters



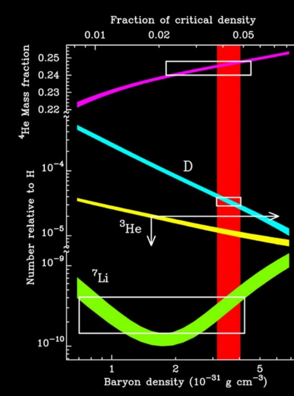
galaxy rotation curves

gravitational lensing

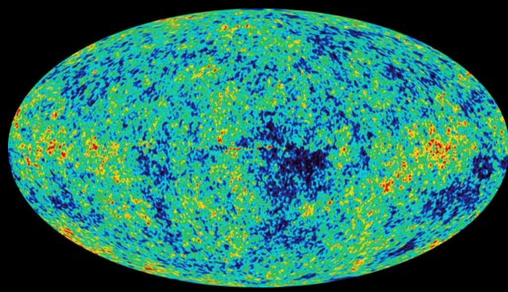


a weakly-interacting relic "dark matter" particle can explain the observations

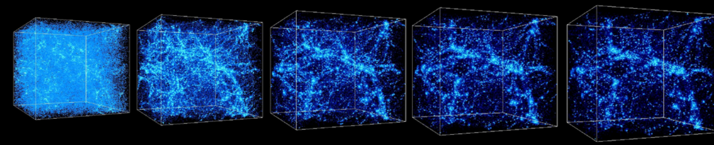
BBN



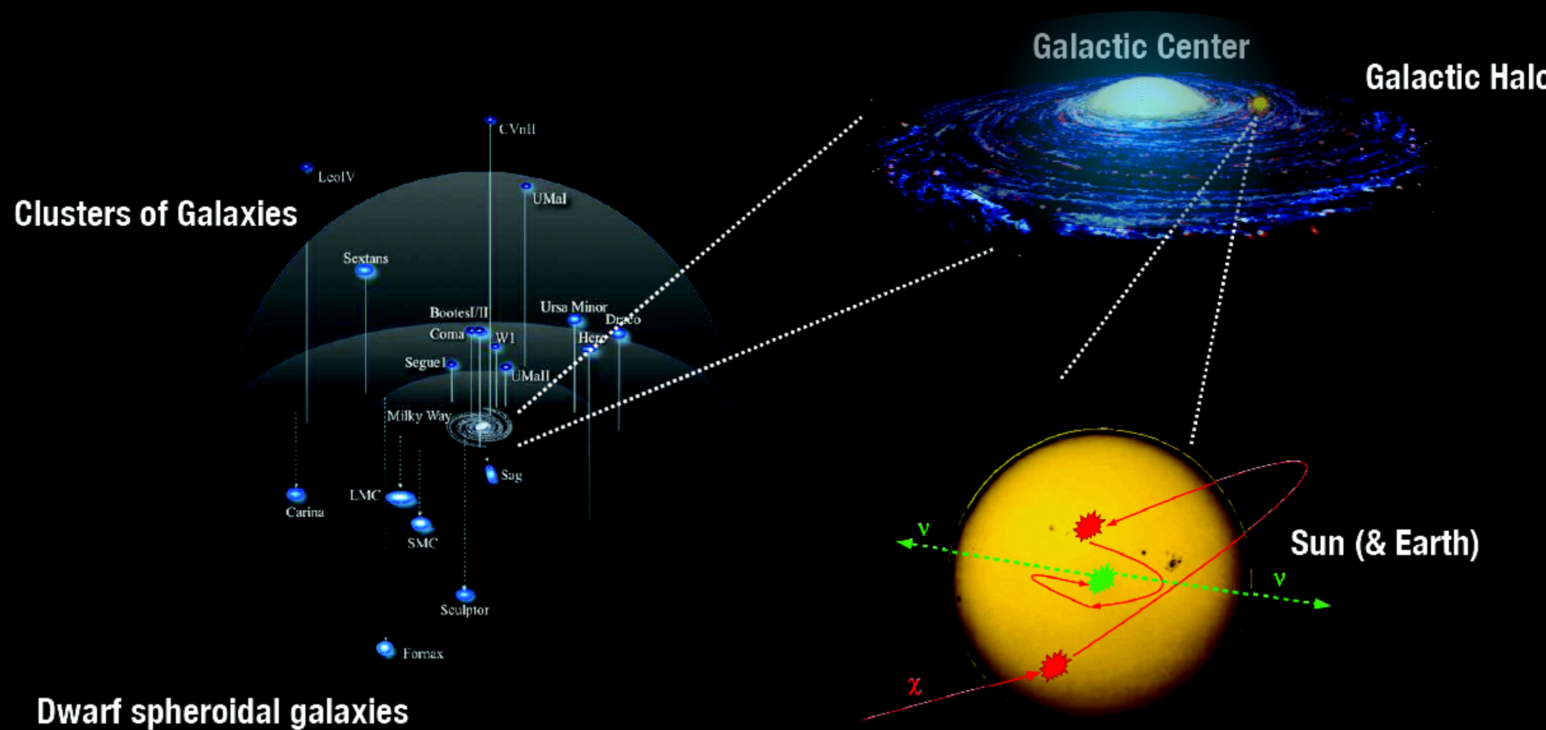
CMB

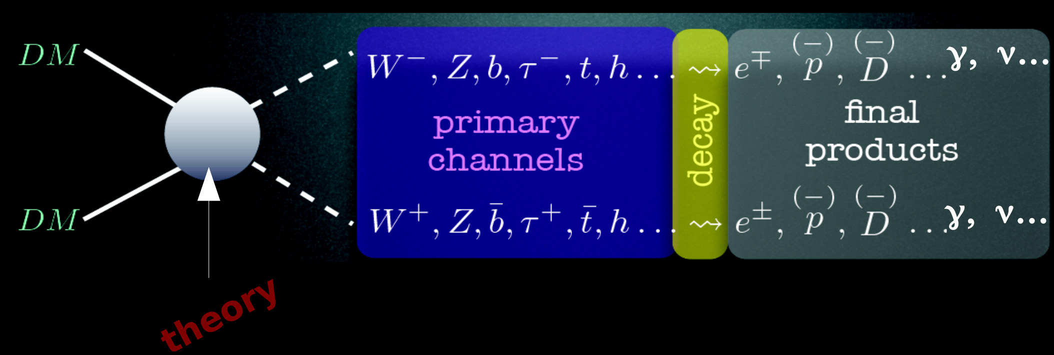


structure formation

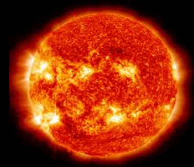


dark matter searches with neutrino telescopes





searches dark matter: what can be measured?



Sun

Earth

dwarf galaxies
&
distant galaxies

Galactic
Halo

Galactic
Center

$$\Phi_\nu \rightarrow \Gamma_A \rightarrow C_C \rightarrow \sigma_{\chi p}$$

probe spin-dependent and spin-independent DM-nucleon cross section, $\sigma^{SD}_{\chi-N}$ $\sigma^{SI}_{\chi-N}$

- complementary to direct detection
- different astrophysical systematic uncertainties

$$\Phi_\nu \rightarrow \Gamma_A \rightarrow \sigma_{\chi\chi}$$

probe velocity-averaged DM annihilation cross secton $<\sigma_{Ann} v>$

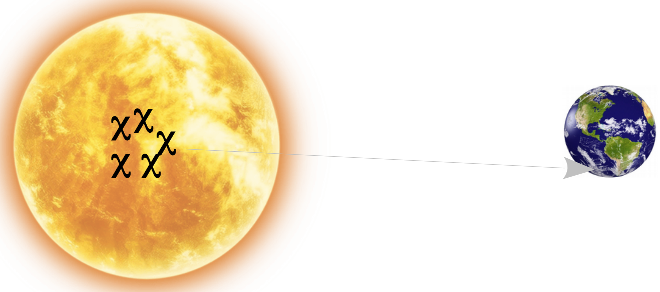
- complementary to searches with other messengers (γ, CRs...)
- shared astrophysical systematic uncertainties (halo profiles...)
- more background-free

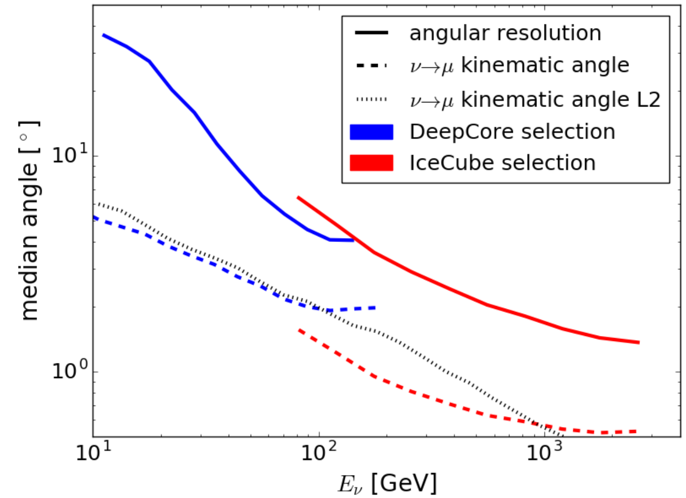
external inputs in the calculations

The prediction of a neutrino signal from dark matter annihilation is complex and involves many subjects of physics

- relic density calculations (cosmology)
- dark matter distribution in the halo (astrophysics)
- velocity distribution of the dark matter in the halo (astrophysics)
- physical properties of the dark matter candidate (particle physics)
- interaction of the dark matter candidate with normal matter (for capture)

  (nuclear physics/particle physics)
- self interactions of the dark matter particles (annihilation) (particle physics)
- transport of the annihilation products to the detector (astrophysics/particle physics)

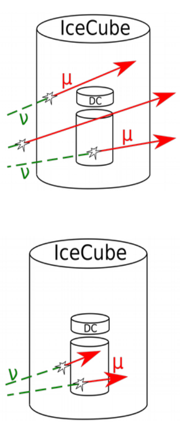


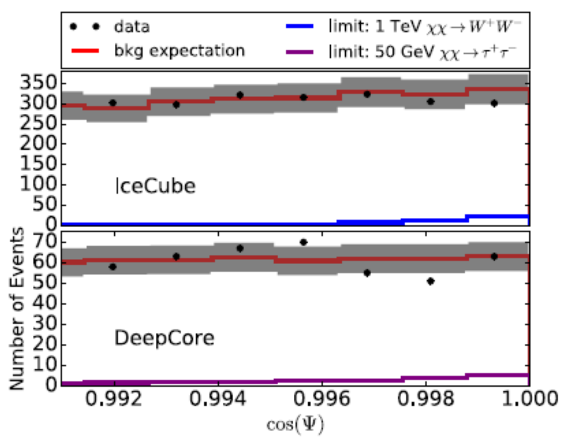


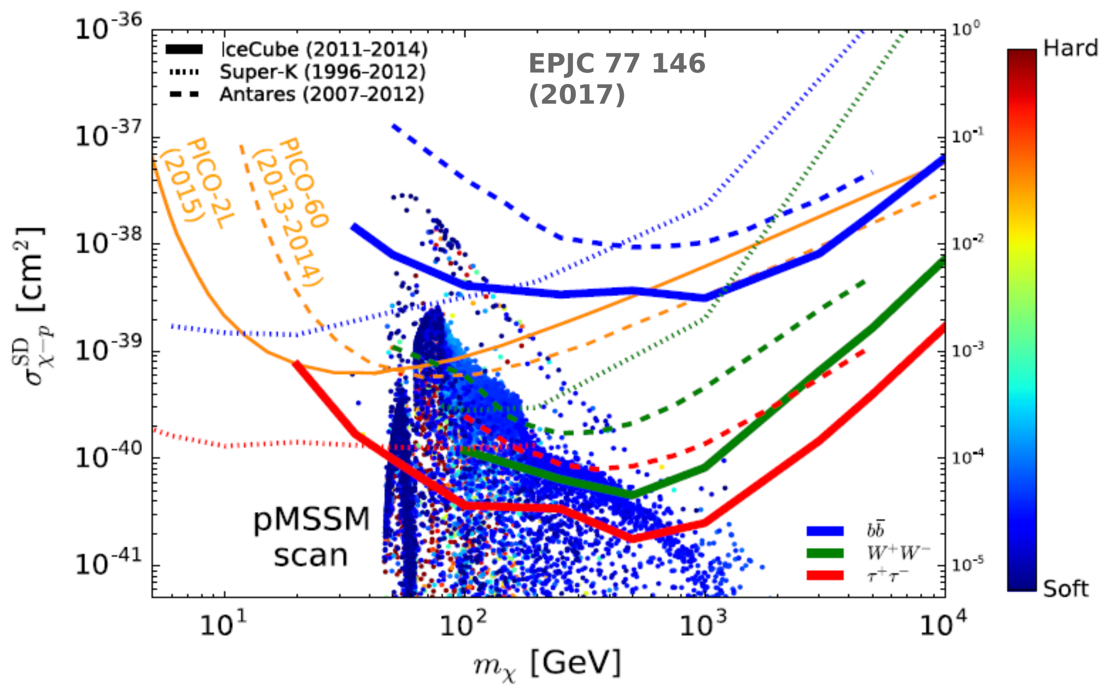
532 d livetime when Sun below horizon

DeepCore lowers energy threshold

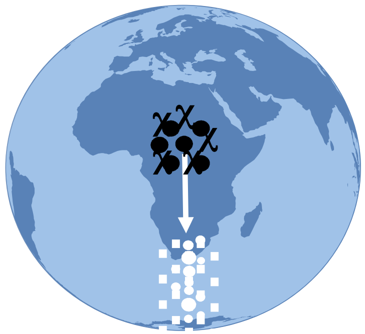
Limit driven by capture on p

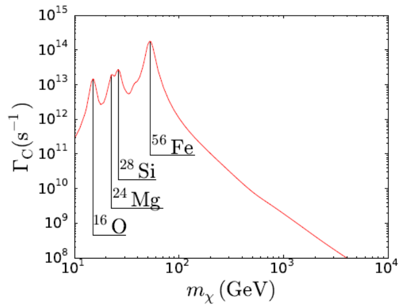






searches for dark matter from the Earth

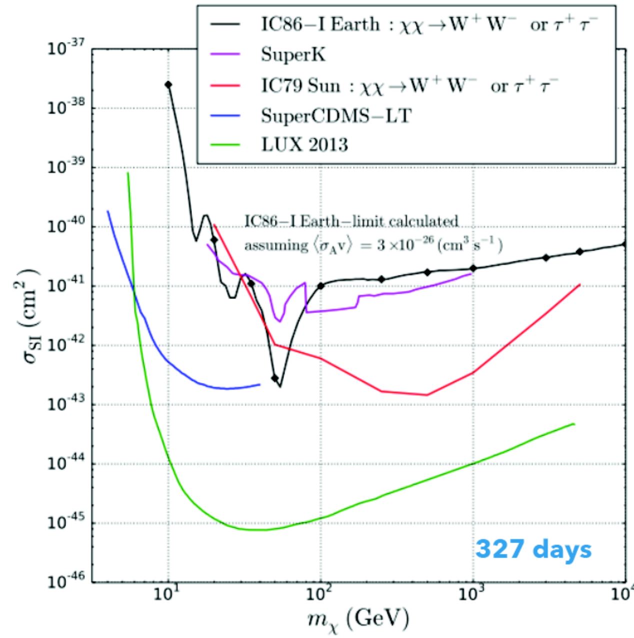




capture rate for an assumed $\sigma_{SI}=10^{-44}$ cm²

- Each string practically an independent detector
- 327 d lifetime
- Background needs to be very well understood:

  Earth has an unique position with respect to the detector
- No equilibrium: assumption on the annihilation cross-section
- Limit driven by resonant capture in Earth's elements (mainly spin 0)



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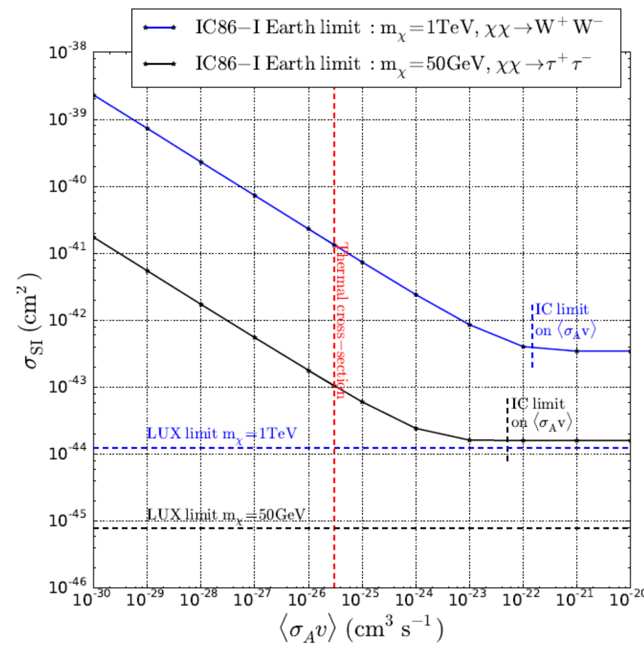
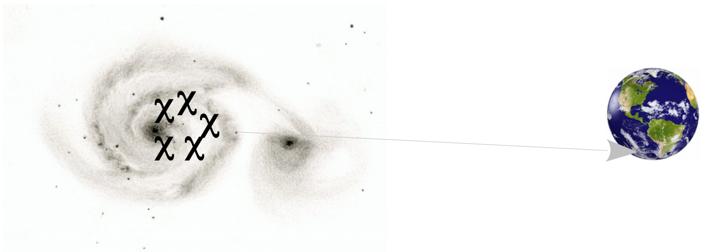


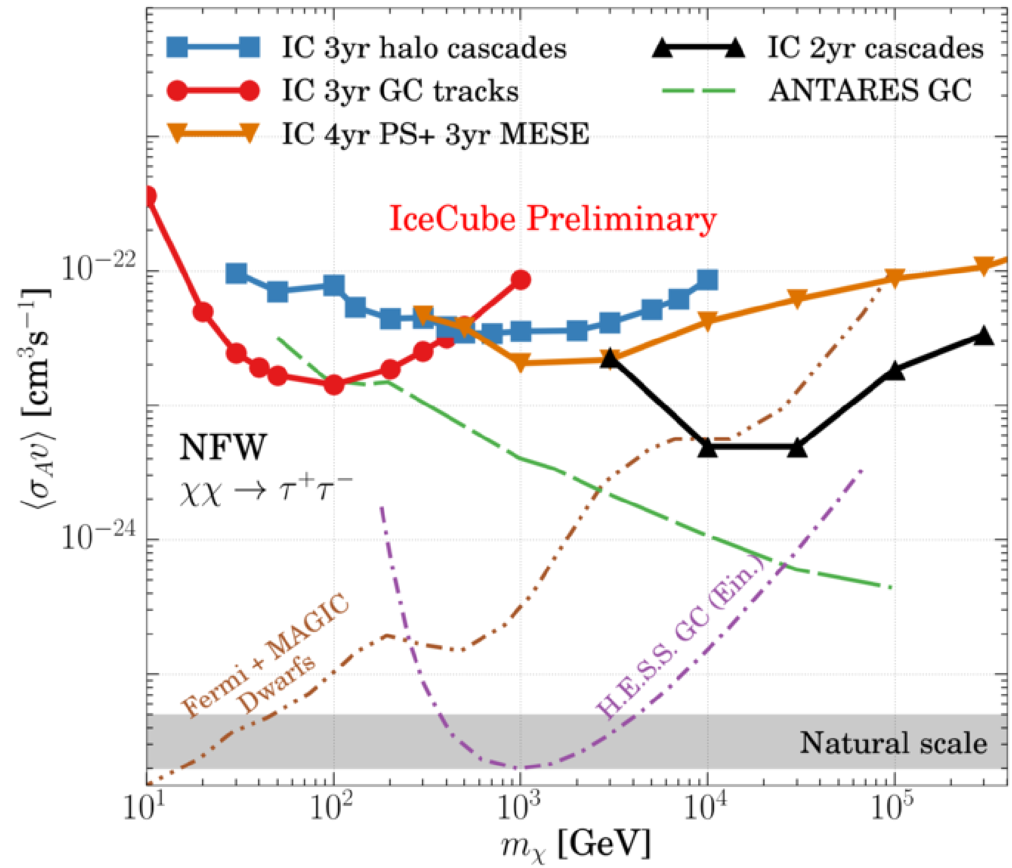
searches dark matter: galactic center and halo

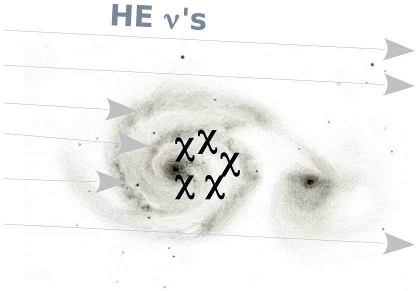


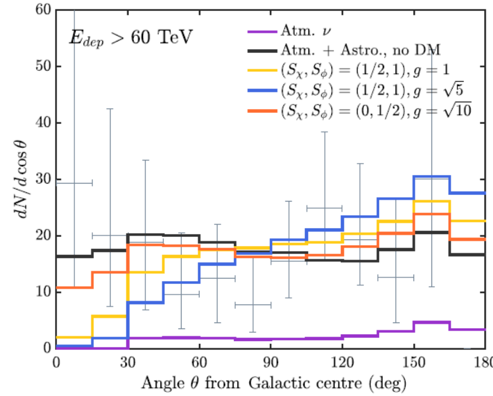
$$\frac{d\Phi(\Delta\Omega)}{dE} = \frac{\langle \sigma_A v \rangle}{4\pi \cdot 2m_\chi^2} \frac{dN}{dE} J(\Delta\Omega)$$

- Several analyses by IceCube using tracks and cascades, and high and low energy samples

- Analysis with large uncertainties due to different halo model assumptions (NFW as benchmark)







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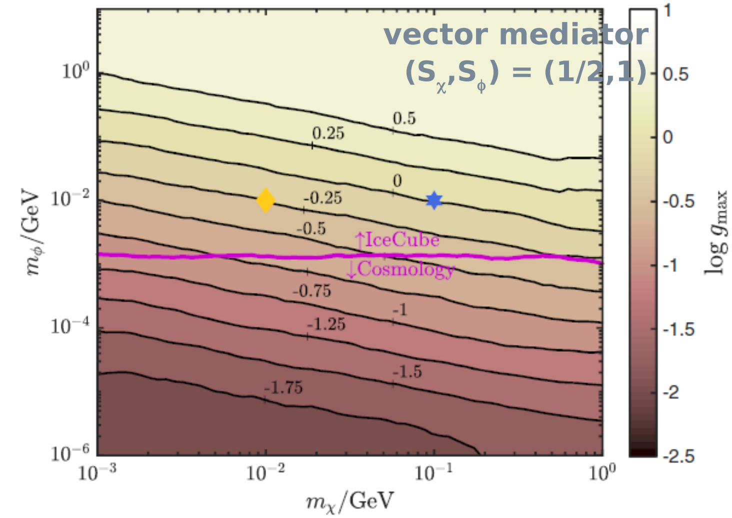
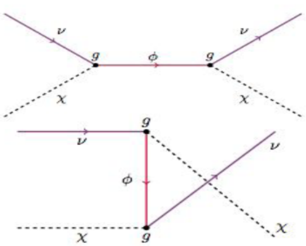
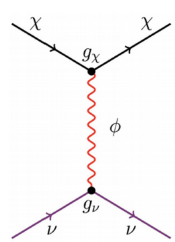
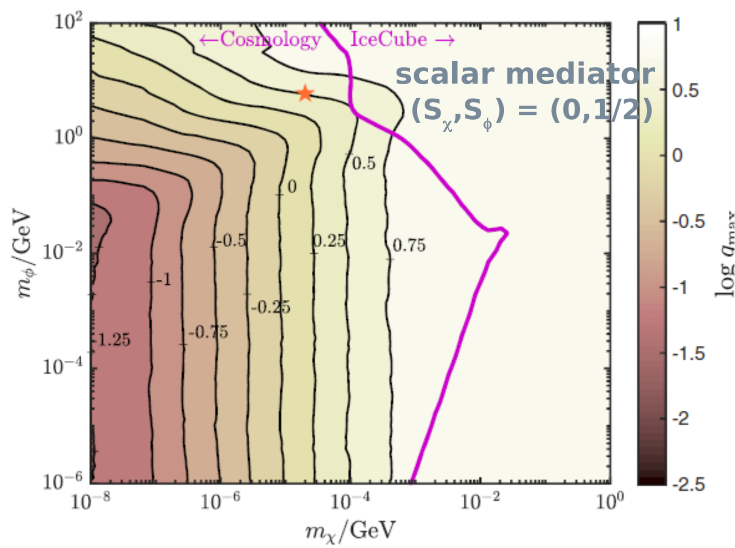


- Scattering of high energy cosmic neutrinos on DM in the halo can lead to a deficit of high energy neutrinos from the GC

- neutrino-DM interactions mediated by a scalar or vector mediator ϕ.



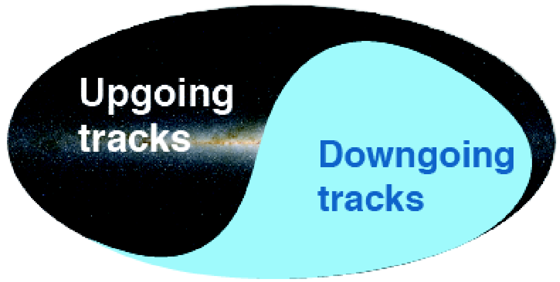




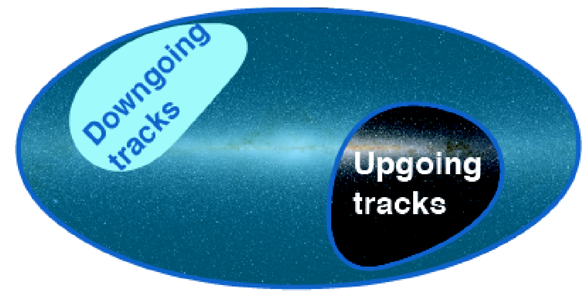
- limits on coupling constant, g, possible by measuring the isotropy of the HE neutrino flux

searches dark matter: combining sister experiments

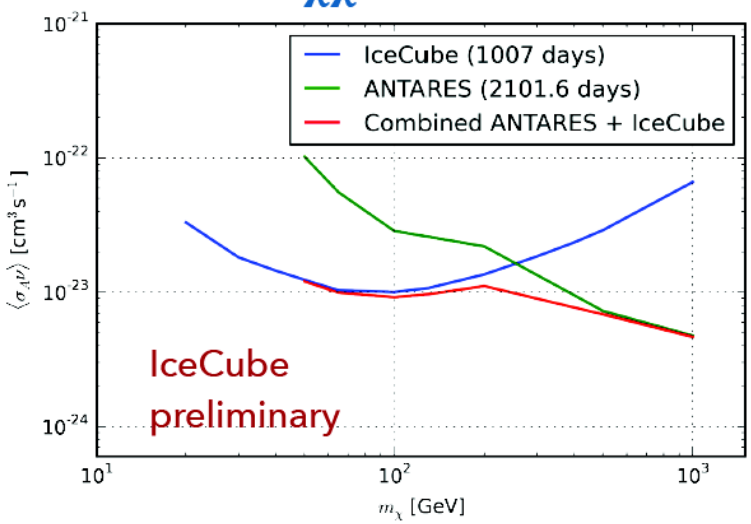
IceCube field of view



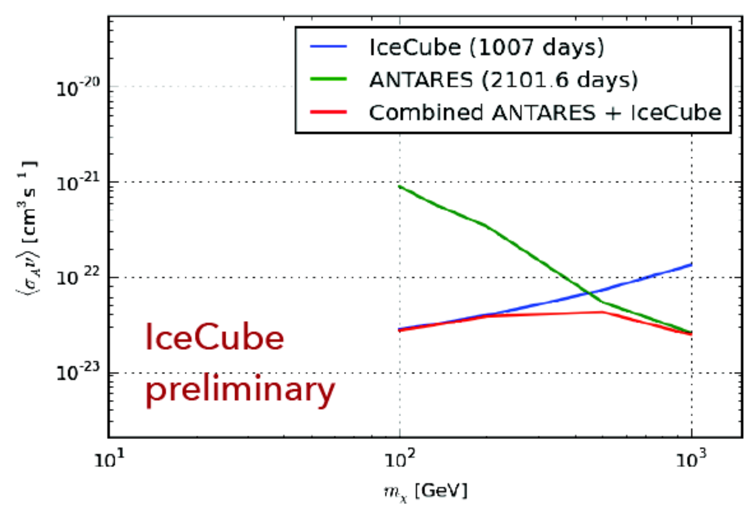
ANTARES field of view



$\chi\chi \rightarrow \tau^+\tau^-$

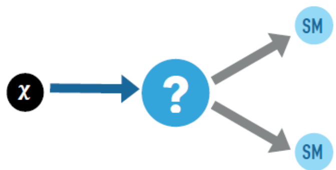


$\chi\chi \rightarrow W^+W^-$

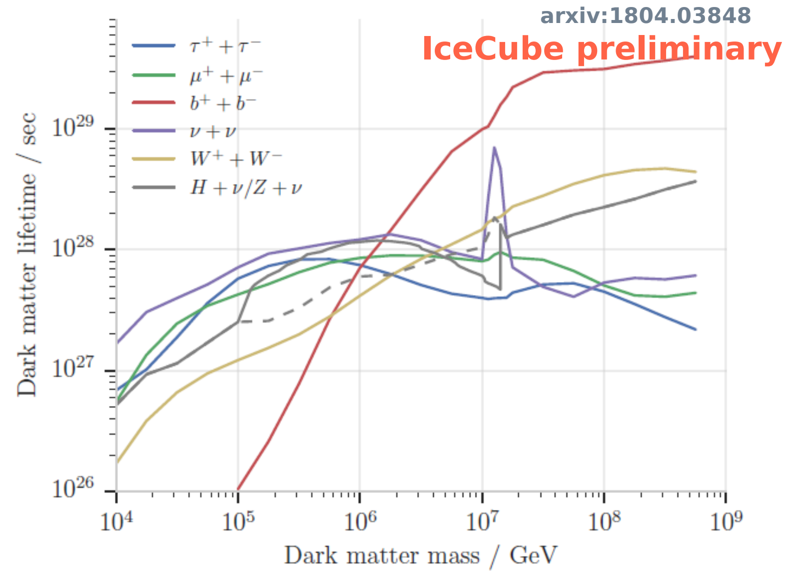


ICRC17 arXiv:1710.01197

searches dark matter: lifetime



- Two independent analyses:
  - 6 years tracks **(northern sky)**
  - 2 years cascades **(all sky)**
- Adding limits > 10 TeV



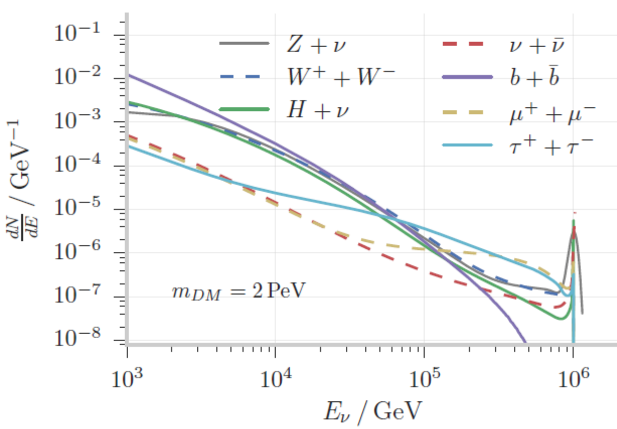
Signal: sum of

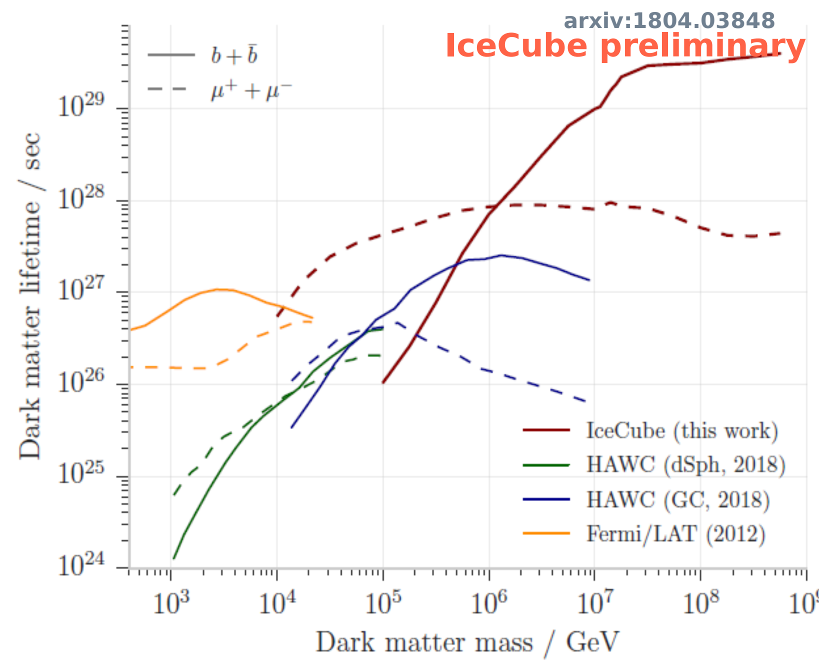
DM decays in the Halo:

$$\frac{d\Phi^{Galactic}}{dE_\nu} = \frac{1}{4\pi m_{DM}\tau_{DM}}\frac{dN_\nu}{dE_\nu}\int_0^\infty \rho(r(s,l,b))\,ds$$

DM decays in the Universe:

$$\frac{d\Phi^{Extra-Galactic}}{dE_\nu} = \frac{\Omega_{DM}\rho_c}{4\pi m_{DM}\tau_{DM}}\int_0^\infty \frac{1}{H(z)}\frac{dN_\nu}{dE_\nu}[(1+z)E_\nu]\,dz$$





Dark Matter remains one of the major open questions in physics today

Indirect detection with neutrino telescopes provides complementarity to other techniques due to different backgrounds and systematics

↳ A positive signal should be understood under the different messengers

IceCube has a lively program of dark matter searches, with competitive limits on dark matter-nucleon spin-dependent cross section and dark matter lifetime

Rich (astro)particle physics program with IceCube (I focused only on DM).
See C. Finley's talk in this workshop for multimessenger astronomy with IceCube