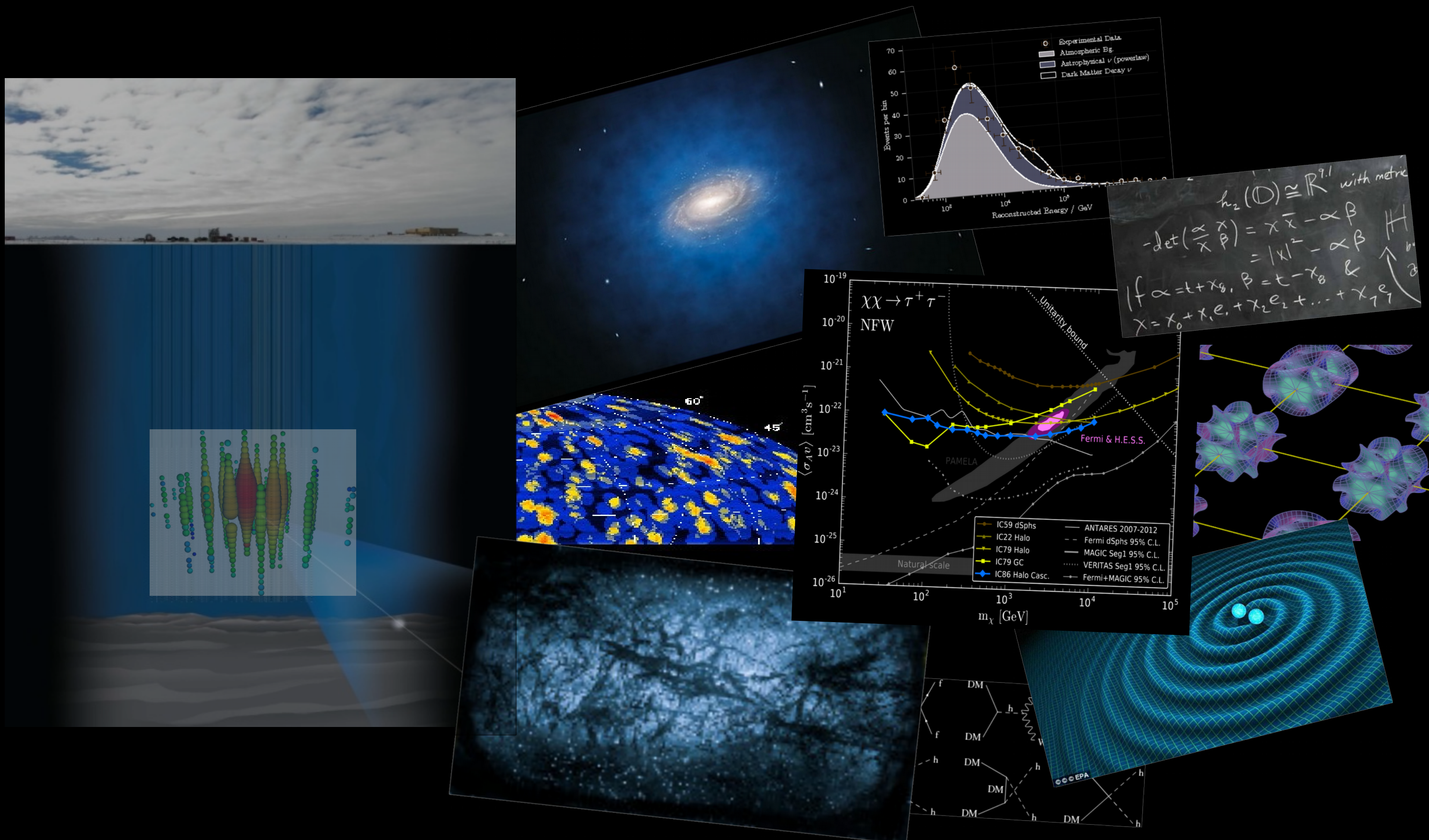
Recent results on Dark Matter searches with the IceCube neutrino telescope



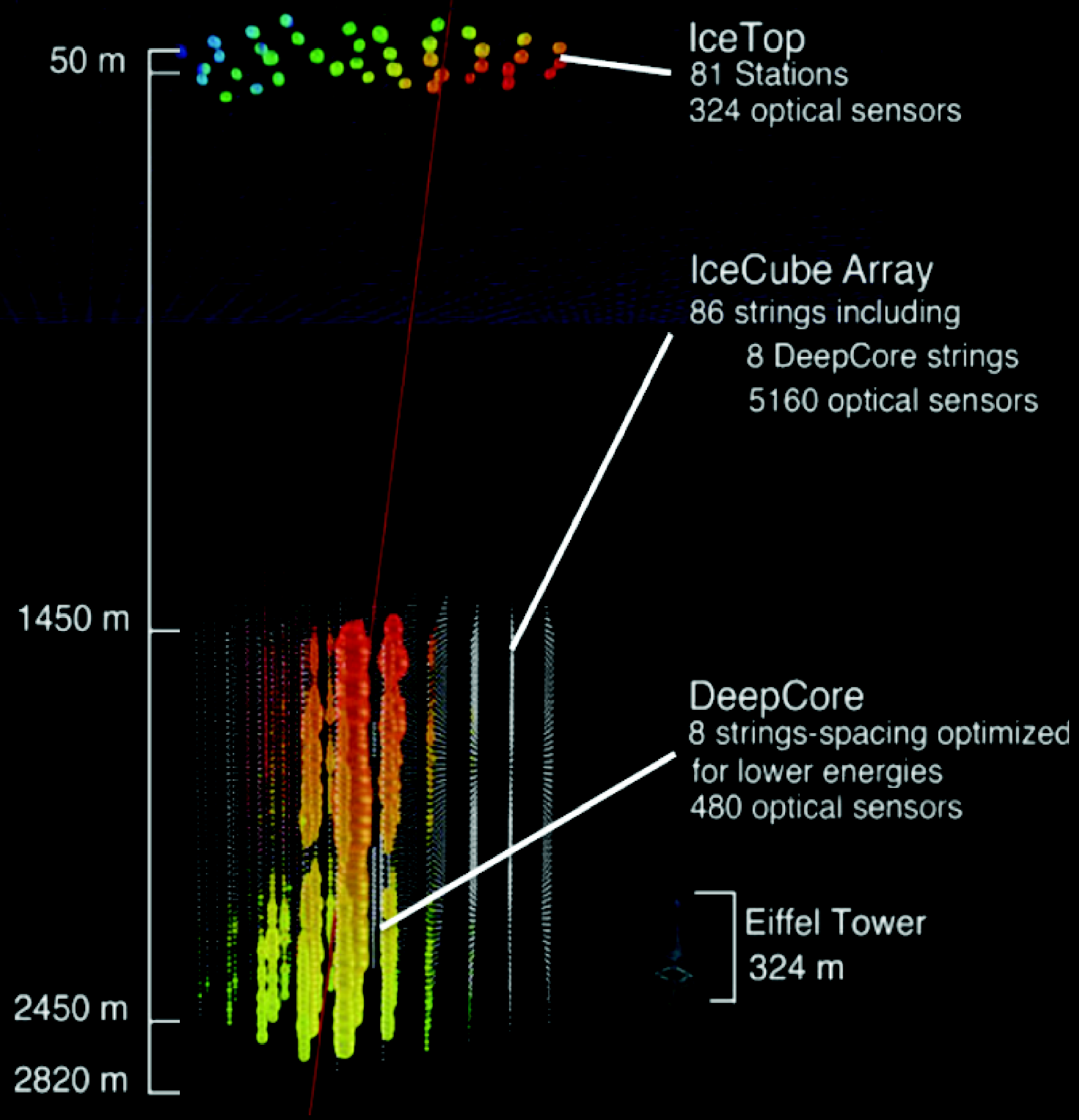
Carlos de los Heros
Uppsala University
for the IceCube Collaboration

DarkGhosts workshop. Brussels, November 13-14, 2018.

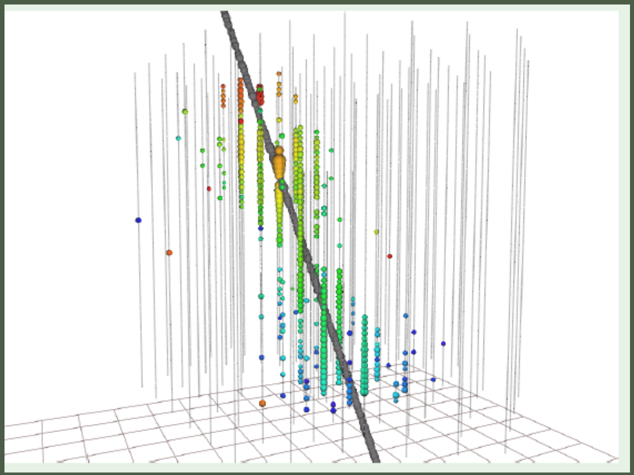
the IceCube Neutrino Observatory

5160 DOMs
instrumenting 1 km^3
(1 GT) of clear ice

2 ns time resolution



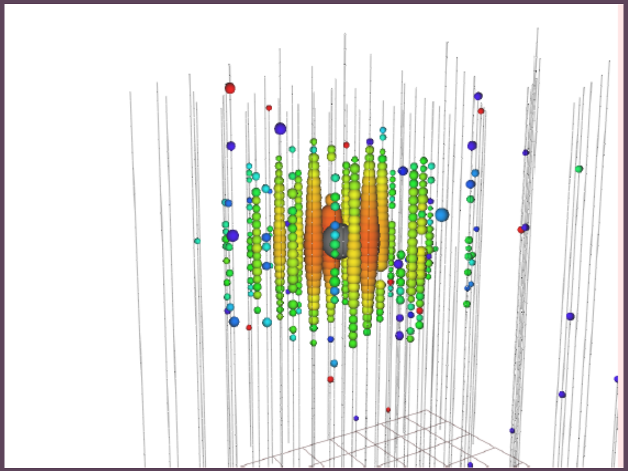
Track



- CC ν_μ
- Angular resolution <1°
- Energy resolution dE/E ≈25%

$$\nu_\mu + N \rightarrow \mu + X$$

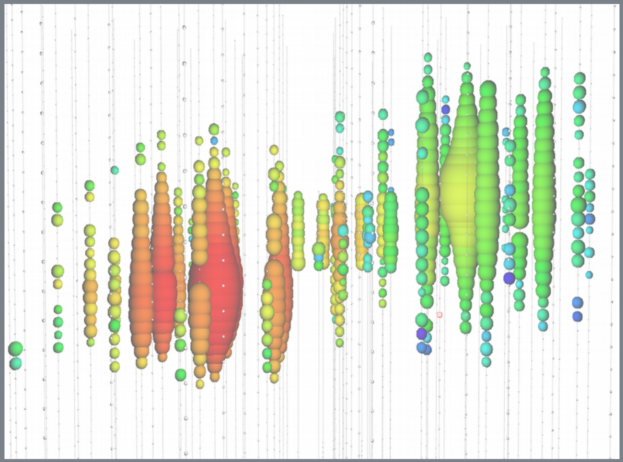
Cascade



- NC or CC ν_e/ν_τ
- Angular resolution ≈10°
- Energy resolution dE/E ≈10%

$$\nu_e + N \rightarrow e + X$$
$$\nu_x + N \rightarrow \nu_x + X$$

Double-bang



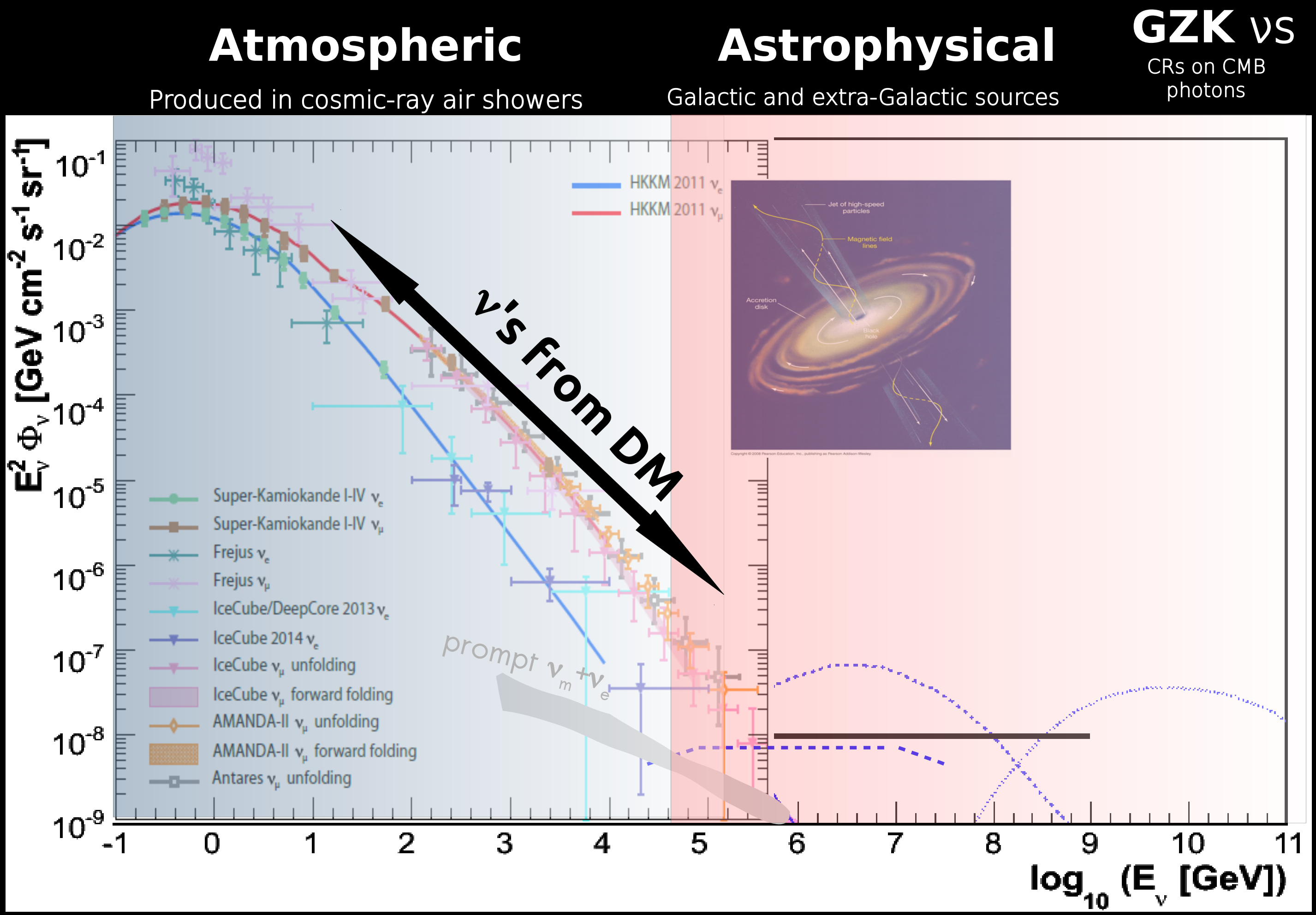
- High energy ν_τ (>100 TeV)
- Not observed yet

$$\nu_\tau + N \rightarrow \tau + X$$

early [color scale] late

amount of light in detector ∝ ν energy

DM searches: energy range



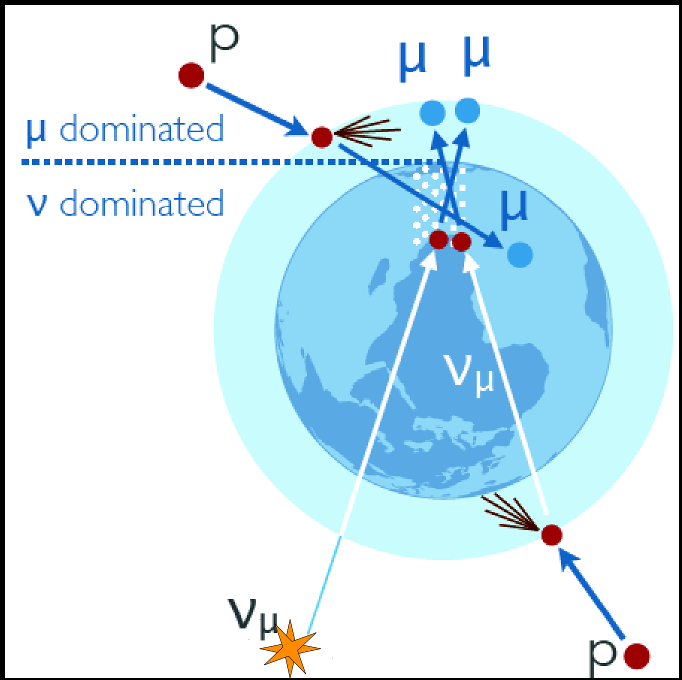
neutrino telescopes are subject to a high statistics (~100.000 /y km³), high-energy neutrino beam from the atmosphere

plus...

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

These are irreducible backgrounds for DM searches

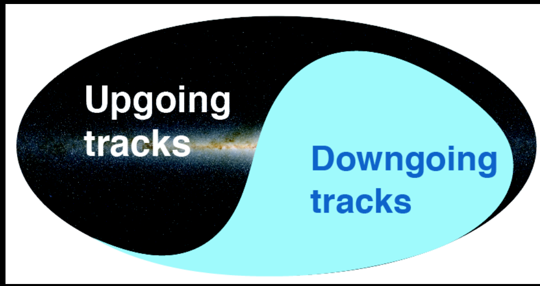
Southern Sky dominated by
atmospheric muons



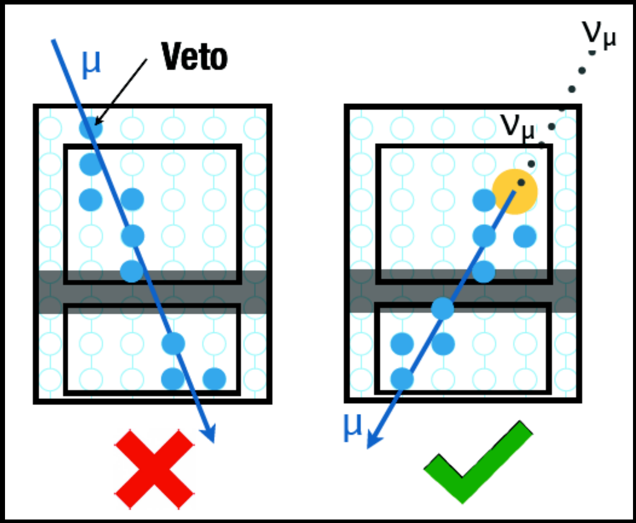
above horizon
(Southern sky)

below horizon
(Nothern sky)

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



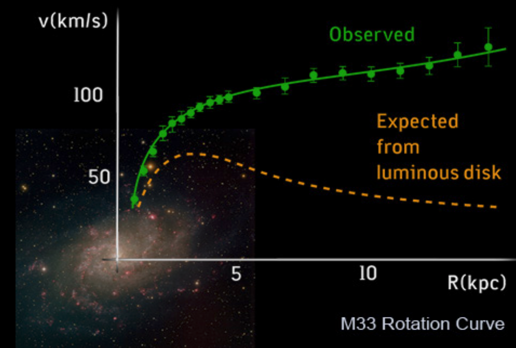
use outer layers as a veto to
select neutrino-induced starting events



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

evidence for dark matter

galaxy clusters

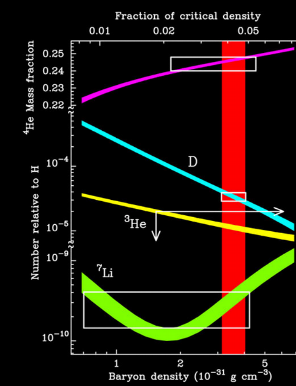


galaxy rotation curves

gravitational
lensing

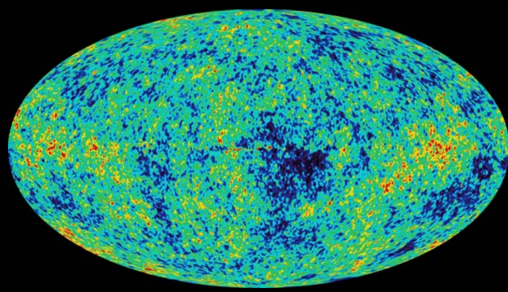
a weakly-interacting relic
“dark matter” particle can
explain the observations

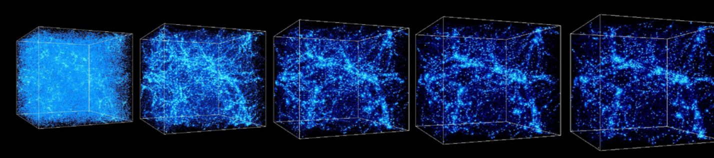
BBN



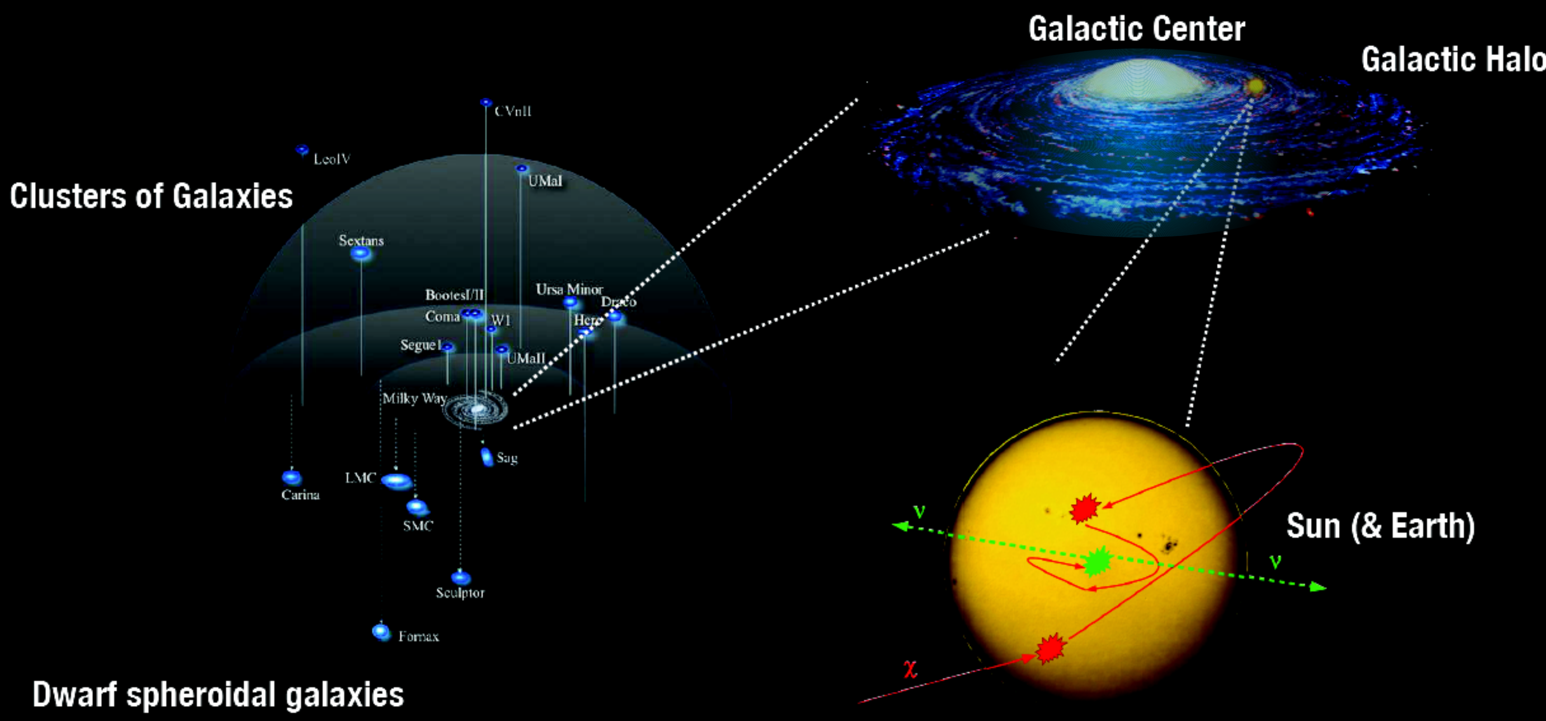
CMB

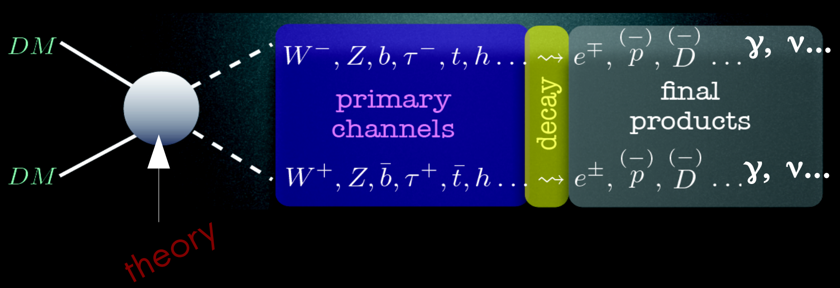
structure
formation





dark matter searches with neutrino telescopes





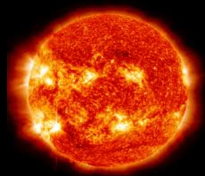
- Analyses based on Likelihood techniques comparing

  Signal: modelled from simulated neutrino events weighted to the desired annihilation/decay spectrum

  Background: Estimated from data (off-source) when possible

- Signal contamination on background estimation is substracted

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, $\sigma^{SD}_{\chi\text{-}N}$ $\sigma^{SI}_{\chi\text{-}N}$

- complementary to direct detection
- different astrophysical systematic uncertainties

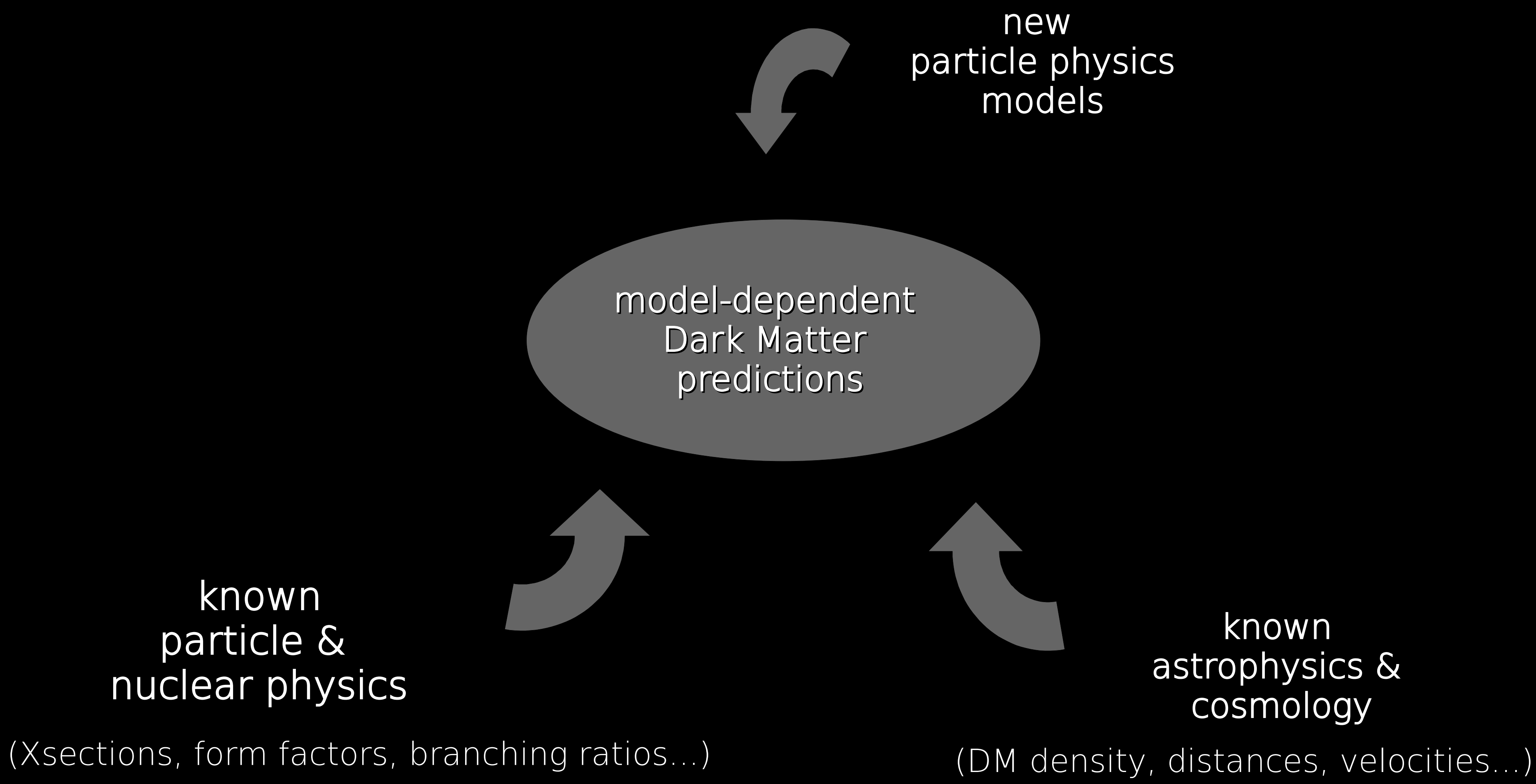
$$\Phi_\nu \rightarrow \Gamma_A \rightarrow \sigma_{\chi\chi}$$

probe velocity-averaged DM annihilation cross secton $\langle\sigma_{Ann} v\rangle$

DM lifetime τ

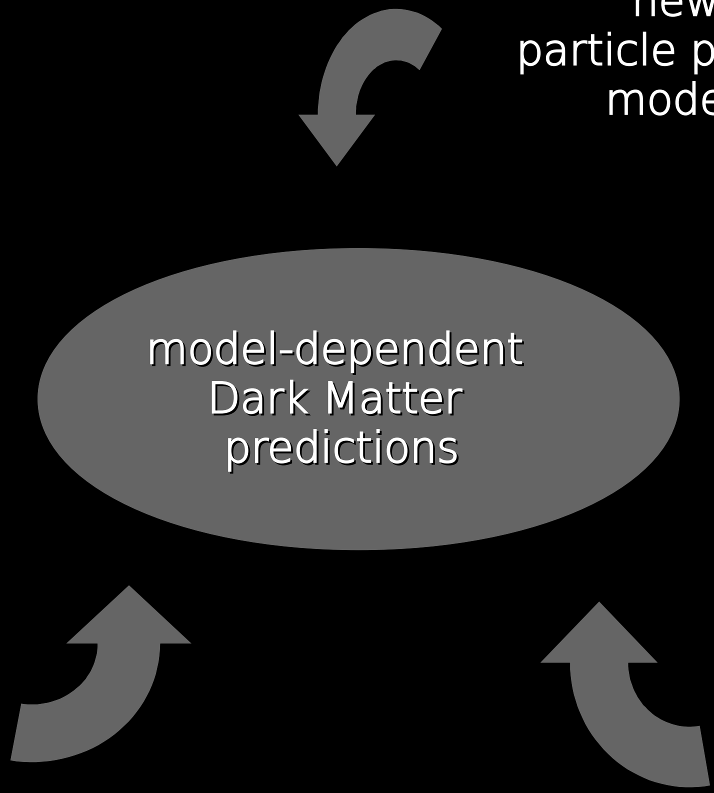
- complementary to searches with other messengers (γ, CRs...)
- shared astrophysical systematic uncertainties (halo profiles...)
- more background-free

external inputs in the calculations



external inputs in the calculations

new
particle physics
models



known
particle &
nuclear physics

(Xsections, form factors, branching ratios...)

known
astrophysics &
cosmology

(DM density, distances, velocities...)

uncertainties on these “known physics” affect dark matter predictions for any given model, and enter differently in different approaches

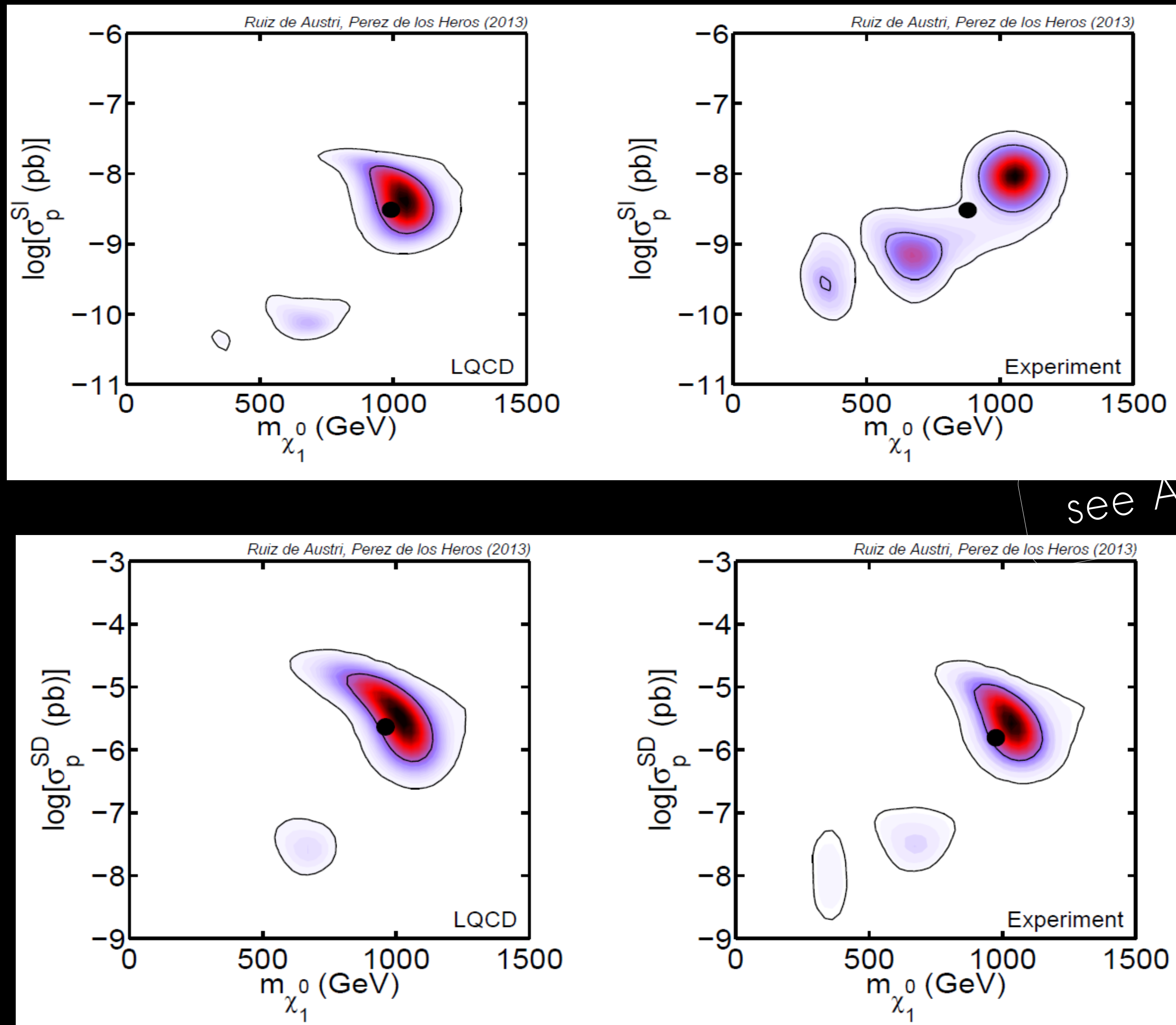
effect of using two calculations of the strangeness form factor of the nucleon

JCAP 1311 (2013) 049

LQCD | Experiment

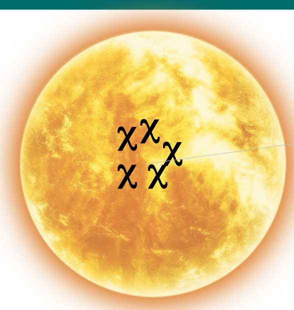
... XENON

... IceCube



see A. Ibarra's talk

searches for dark matter from the Sun



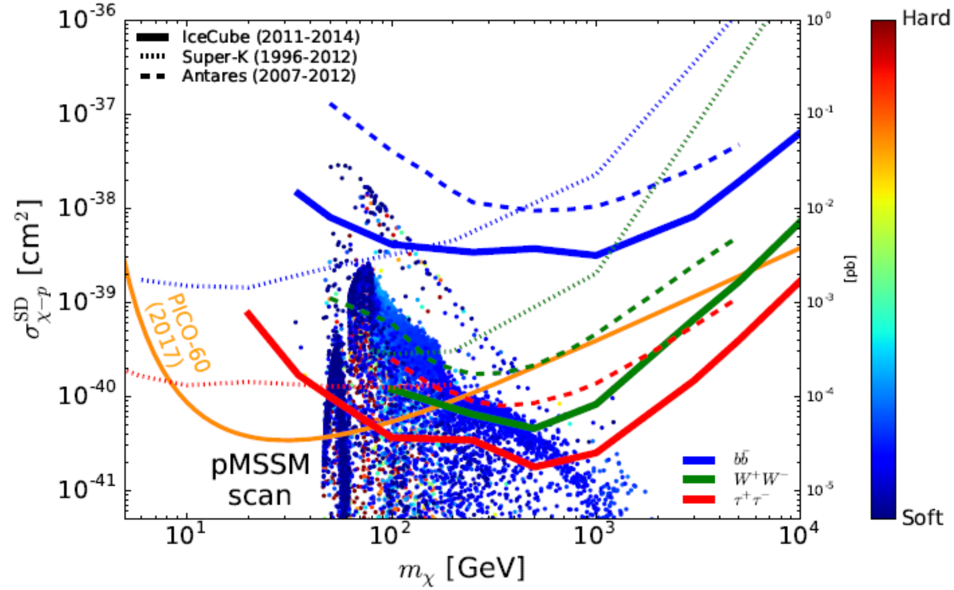
signal PDF:

$$S_i(\vec{x}_i, E_i, m_X, c_{ann}) =$$

$$K(|\vec{x}_i - \vec{x}_{sun}(t_i)|, k_i) \times E_{m_X, c_{ann}}(E_i)$$

angular x energy term

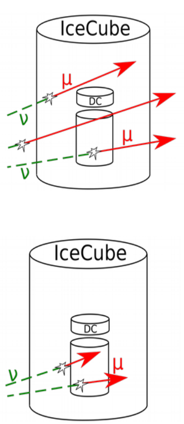
EPJ C77 (2017)3,146
PoS(ICRC2017)912

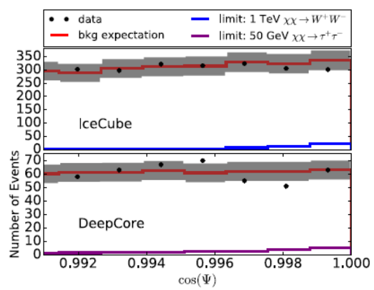


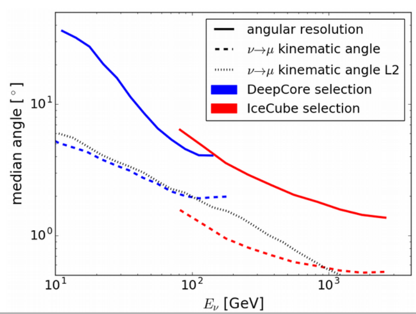
532 d livetime when Sun below horizon

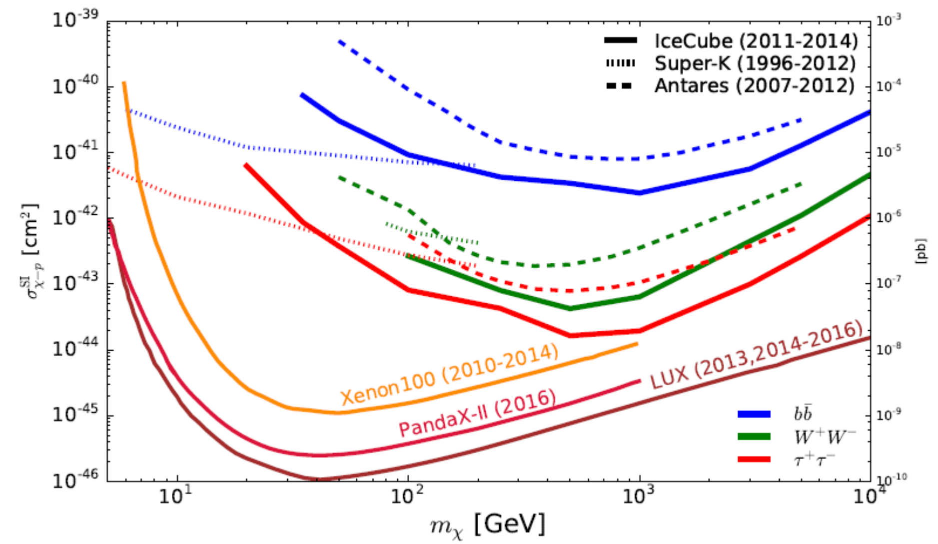
Use tracks for better pointing

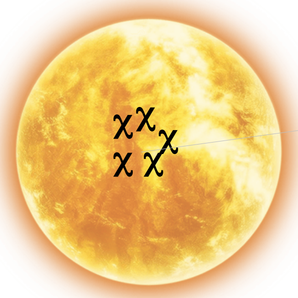
Limit driven by capture on p











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angular x energy term

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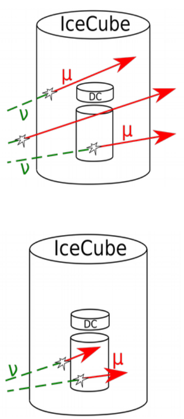
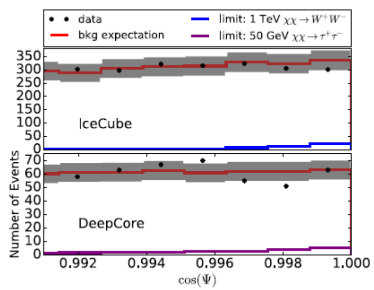
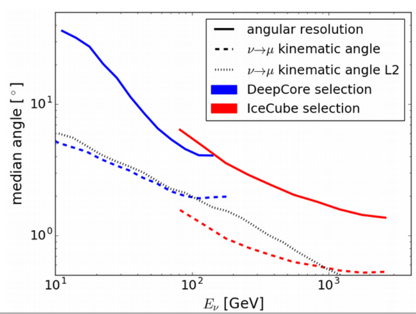
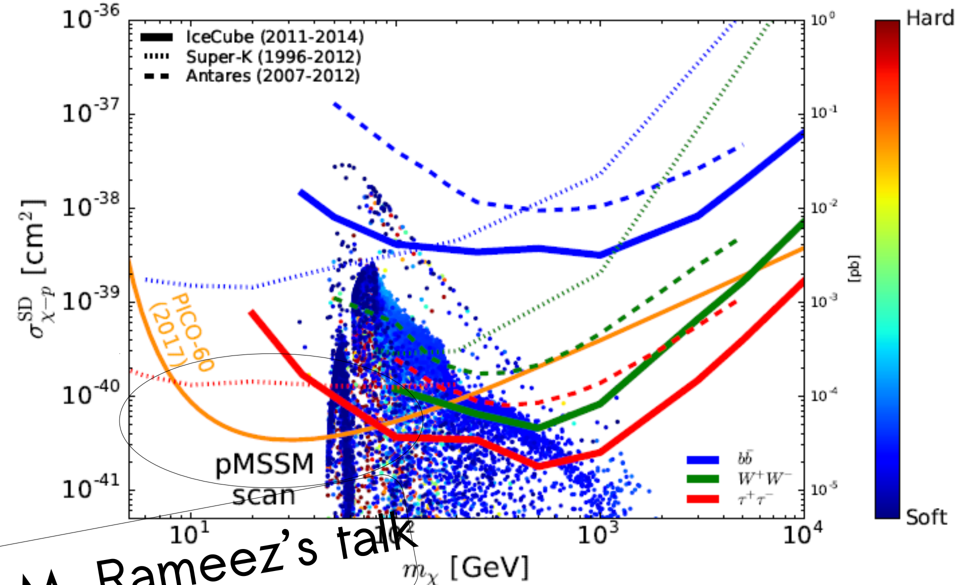


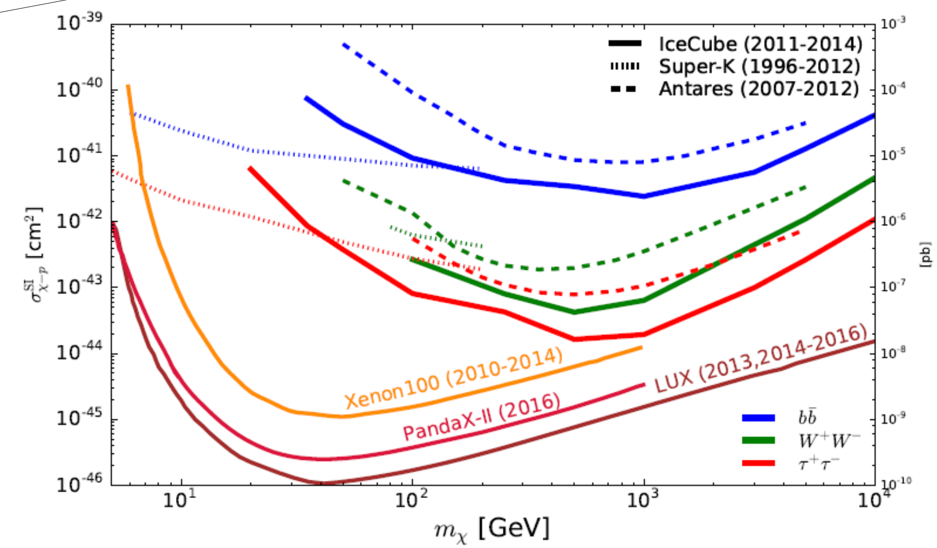


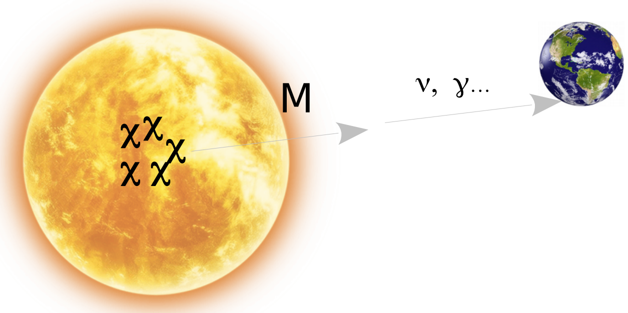


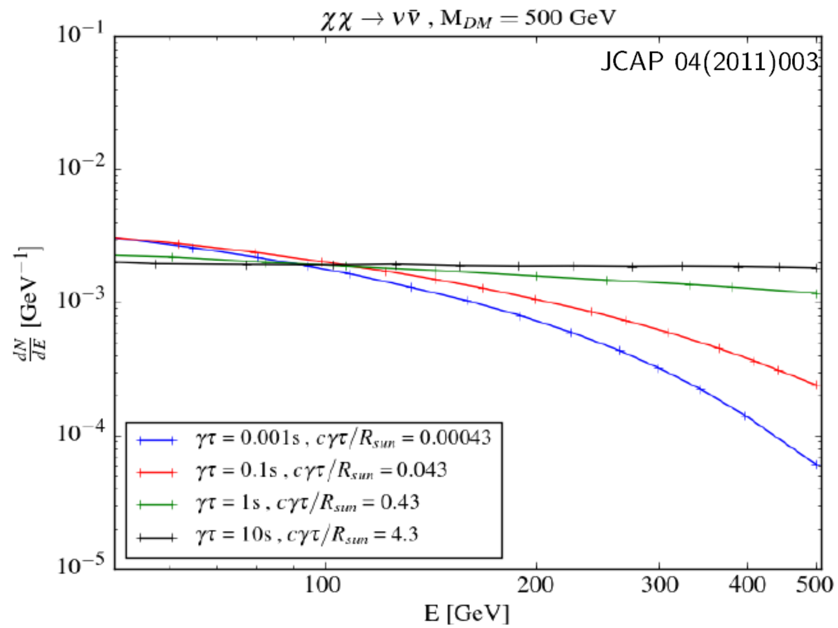
EPJ C77 (2017)3,146
PoS(ICRC2017)912



see M. Rameez's talk







- DM annihilates to a mediator that can decay outside the Sun

- Energies of resulting particles not degraded by their passage through the Sun

- Mediator can decay to other channels, γ...

--> possibility of "multimessenger DM searches" from the Sun

see C. Tönnis talk

Self interacting DM

If the dark matter has a self-interaction component, $\sigma_{\chi\chi}$, the capture in astrophysical objects should be enhanced

$$\frac{dN_\chi}{dt} = \Gamma_C - \Gamma_A = (\Gamma_{\chi N} + \Gamma_{\chi\chi}) - \Gamma_A$$

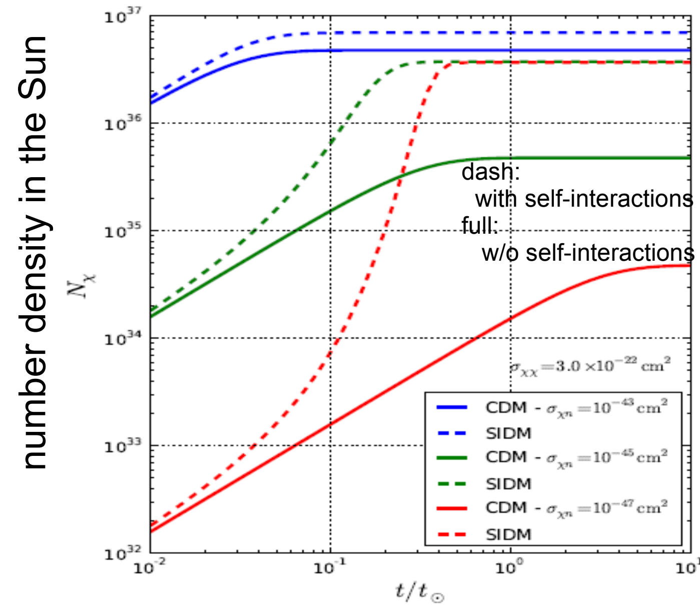
(Zentner, Phys. Rev. D80, 063501, 2009)

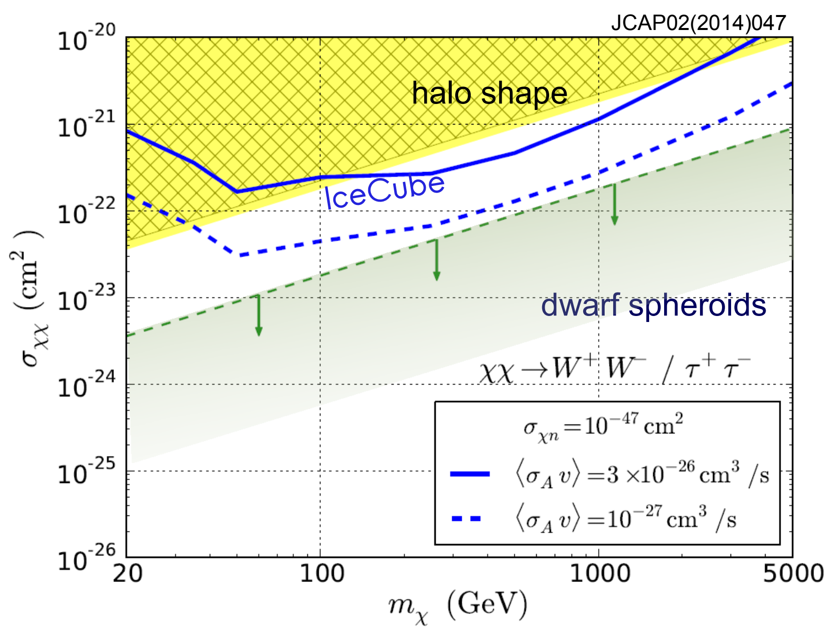
→ maximum annihilation rate reached earlier than in collisionless models

$\sigma_{\chi\chi}$ can naturally avoid cusped halo profiles

can induce a higher neutrino flux from annihilations in the Sun

limits on $\sigma_{\chi\chi}$ can be set by neutrino telescopes





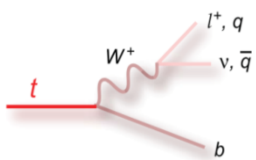
Super heavy DM

Produced non-thermally at the end of inflation

Strong Xsection (simply means non-weak in this context)

mass from ~10^4 GeV to 10^{18} GeV (no unitarity limit since production non thermal)

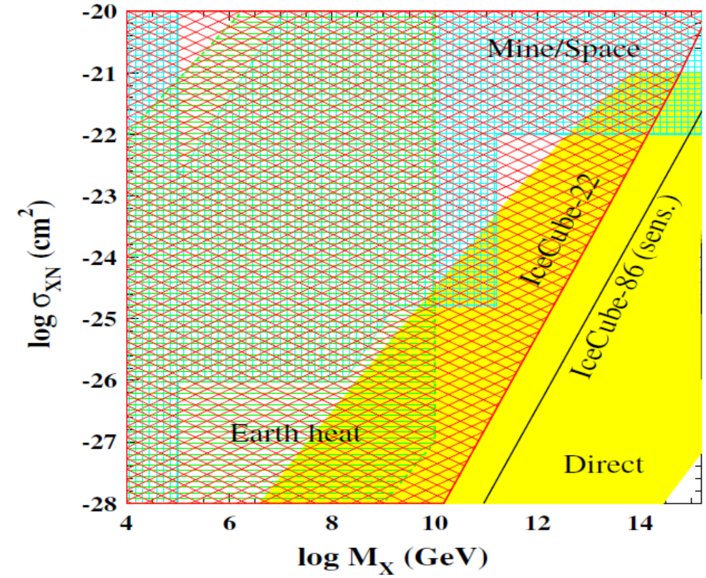
S+S → t $\bar{t}$

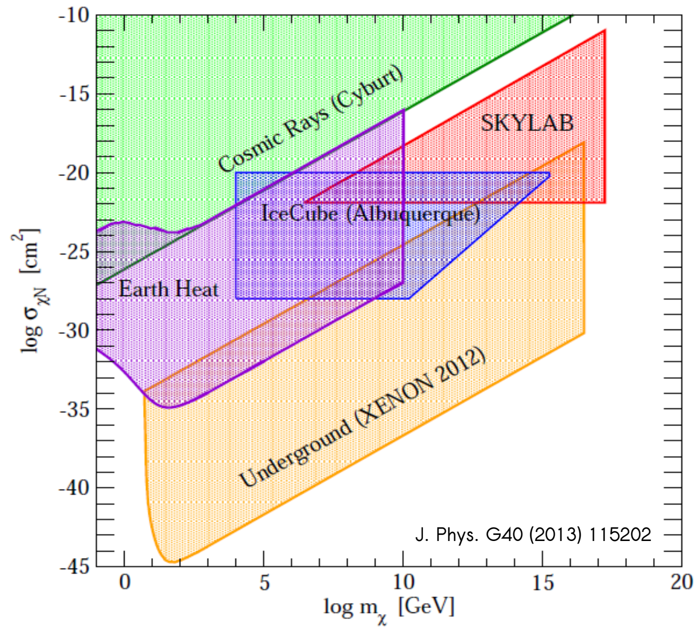


~$3 \times 10^5 \sqrt{m_x}/10^{12}$ tops per annihilation

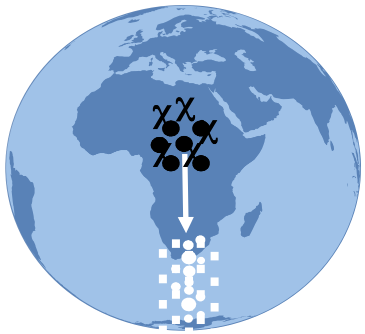
$$\rightarrow \quad N_s(m_X, \sigma_{XN}) = N_t \cdot BR_W \cdot \Gamma_A(m_X, \sigma_{XN}) \cdot T \cdot \int \frac{dN_\nu}{dE} A_{eff}\, dE$$

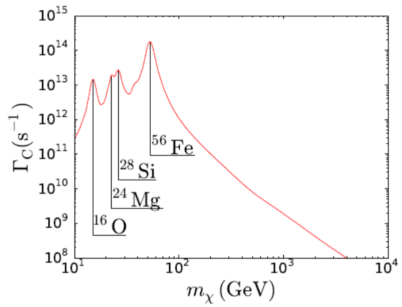
Phys. Rev. D81, 063510 (2010)





J. Phys. G40 (2013) 115202

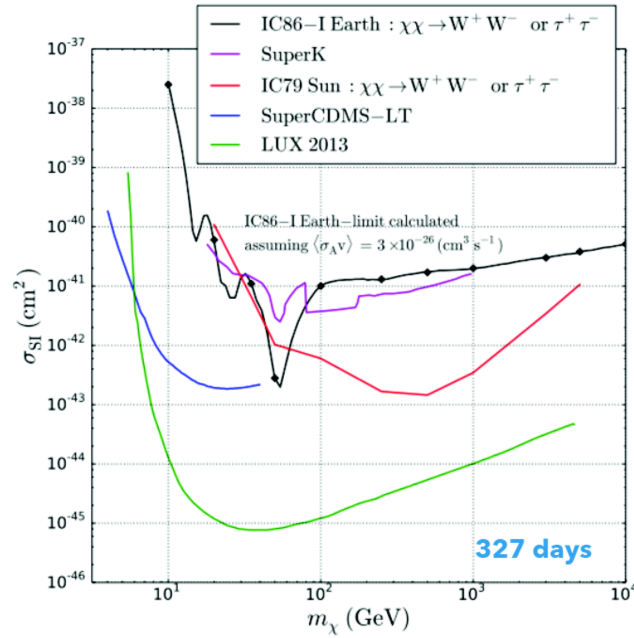




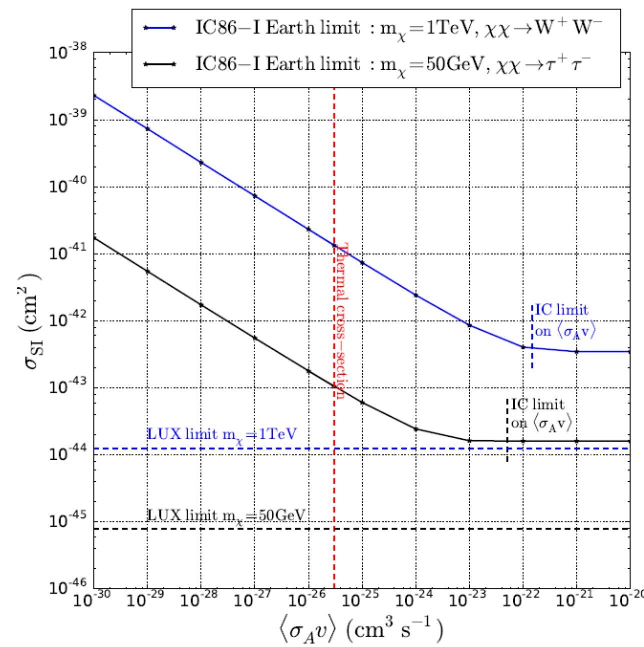
capture rate for an assumed $\sigma_{SI}=10^{-44}$ cm^2

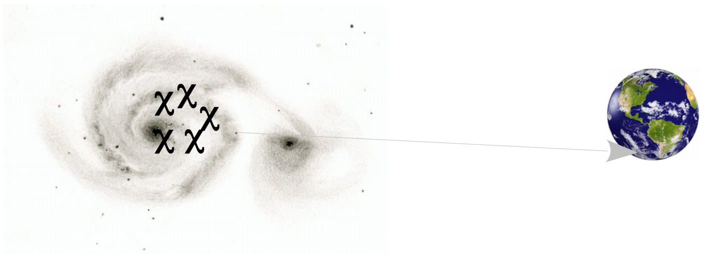
- Each string practically an independent detector
- 327 d lifetime
- Background needs to be very well understood:

  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)



Eur. Phys. J. C (2017) 77:82

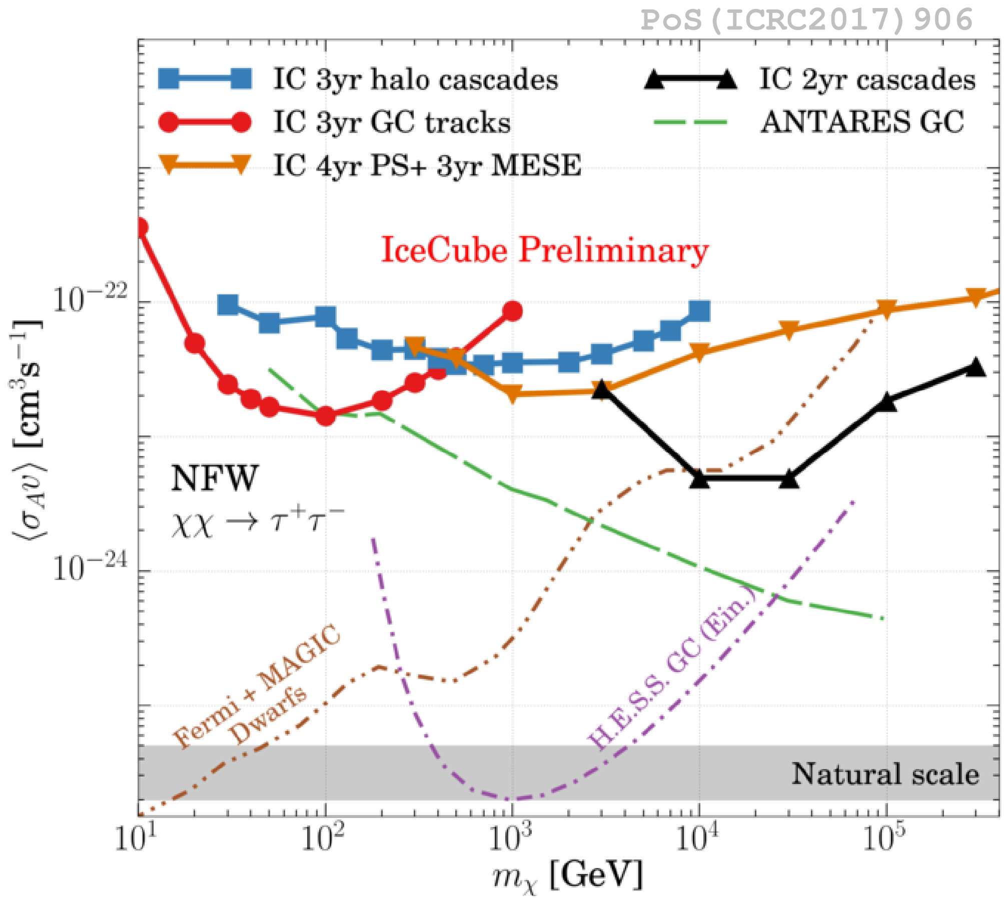


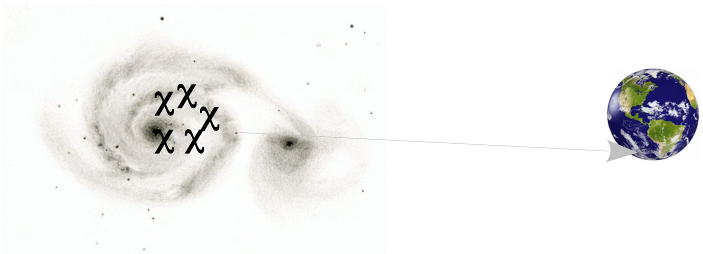


$$\frac{d\Phi(\Delta\Omega)}{dE} = \frac{\langle \sigma_A v \rangle}{4\pi \cdot 2 m_\chi^2} \frac{dN}{dE} J(\Delta\Omega)$$

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

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

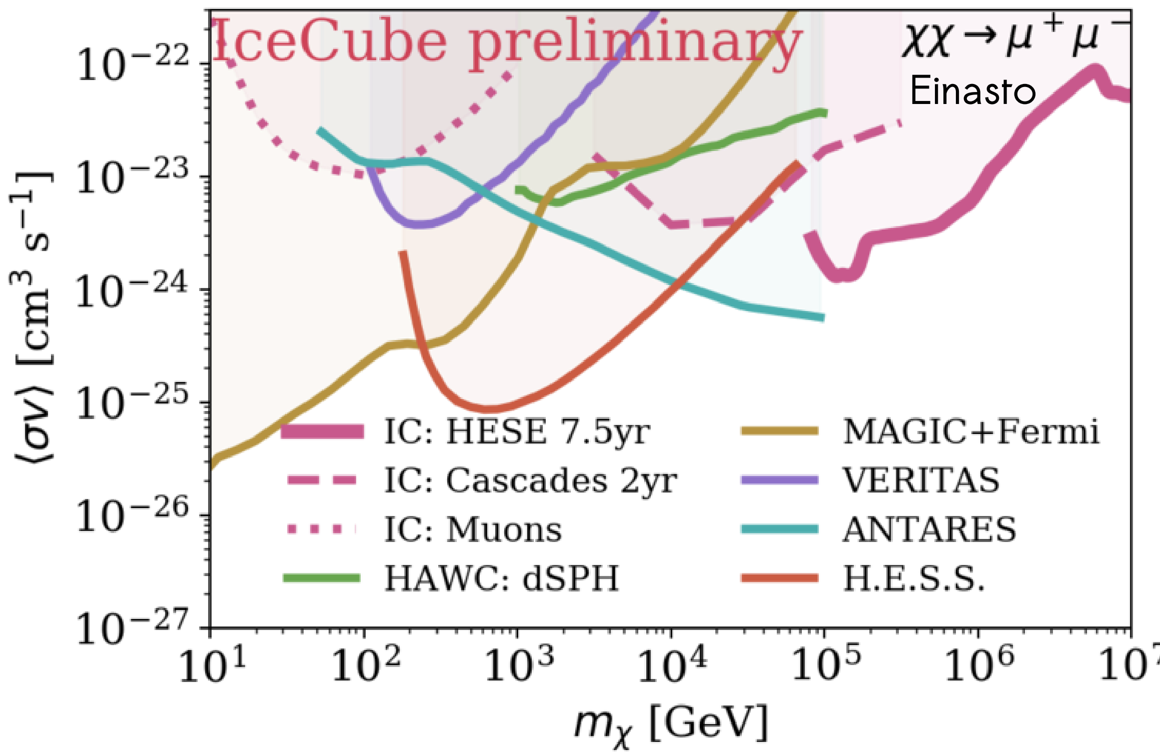




$$\frac{d\Phi(\Delta\Omega)}{dE} = \frac{\langle\sigma_A v\rangle}{4\pi \cdot 2m_\chi^2}\frac{dN}{dE}J(\Delta\Omega)$$

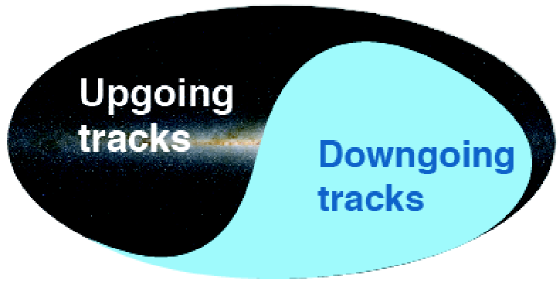
- High Energy Starting Event (HESE) 7-year sample allows to extend limits beyond m_x 10^5 GeV

- Shown μμ channel assuming a Einasto profile

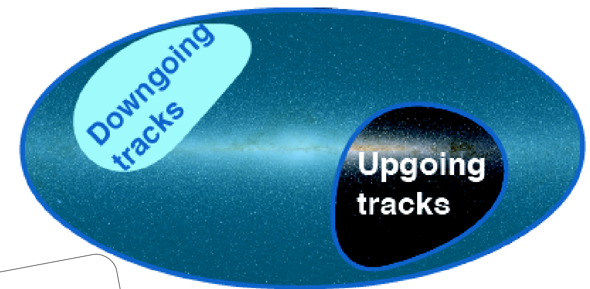


searches dark matter: combining sister experiments

IceCube field of view

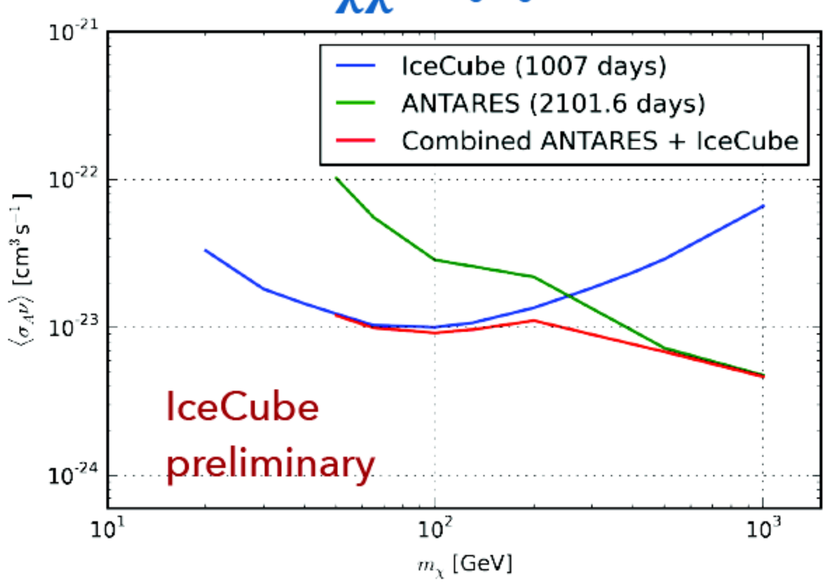


ANTARES field of view

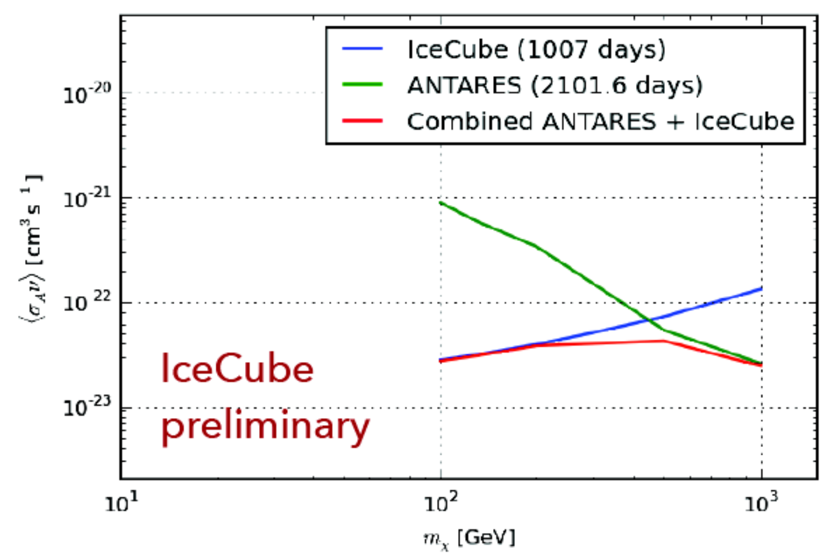


see I. Nadege's talk

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



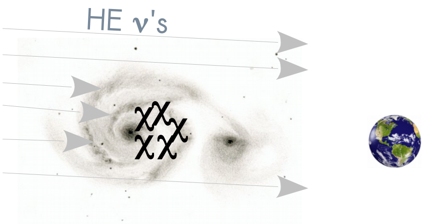
$\chi\chi \rightarrow W^+W^-$

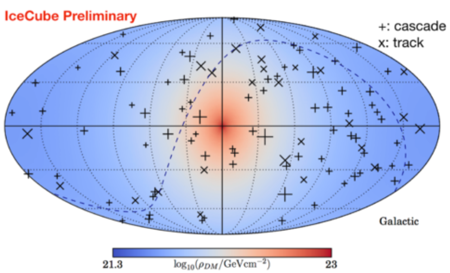


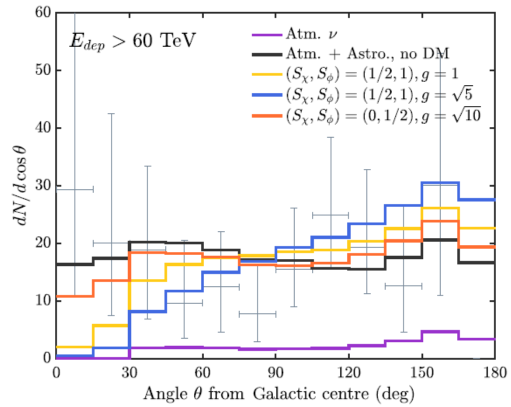
ICRC17 arXiv:1710.01197

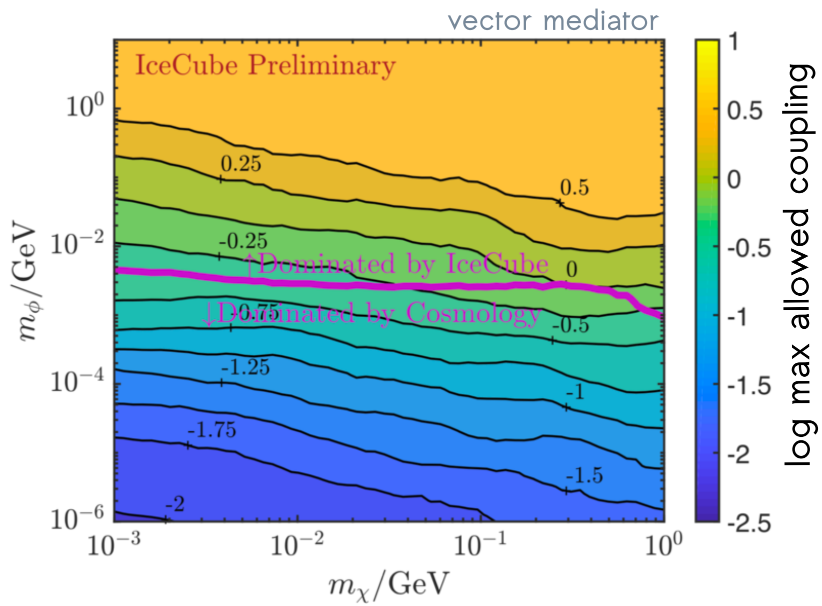
searches dark matter: neutrino-DM scattering

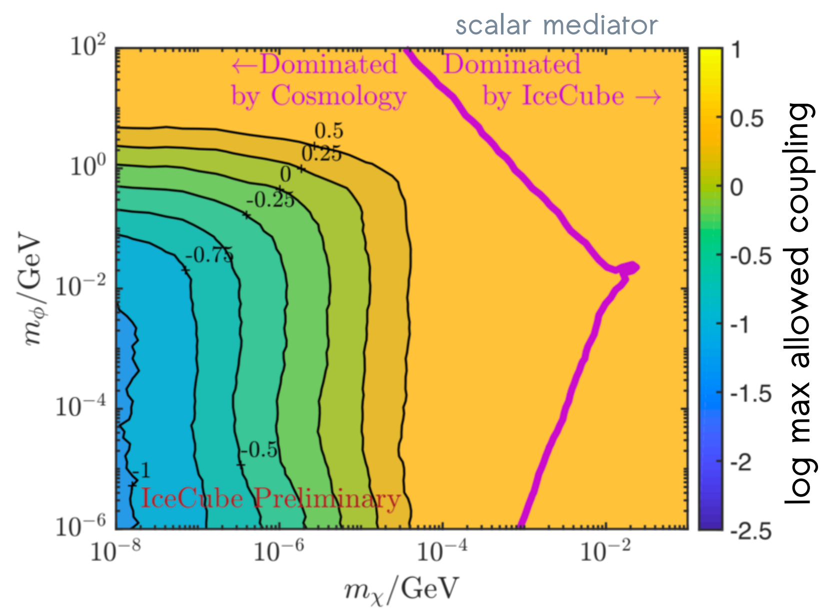
PRL 119, 201801 (2017)





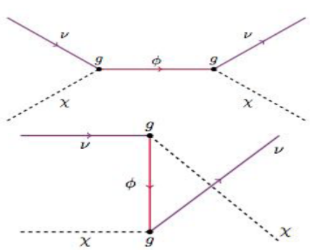


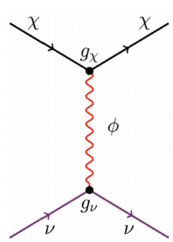




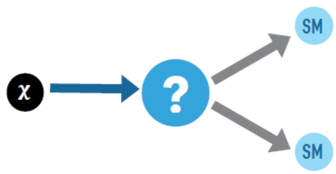
- Scattering of high energy cosmic neutrinos on DM in the halo can lead to a deficit of high energy neutrinos from the GC

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

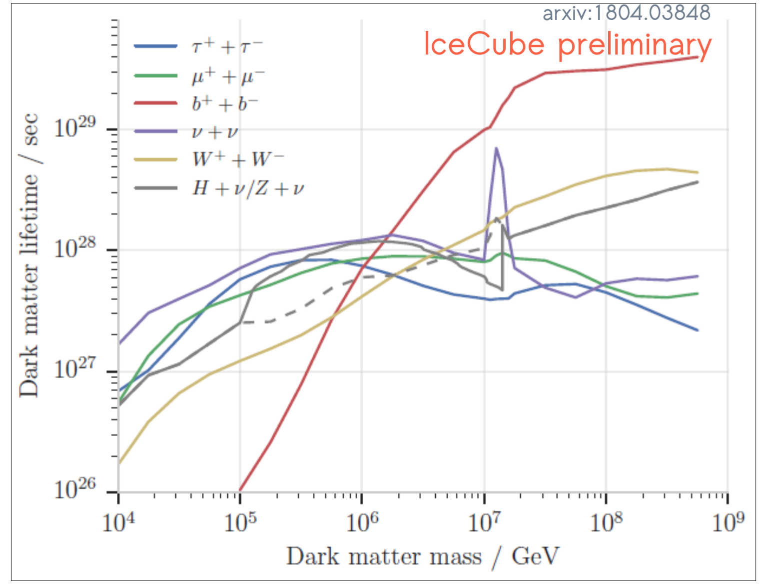




- limits on coupling constant, g, possible by measuring the isotropy of the HE neutrino flux



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



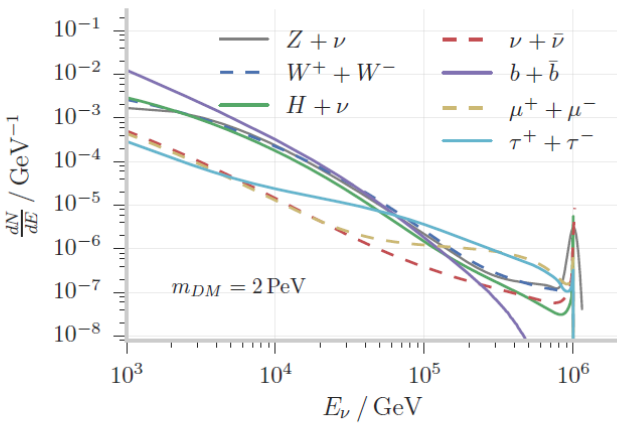
Signal: sum of

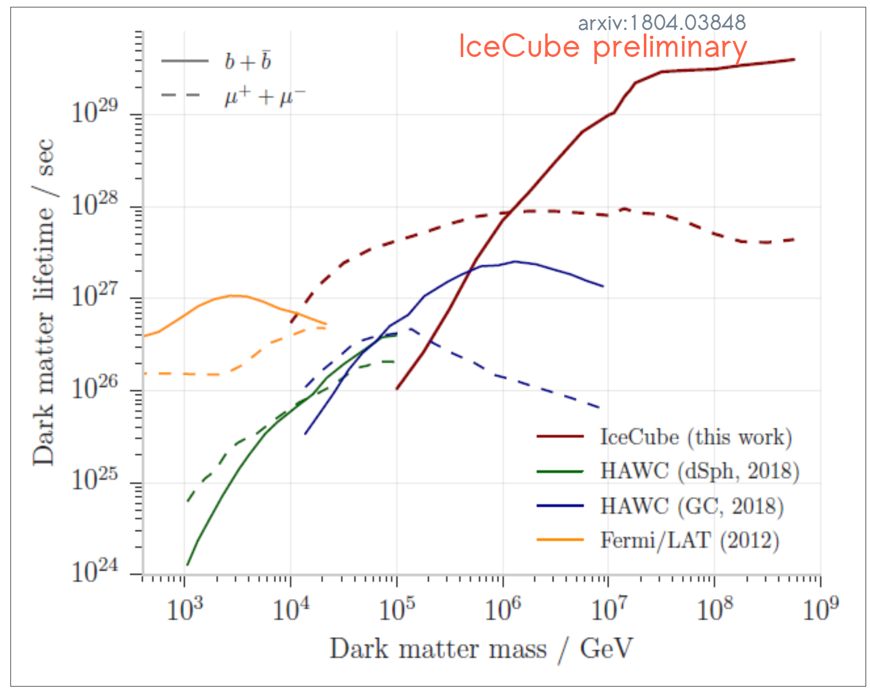
DM decays in the Halo:

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

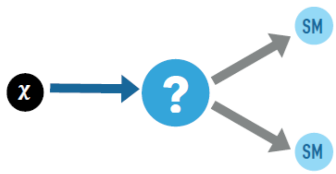
DM decays in the Universe:

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





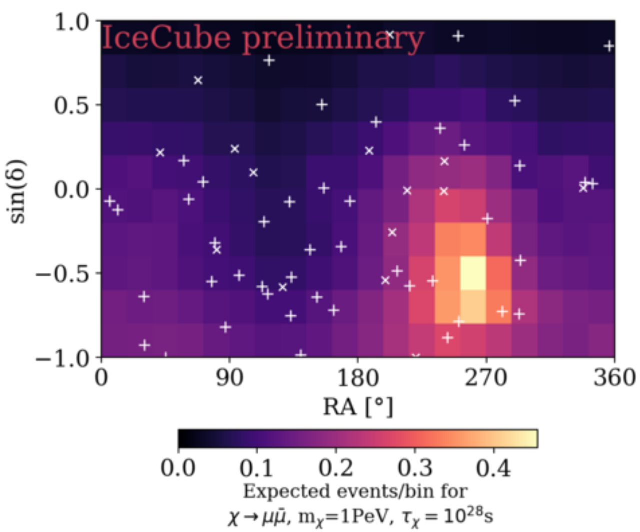
searches dark matter: lifetime

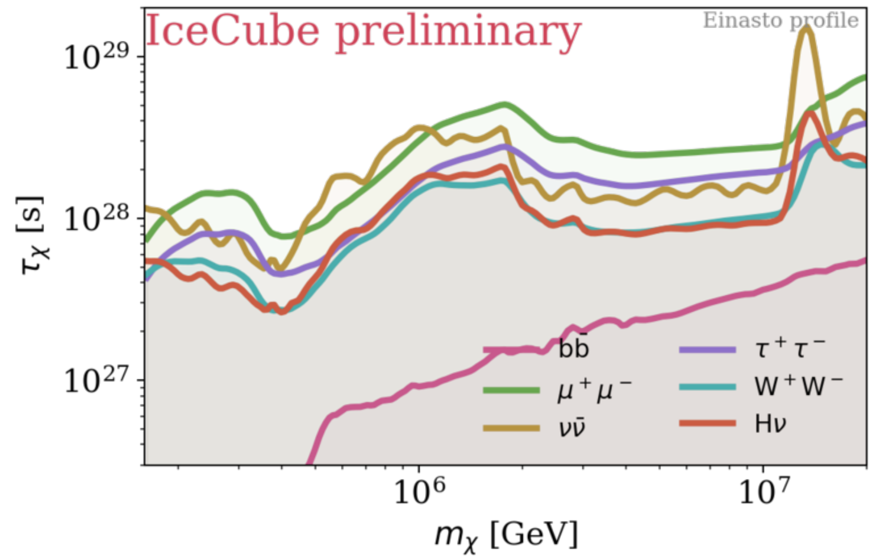


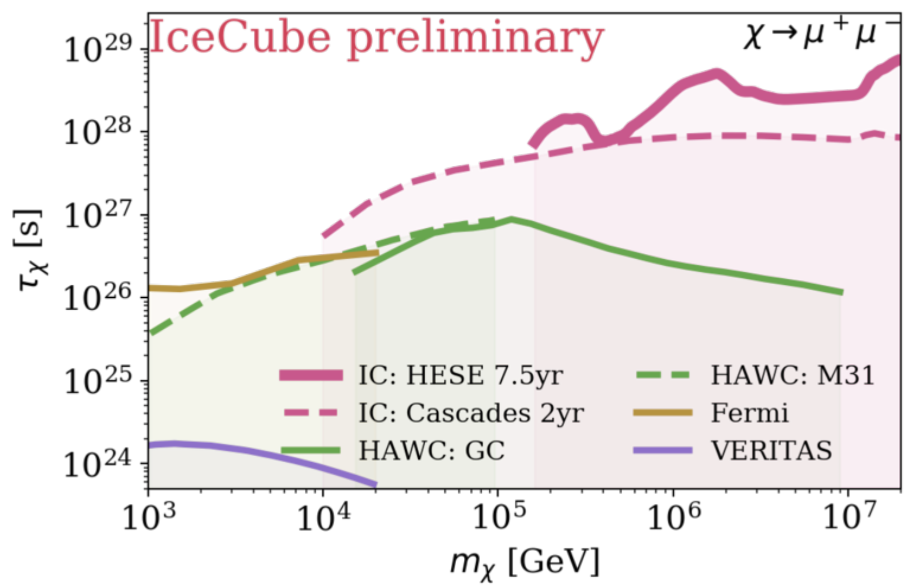
High Energy Starting Events (HESE) analysis

7-year data sample

events with > 60 TeV energy







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

- … and the potential to probe many non-standard DM scenarios.