Dark matter at neutrino telescopes

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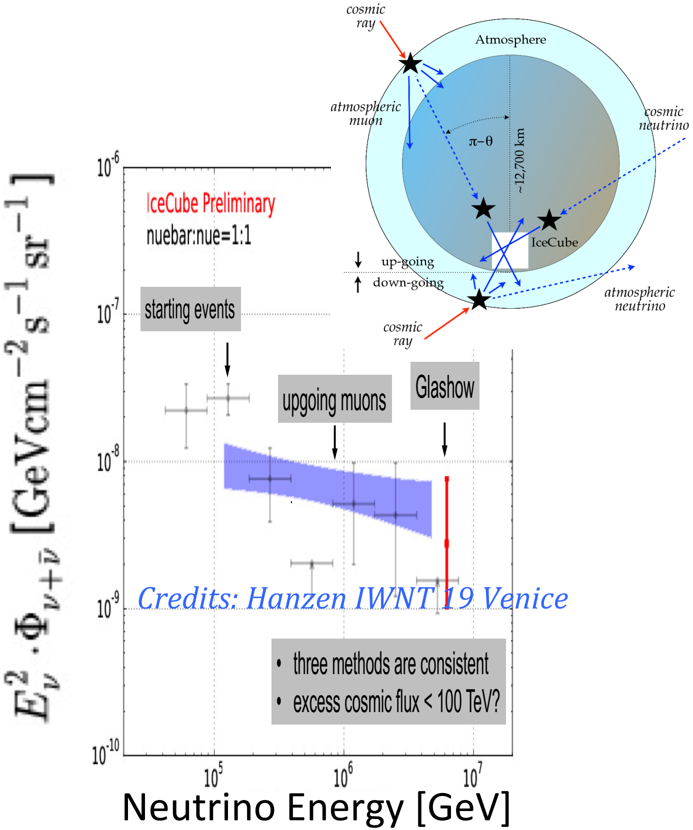
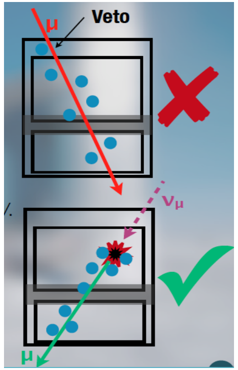
Astroparticle Group Naples

INFN Istituto Nazionale di Fisica Nucleare
NAPOLI Sezione di Napoli

O(100) TeV excess @ neutrino telescopes

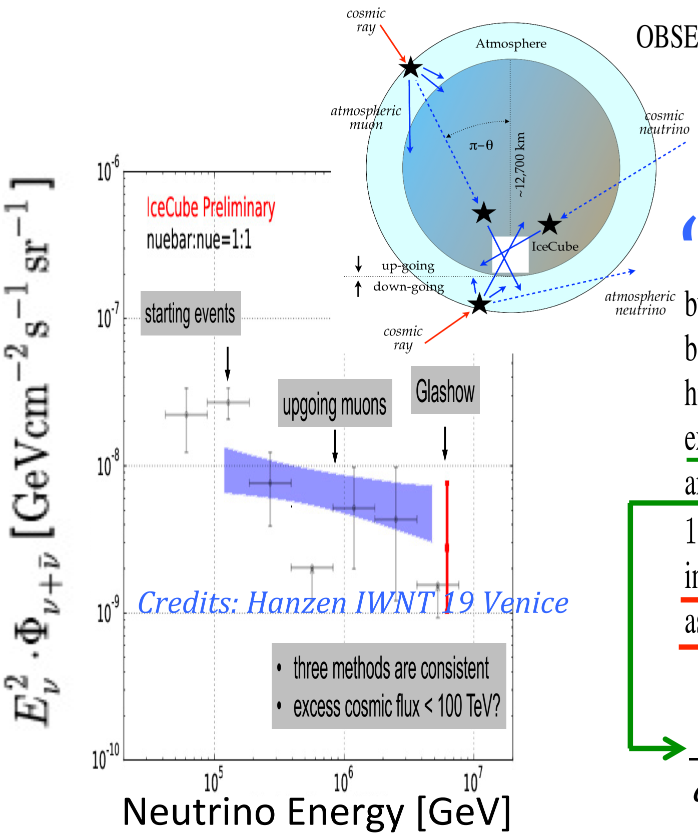


Credits: Hanzen IWNT 19 Venice



High Energy
Starting Events (HESE)

O(100) TeV excess @ neutrino telescopes



Credits: Hanzen IWNT 19 Venice

OBSERVATION AND CHARACTERIZATION OF A COSMIC MUON NEUTRINO FLUX FROM THE NORTHERN HEMISPHERE USING SIX YEARS OF ICECUBE DATA

Aartsen et al [IceCube collaboration] Astrophys J 833 2016

ABSTRACT

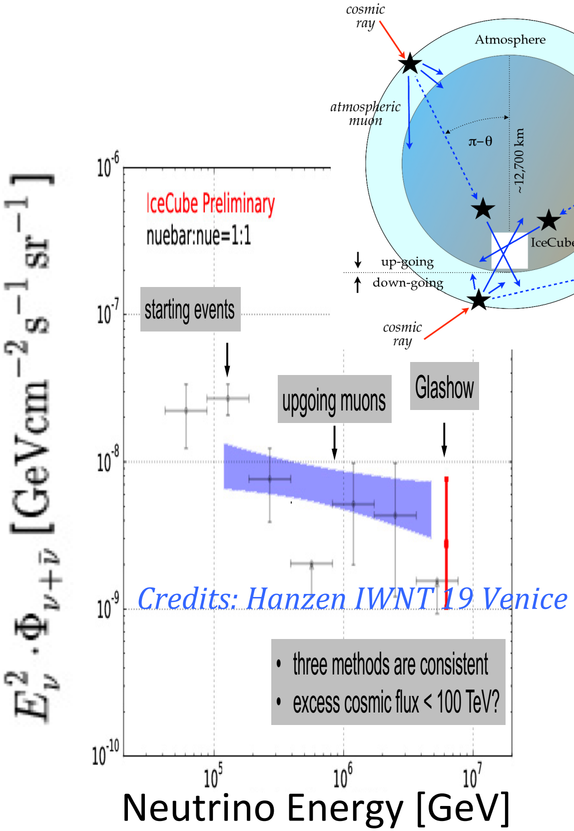
" ……………………………

but the field of view is restricted to the Northern Hemisphere. IceCube data from 2009 through 2015 have been analyzed using a likelihood approach based on the reconstructed muon energy and zenith angle. At the highest neutrino energies between 194 TeV and 7.8 PeV a significant astrophysical contribution is observed, excluding a purely atmospheric origin of these events at $5.6\,\sigma$ significance. The data are well described by an isotropic, unbroken power law flux with a normalization at 100 TeV neutrino energy of $\left(0.90^{+0.30}_{-0.27}\right) \times 10^{-18}\,\mathrm{GeV^{-1}\,cm^{-2}\,s^{-1}\,sr^{-1}}$ and a hard spectral index of $\gamma = 2.13 \pm 0.13$. The observed spectrum is harder in comparison to previous IceCube analyses with lower energy thresholds which may indicate a break in the astrophysical neutrino spectrum of unknown origin. The highest energy event observed has a reconstructed

…………… "

$$\frac{d\Phi_{\mathrm{astro}}}{dE_\nu d\Omega} = \Phi^0_{\mathrm{astro}} \left(\frac{E_\nu}{100\ \mathrm{TeV}}\right)^{-\gamma_{\mathrm{astro}}}$$

O(100) TeV excess @ neutrino telescopes



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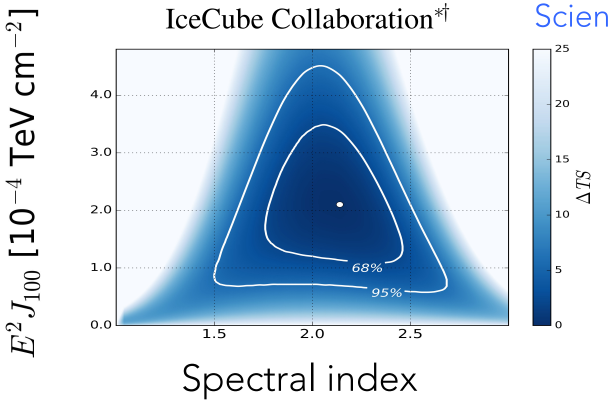
OBSERVATION AND CHARACTERIZATION OF A COSMIC MUON NEUTRINO FLUX FROM THE NORTHERN HEMISPHERE USING SIX YEARS OF ICECUBE DATA

Aartsen et al [IceCube collaboration] Astrophys J 833 2016

Compatible!

Neutrino emission from the direction of the blazar TXS 0506+056 prior to the IceCube-170922A alert

Science 2018



O(100) TeV excess @ neutrino telescopes

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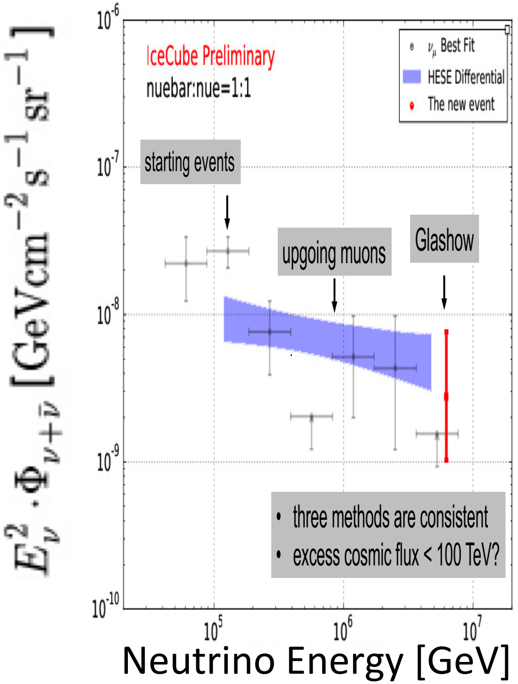
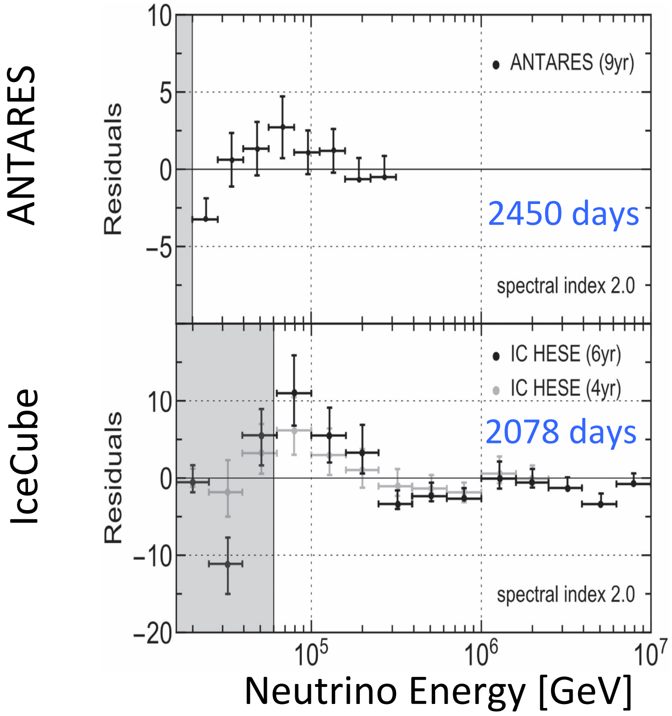


Chianese, Mele, Miele, Migliozzi, SM, Astro J. (2017)



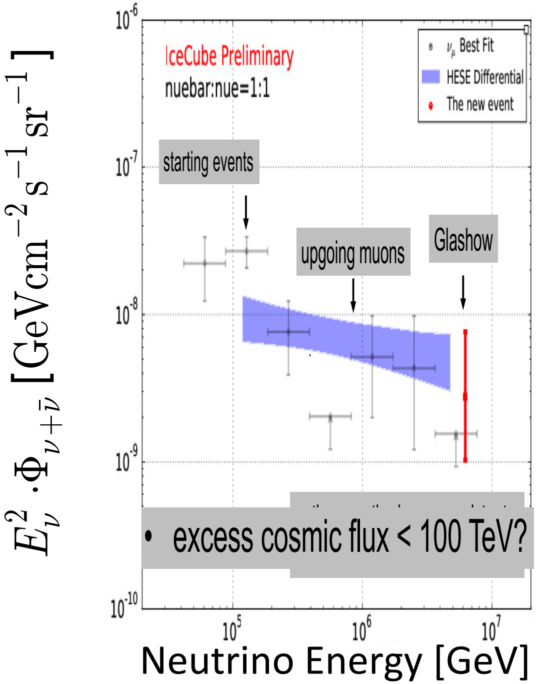
Residuals with respect

$$\frac{d\Phi_{\rm astro}}{dE_\nu d\Omega} = \Phi^0_{\rm astro}\left(\frac{E_\nu}{100\ \rm TeV}\right)^{-\gamma_{\rm astro}}$$

$\gamma_{\rm Astro} = 2$

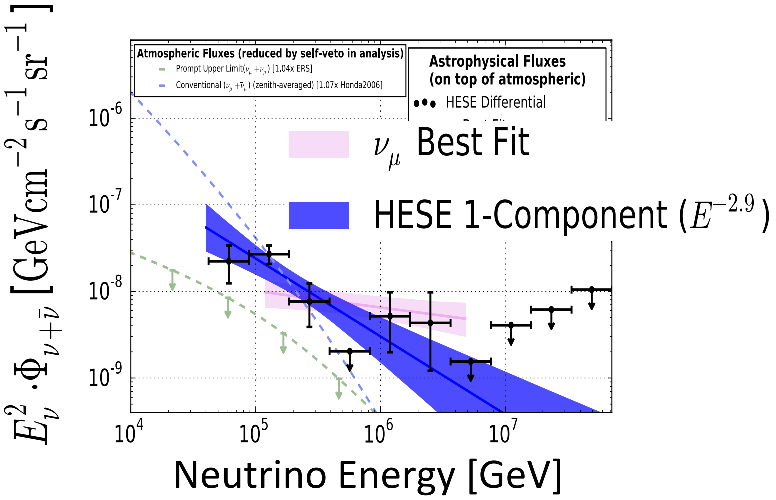
$\mathcal{O}$(100) TeV excess @ neutrino telescopes

Credits: Hanzen IWNT 19 Venice



- excess cosmic flux < 100 TeV?

- only few sigma (about 2.5 sigma) but…
- depends on the assumed astrophysical source
- 1-component fit with softer spectral index works



O(100) TeV excess @ neutrino telescopes

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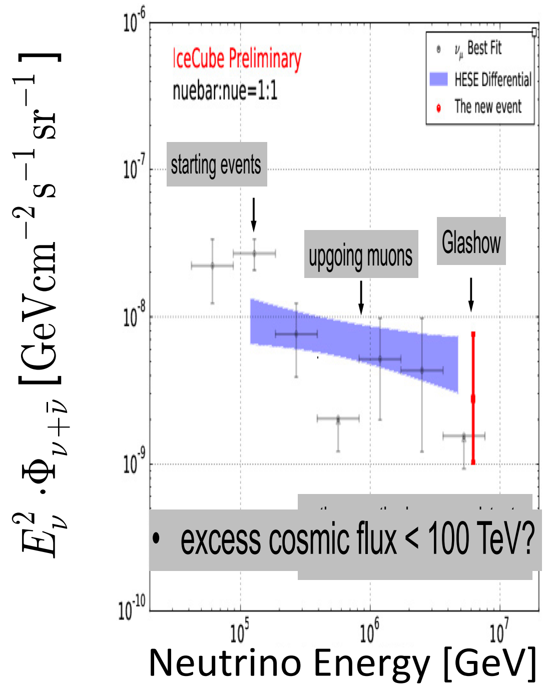

- excess cosmic flux < 100 TeV?

is it related to the Dark Matter problem?

Annihilating dark matter

Feldstein, Kusenko, Matsumoto, Yanagida PRD (2013)

$$\Gamma_{\rm Events} \sim V\, L_{\rm MW}\, n_{\rm N}\, \sigma_{\rm N} \left(\frac{\rho_{\rm DM}}{m_{\rm DM}}\right)^2 \langle \sigma_{\rm Ann} v\rangle \lesssim \boxed{1 \text{ per few hundred years}}$$

V = detector volume

$n_{\rm N} \simeq n_{\rm Ice}$

$L_{\rm MW}$ = dim of galaxy

$\sigma_{\rm N} \sim$ Typical neutrino-nucleon Cross section at 1PeV

$\sigma_{\rm Ann} \leq 4\pi/(m_{\rm DM}^2 v^2)$ from unitarity limit

Possible enhancement
Dark Matter substructure
Zavala, PRD 89 2014

Decaying dark matter

Feldstein, Kusenko, Matsumoto, Yanagida PRD (2013)

$$\Gamma_{\rm Events} \sim V\, L_{\rm MW}\, n_{\rm N}\, \sigma_{\rm N} \frac{\rho_{\rm DM}}{m_{\rm DM}} \Gamma_{\rm DM} \sim \boxed{\left(\frac{\lambda}{10^{-29}}\right)^2 / \text{ year}}$$

Decay seems favorite with respect to annihilation

Standard Model particles and dark matter stability: a comment

Credits: Hambye

- photon stable because massless (for gauge symmetry motivation)
- neutrino stable because is lightest fermion (Lorentz invariance)
- electron stable because is lightest charged particle (electric charge conservation)
- proton (?) stable if baryon number exactly conserved

What is the symmetry that stabilize DM?
(R)-parity, mirror world,….but so far no evidence

To have a stable particle on top of SM without any extra symmetry
is not automatic even if not impossible…. **BUT quite baroque**

Decaying Dark Matter and IceCube

Aisati, Gustafsson, Hambye PRD 2015
Chianese, SM, Miele, Vitagliano PLB 2016
Chianese, SM, Miele JCAP 2017
Chianese, SM, Miele PLB 2017
Hirishima, Kitano, Murase, PRD 2018
Sui, Dev, JCAP 18
Chianese, SM, Miele, Peinado, JCAP 2018
Bhattacharya, Esmaili, Ruiz, Sarcevic, arxiv 1903.12623

Feldstein, Kusenko, Matsumoto, Yanagida PRD (2013)
Esmaili, Serpico JCAP 2013
Bai, Lu, Salvado JHEP 2013
Higaki,Kitano, Sato JHEP 2014
Bhattacharya, Gandhi, Gupta JCAP 2015
Murase, Laha, Ando, Ahlers PRL 2015
Esmaili, Kang, Serpico, JCAP 2014
Fong, Minakata,Panes, Funchal JHEP 2015
Cheng, Dev, Soni PRD 2015
Koop,Liu,Wang, JHEP 2015
Anchordoqui et al, PRD 2015
Boucenna, Chianese, Mangano, Miele, SM, Pisanti, JCAP 2015
Ko,Tang PRB 2015
Fiorentin, Niro, Fornengo JHEP 2016
DeV, Kazanas, Mohapatra,Tepliz, Zhang JCAP 2016
Dibari, Ludl, Ruiz, JCAP 2016
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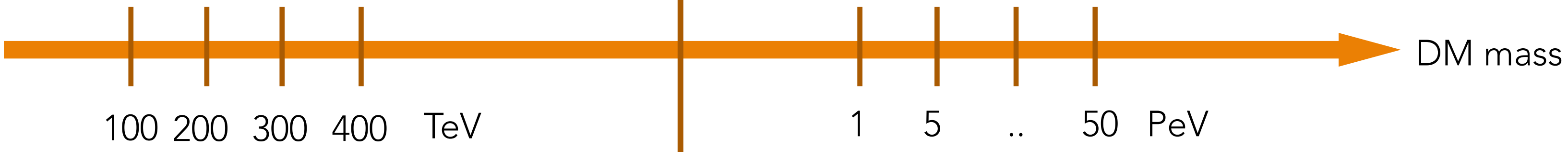
Kachelriess, Kalashev, KuznetsovPRD18

Decaying Dark Matter and IceCube



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Search for neutrino from decaying DM with IC

IceCube Collaboration EPJC 2018

Feldstein, Kusenko, Matsumoto, Yanagida PRD (2013)
Esmaili, Serpico JCAP 2013
Bai, Lu, Salvado JHEP 2013
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Dibari, Ludl, Ruiz, JCAP 2016
Battacharya, Esmaili, Ruiz, Sarcevic, JCAP 2017
Kachelriess, Kalashev, KuznetsovPRD18

Neutrino flux at Earth

$$\frac{\mathrm{d}\phi}{\mathrm{d}E_\nu \mathrm{d}\Omega} = \boxed{\frac{\mathrm{d}\phi^{\mathrm{bkg}}}{\mathrm{d}E_\nu \mathrm{d}\Omega}} + \boxed{\frac{\mathrm{d}\phi^{\mathrm{Astro}}}{\mathrm{d}E_\nu \mathrm{d}\Omega}} + \boxed{\frac{\mathrm{d}\phi^{\mathrm{DM}}}{\mathrm{d}E_\nu \mathrm{d}\Omega}}$$

three componets are assumed:

1) Atmospheric neutrino

Honda, Kajita, Kasahara, Midorikawa, Sanuki, PRD (2007)
Enberg,Reno,Sarcevic, PRD (2008)

2) Astrophysical isotropic neutrino flux

$$\frac{d\Phi_{\mathrm{astro}}}{dE_\nu d\Omega} = \Phi^0_{\mathrm{astro}} \left(\frac{E_\nu}{100\ \mathrm{TeV}} \right)^{-\gamma_{\mathrm{astro}}}$$

3) Decaying Dark Matter neutrino flux

$$\frac{\mathrm{d}\phi^{\mathrm{DM}}_\alpha}{\mathrm{d}E_\nu \mathrm{d}\Omega} = \sum_\beta P_{\alpha\beta} \left[\frac{\mathrm{d}\phi^{\mathrm{G}}_\beta}{\mathrm{d}E_\nu \mathrm{d}\Omega} + \frac{\mathrm{d}\phi^{\mathrm{EG}}_\beta}{\mathrm{d}E_\nu \mathrm{d}\Omega} \right]$$

Dark Matter Neutrino flux: Galactic and Extra-Galactic contributions

$$\frac{\mathrm{d}\phi_\alpha^{\mathrm{DM}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} = \sum_\beta P_{\alpha\beta} \left[\frac{\mathrm{d}\phi_\beta^{\mathrm{G}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} + \frac{\mathrm{d}\phi_\beta^{\mathrm{EG}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} \right]$$

P: flavor convertion due to oscillation

See for instance
Mena,Ruiz,Vincent, PRL 2014
Palladino, Pagliaroli, Villante VissaniPRL 2015

Dark Matter Neutrino flux: Galactic and Extra-Galactic contributions

$$\frac{\mathrm{d}\phi_\alpha^{\mathrm{DM}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} = \sum_\beta P_{\alpha\beta}\left[\frac{\mathrm{d}\phi_\beta^{\mathrm{G}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} + \frac{\mathrm{d}\phi_\beta^{\mathrm{EG}}}{\mathrm{d}E_\nu \mathrm{d}\Omega}\right]$$

Extra-Galactic

$$\frac{\mathrm{d}\phi_\beta^{\mathrm{EG}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} = \frac{\Omega_\chi \rho_c}{4\pi\, m_\chi\, \tau_\chi}\int_0^\infty dz\, \frac{1}{H(z)}\, \frac{\mathrm{d}N_\beta}{\mathrm{d}E_\nu}\bigg|_{E(1+z)}$$

Galactic

$$\frac{\mathrm{d}\phi_\beta^{\mathrm{G}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} = \frac{1}{4\pi\, m_{\mathrm{DM}}\, \tau_{\mathrm{DM}}}\frac{\mathrm{d}N_\nu}{\mathrm{d}E_\nu}\int_0^\infty \mathrm{d}s\, \rho_{\mathrm{h}}\left[r\left(s,l,b\right)\right]$$

Dark Matter Neutrino flux: expected angular distribution

$$\frac{\mathrm{d}\phi_\alpha^{\mathrm{DM}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} = \sum_\beta P_{\alpha\beta} \left[\frac{\mathrm{d}\phi_\beta^{\mathrm{G}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} + \frac{\mathrm{d}\phi_\beta^{\mathrm{EG}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} \right]$$

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$$\frac{\mathrm{d}\phi_\beta^{\mathrm{EG}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} = \frac{\Omega_\chi \rho_c}{4\pi\, m_\chi\, \tau_\chi} \int_0^\infty dz\, \frac{1}{H(z)} \left.\frac{\mathrm{d}N_\beta}{\mathrm{d}E_\nu}\right|_{E(1+z)}$$

Galactic

$$\frac{\mathrm{d}\phi_\beta^{\mathrm{G}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} = \frac{1}{4\pi\, m_{\mathrm{DM}}\, \tau_{\mathrm{DM}}} \frac{\mathrm{d}N_\nu}{\mathrm{d}E_\nu} \int_0^\infty \mathrm{d}s\, \rho_{\mathrm{h}} \left[r(s, l, b) \right]$$

the contributions are comparable
but
difference in the angular distributions

Dark Matter Neutrino flux: expected angular distribution

$$\frac{\mathrm{d}\phi_\alpha^{\mathrm{DM}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} = \sum_\beta P_{\alpha\beta} \left[\frac{\mathrm{d}\phi_\beta^{\mathrm{G}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} + \frac{\mathrm{d}\phi_\beta^{\mathrm{EG}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} \right]$$

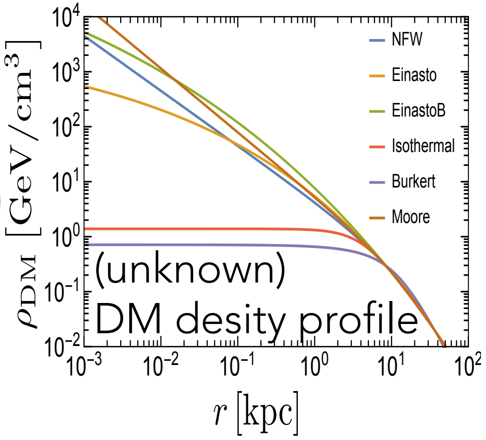
Extra-Galactic

$$\frac{\mathrm{d}\phi_\beta^{\mathrm{EG}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} = \frac{\Omega_\chi \rho_c}{4\pi\, m_\chi\, \tau_\chi} \int_0^\infty dz\, \frac{1}{H(z)} \left.\frac{\mathrm{d}N_\beta}{\mathrm{d}E_\nu}\right|_{E(1+z)}$$

isotropic

Galactic

$$\frac{\mathrm{d}\phi_\beta^{\mathrm{G}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} = \frac{1}{4\pi\, m_{\mathrm{DM}}\, \tau_{\mathrm{DM}}} \frac{\mathrm{d}N_\nu}{\mathrm{d}E_\nu} \int_0^\infty \mathrm{d}s\, \rho_{\mathrm{h}} \left[r(s,l,b) \right]$$



line-of-sight

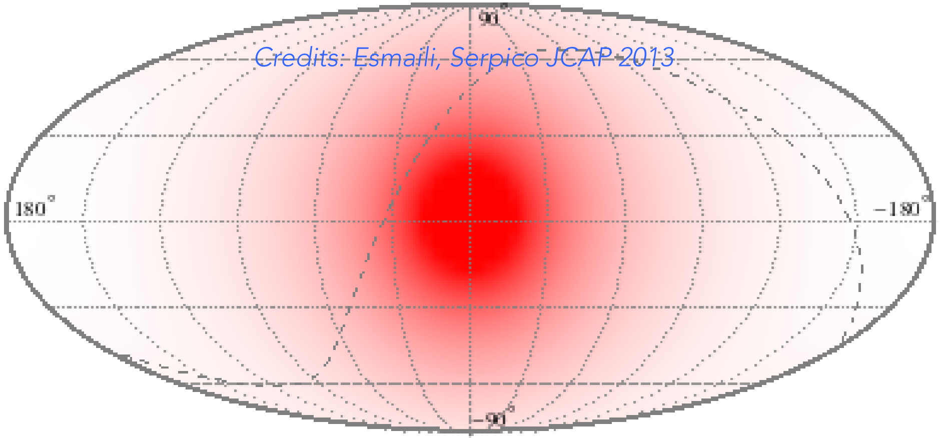
$$r(s,l,b) = \sqrt{s^2 + R_\odot^2 - 2sR_\odot \cos b \cos l}$$

larger flux close to galaxy center

Dark Matter Neutrino flux: expected angular distribution

$$\frac{\mathrm{d}\phi_\alpha^{\mathrm{DM}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} = \sum_\beta P_{\alpha\beta} \left[\frac{\mathrm{d}\phi_\beta^{\mathrm{G}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} + \frac{\mathrm{d}\phi_\beta^{\mathrm{EG}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} \right]$$

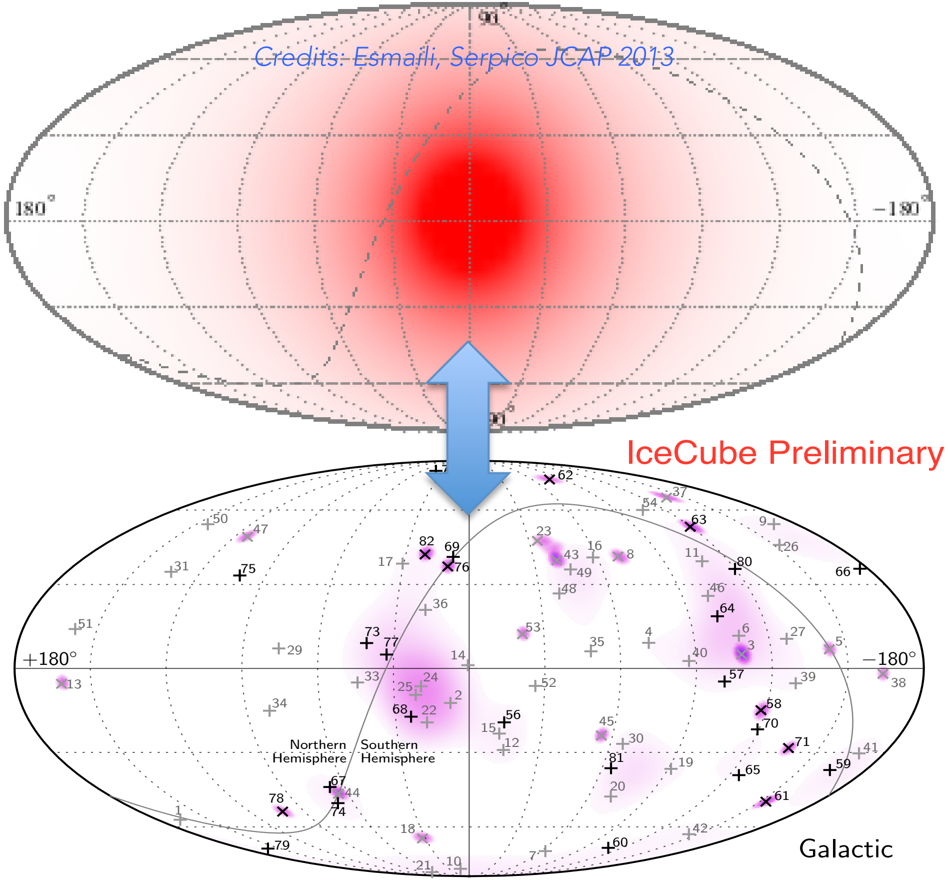
Galactic | Extra-Galactic



Dark Matter Neutrino flux: expected angular distribution

$$\frac{d\phi_\alpha^{\mathrm{DM}}}{dE_\nu d\Omega} = \sum_\beta P_{\alpha\beta} \left[\frac{d\phi_\beta^{\mathrm{G}}}{dE_\nu d\Omega} + \frac{d\phi_\beta^{\mathrm{EG}}}{dE_\nu d\Omega} \right]$$

Galactic | Extra-Galactic



Esmaili, Serpico JCAP 2013

- Data prefer mildly DM rather than isotropic distribution at 98% CL

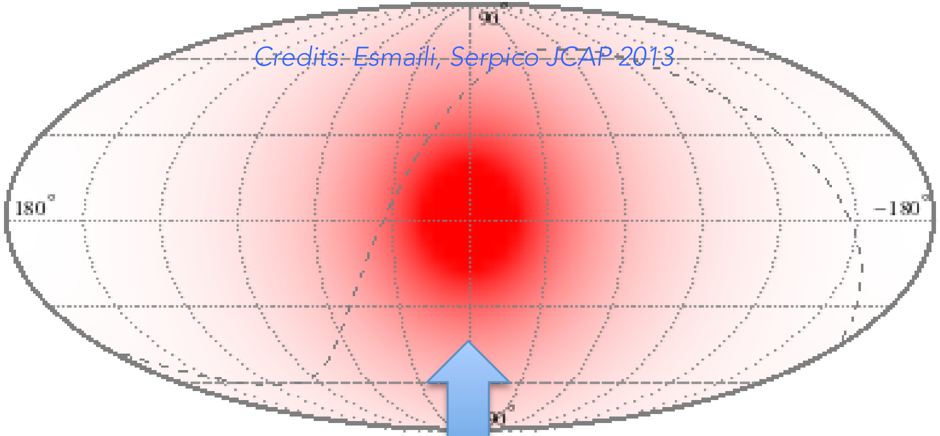
Chianese, SM, Miele, Vitagliano PLB 2016

- 10% p-values, DM scenario can not be excluded

Dark Matter Neutrino flux: expected angular distribution

$$\frac{\mathrm{d}\phi_\alpha^{\mathrm{DM}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} = \sum_\beta P_{\alpha\beta} \left[\frac{\mathrm{d}\phi_\beta^{\mathrm{G}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} + \frac{\mathrm{d}\phi_\beta^{\mathrm{EG}}}{\mathrm{d}E_\nu \mathrm{d}\Omega} \right]$$

Galactic | Extra-Galactic



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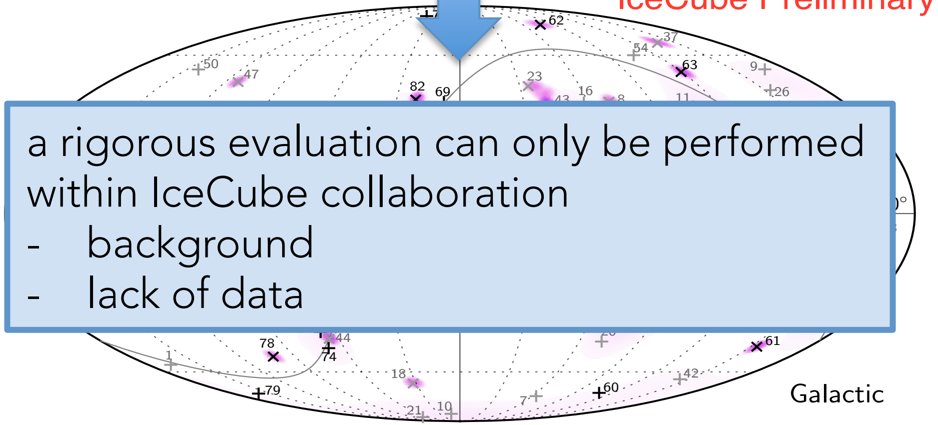
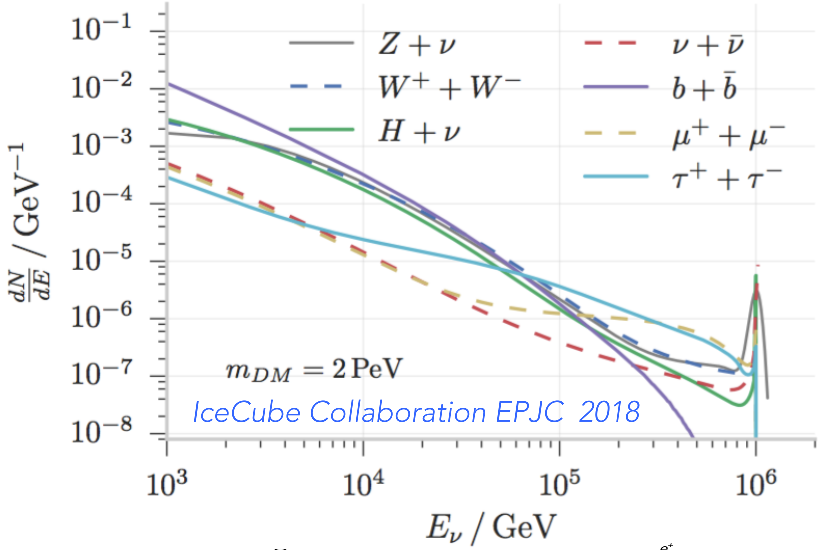


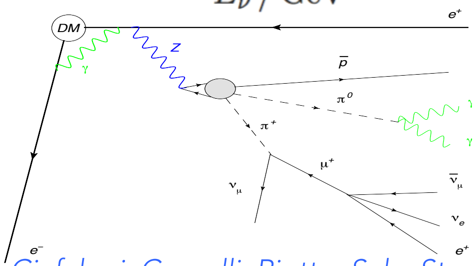
a rigorous evaluation can only be performed within IceCube collaboration
- background
- lack of data

Neutrino spectrum from DM decay (weak corrections)

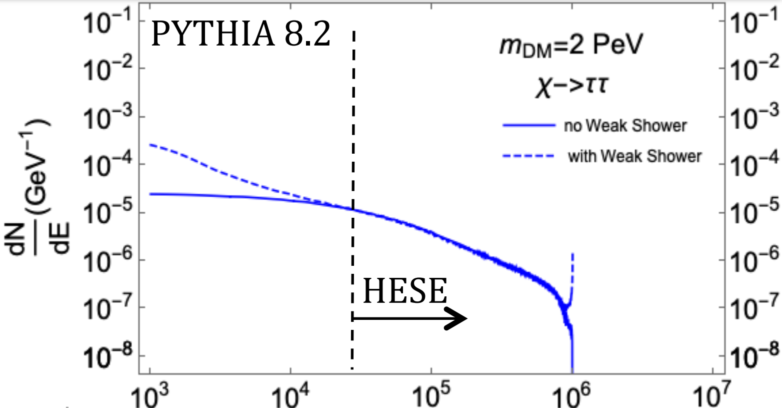


IceCube Collaboration EPJC 2018

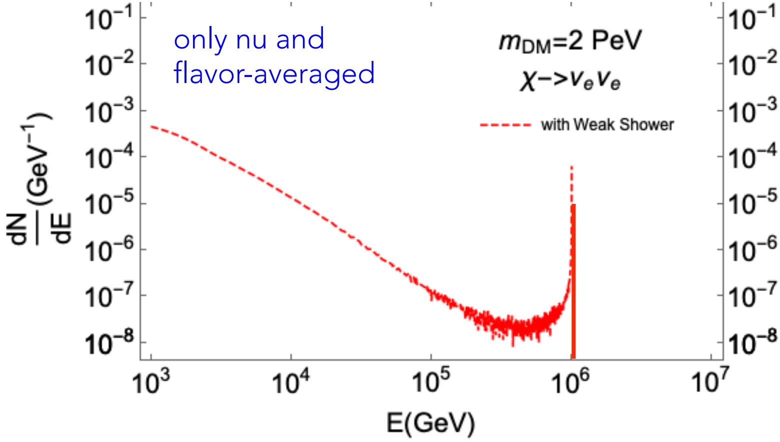
$$\frac{dN_\beta}{dE_\nu}$$



Ciafaloni, Comelli, Riotto, Sala, Strumia, Urbano, JCAP (2011)



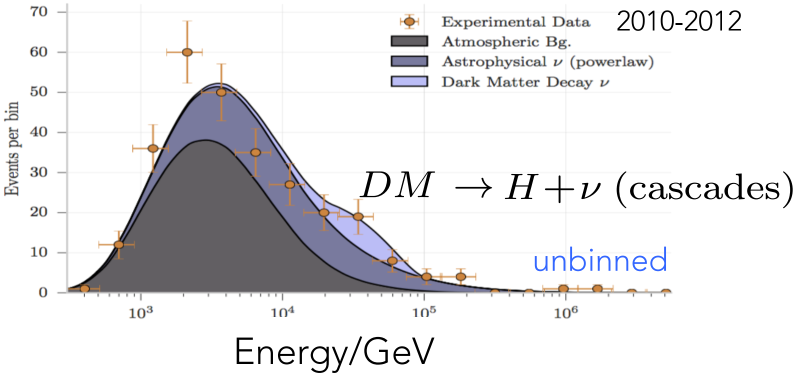
work in progress



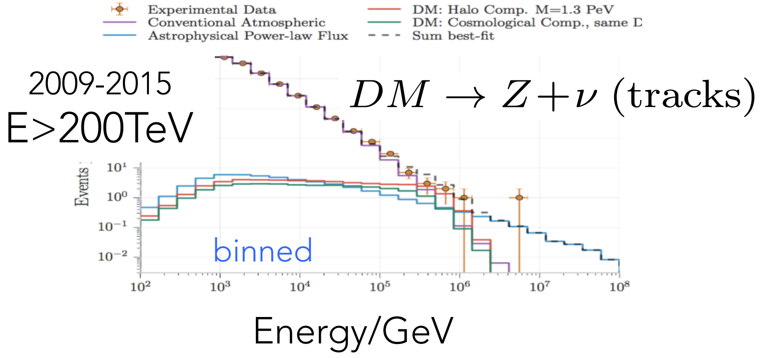
IceCube Collaboration analysis

IceCube Collaboration EPJC 2018

two-years **cascade** events: all-sky



six-years nu-mu **track** events: North-hemisphere



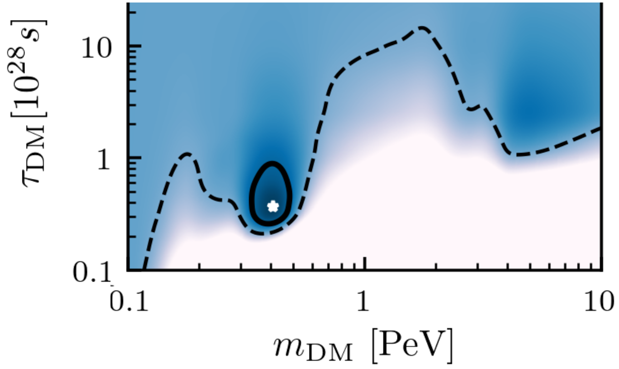
	Tracks		Cascades	
	Bg.	Signal+Bg.	Bg.	Signal+Bg.
$m_{\rm DM}$ / PeV	-	1.3	-	$\boxed{0.1}$
$\tau_{\rm DM}$ / 10^{27}s	-	22	-	8.3
Astroph. norm.[1]	0.97	0.16	2.15	1.62
Spectr. index	$\boxed{2.16}$	1.99	2.75	2.81
TS $= 2 \times \Delta$LLH	6.7 ($p = 0.035$)		3.4 $\boxed{(p = 0.55)}$	

- the two analysis give very different DM mass
- but not surprising: different data
- p-value above 1%

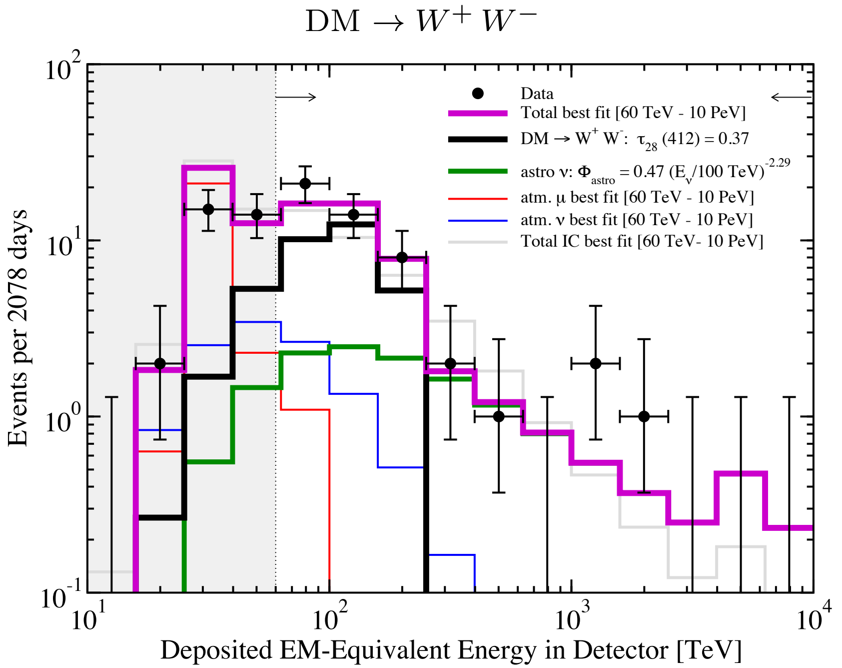
Although best fit includes a non-zero DM component the result is not significant, no DM signal

Other analysis 1

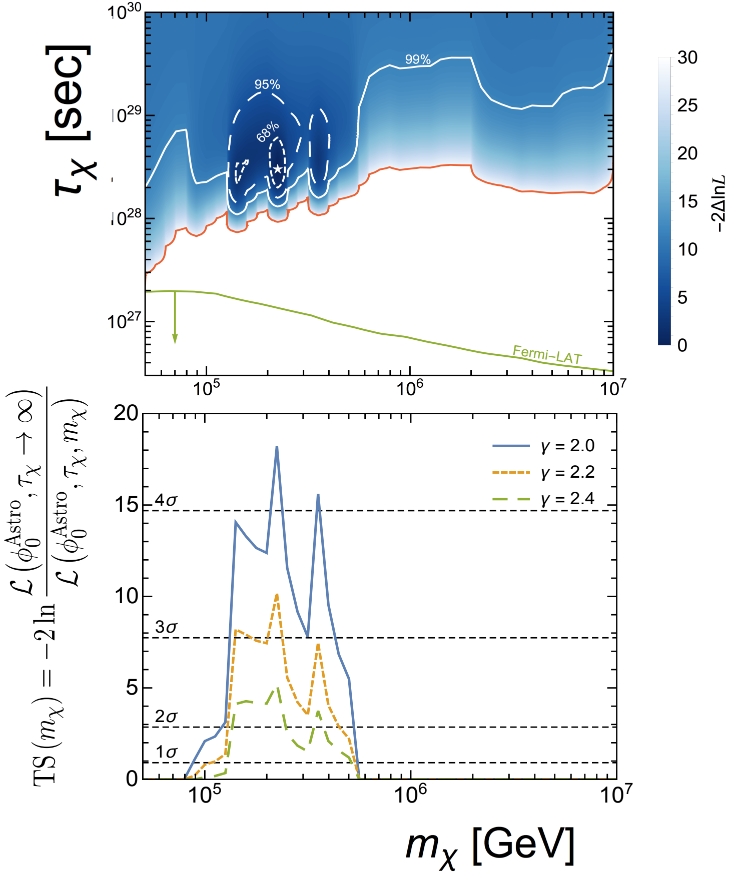
Decay channel	$\tau_{DM}[10^{28}$ s]	(N_{DM})	m_{DM} [TeV]	ϕ_{astro}	(N_{astro})	γ
$u\bar{u}$	0.11	(28.4)	1761	0.52	(13.0)	2.34
$b\bar{b}$	0.07	(26.9)	1103	0.58	(14.3)	2.35
$t\bar{t}$	0.11	(28.7)	598	0.45	(12.5)	2.27
$\boldsymbol{W^+W^-}$	**0.37**	**(28.5)**	**412**	**0.47**	**(12.6)**	**2.29**
ZZ	0.43	(27.8)	407	0.52	(13.3)	2.32
hh	0.12	(28.8)	611	0.45	(12.6)	2.27
e^+e^-	2.20	(4.0)	4160	3.53	(37.3)	3.36
$\mu^+\mu^-$	9.77	(4.9)	6583	3.51	(36.5)	3.39
$\tau^+\tau^-$	0.89	(27.4)	472	0.59	(14.3)	2.36
$\nu_e\bar{\nu}_e$	4.12	(3.6)	4062	3.52	(37.7)	3.33
$\nu_\mu\bar{\nu}_\mu$	4.63	(5.0)	4196	3.52	(36.4)	3.41
$\nu_\tau\bar{\nu}_\tau$	0.96	(16.6)	341	1.58	(24.9)	2.74



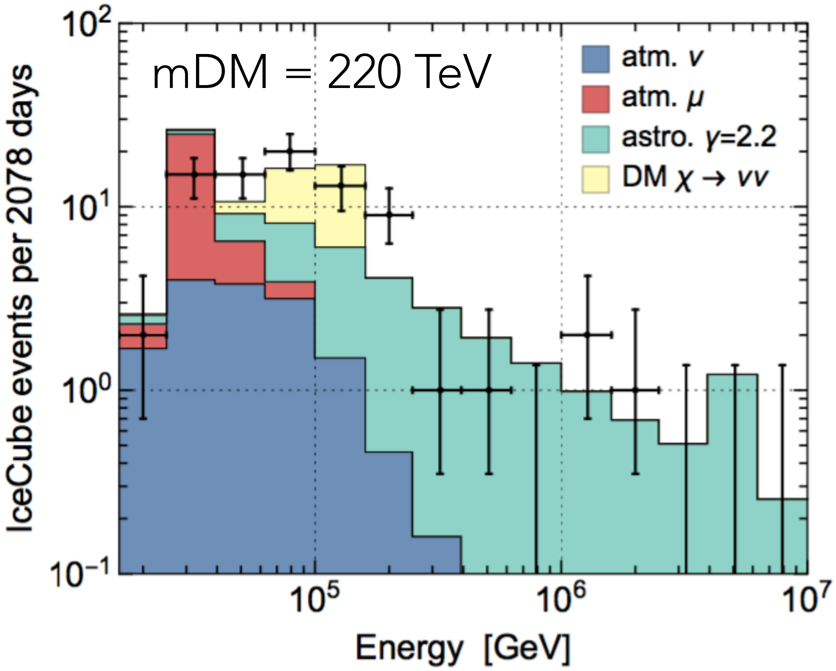
Bhattacharya, Esmaili, Ruiz, Sarcevic, 1903.12623



Other analysis 2

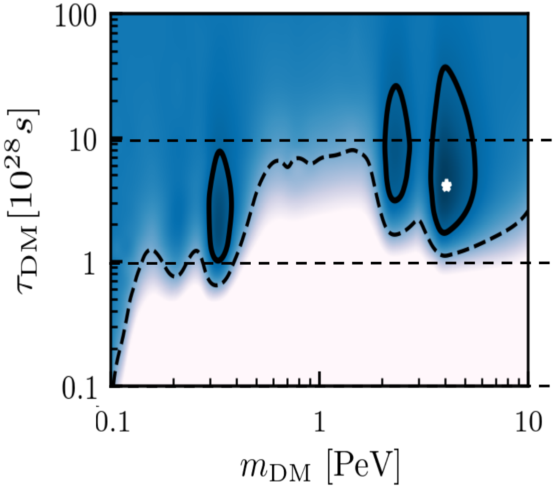


Chianese, Miele, M, Peinado, JCAP 2018

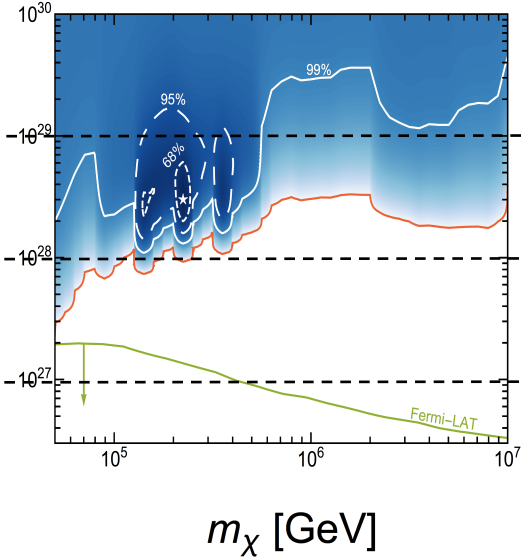


Life-time vs DM mass: comparing different analysis

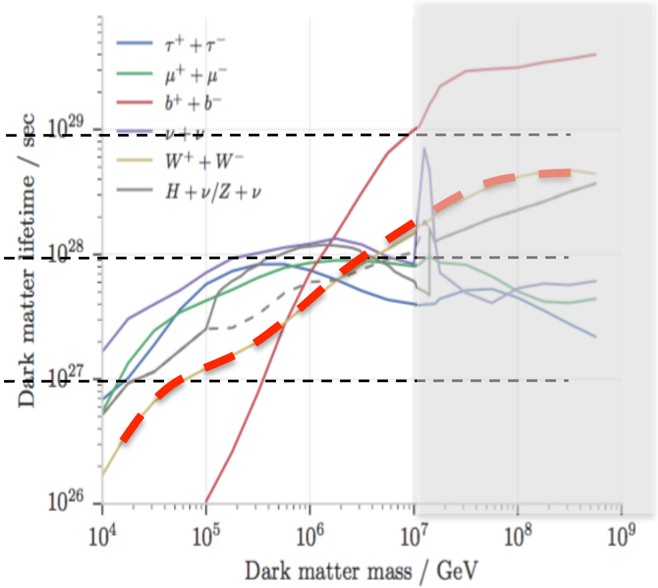
DM ⟶ neutino



Analysis 1



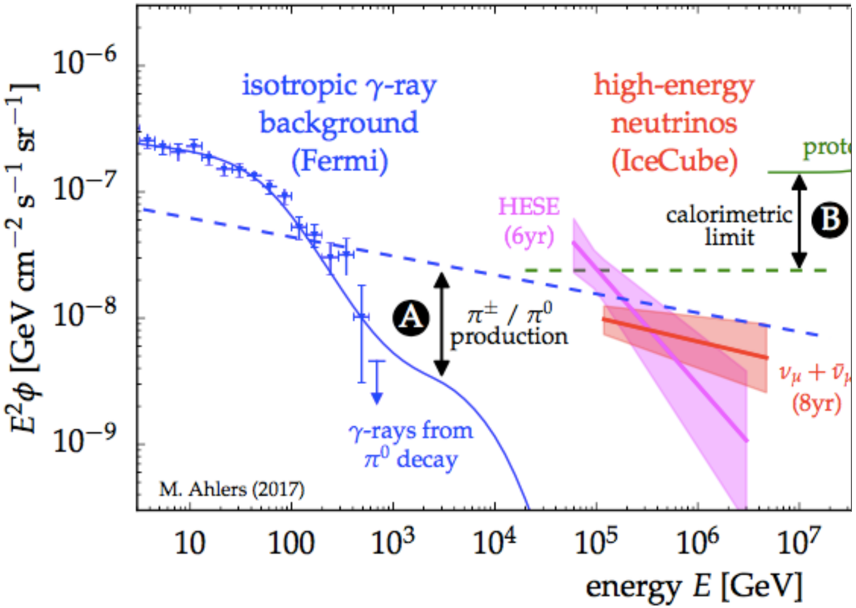
Analysis 2



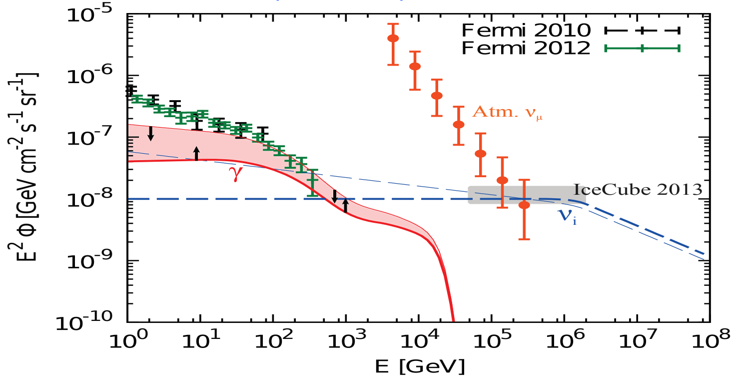
Analysis IC

Neutrino and gamma: a multimessenger approach

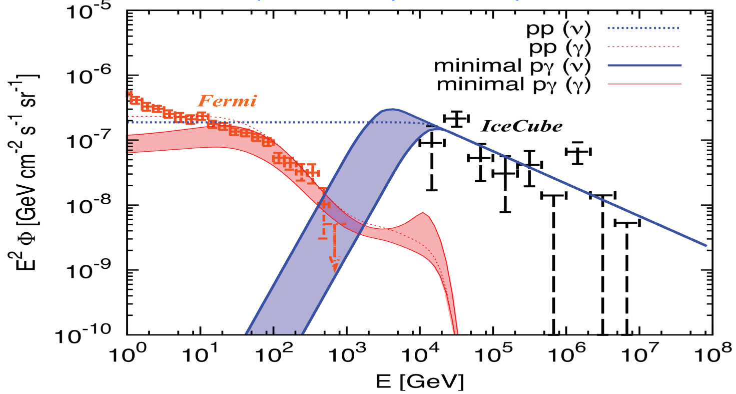
Ahlers. Halzen PPNP 2018



Murase, Ahlers, Lacki PRD 2013

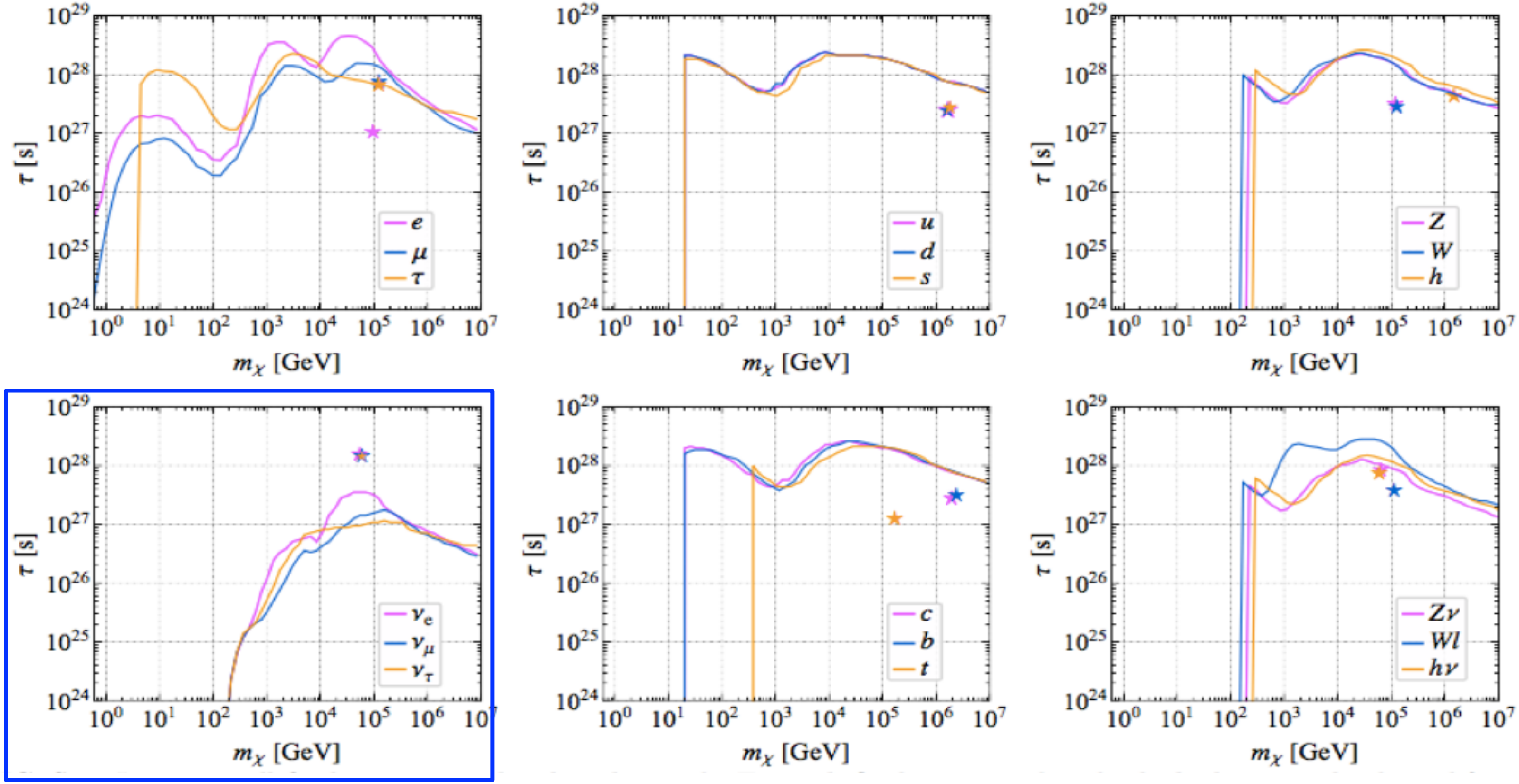


Murase, Guetta, Ahlers, PRL 2016



Fermi limits for decaying dark matter

Cohen, Murase, Rodd, Safdi, Soreq,PRL 2017



Clasification of operator with neutrino final state

$(R_{SU(2)})_Y$	operator	final states
spin 0		
$(0)_0$	$\chi H^\dagger H$	$hh,\ Z^0Z^0, W^+W^-, f\bar{f}$
	$\chi\,(LH)^2$	$\nu\nu hh,\ \nu\nu Z^0Z^0,\ \nu\nu Z^0 h,$ $\nu e^- hW^+,\ \nu e^- Z^0W^+,\ e^-e^-W^+W^+,$ $\nu\nu h,\ \nu\nu Z^0,\ \nu e^- W^+,\ \nu\nu$
	$\chi H\bar{L}E$	$h\ell^+\ell^-,\ Z^0\ell^+\ell^-,\ W^\pm\ell^\mp\nu,\ \ell^+\ell^-$
	$\chi\tilde{H}\bar{Q}U,\ \phi H\bar{Q}D$	$hq\bar{q},\ Z^0q\bar{q},\ W^\pm q'\bar{q},\ q\bar{q}$
	$\chi B_{\mu\nu}\overset{(\sim)}{B}{}^{\mu\nu}$	$\gamma\gamma,\ \gamma Z,\ ZZ$
	$\chi W_{\mu\nu}\overset{(\sim)}{W}{}^{\mu\nu}$	$\gamma\gamma,\ \gamma Z^0,\ Z^0Z^0,\ W^+W^-$ [b]
	$\chi G_{\mu\nu}\overset{(\sim)}{G}{}^{\mu\nu}$	hadrons
	$\chi D_\mu H^\dagger D^\mu H$	$hh,\ Z^0Z^0,\ W^+W^-$ [c]
$(2)_{1/2}$ [d]	$V_{\hat{\lambda}}$ [114][e]	$hhh,\ hZ^0Z^0,\ hW^+W^-$
	$V_{c_{\beta-\alpha}}$ [114][e,f]	$hh,\ Z^0Z^0,\ W^+W^-$
	$\phi\bar{L}E$	$\ell^+\ell^-$
	$\tilde{\phi}\bar{Q}U,\ \phi\bar{Q}D$	$q\bar{q}$
$(3)_0$	$\phi^a\tilde{H}\sigma^a H$	$hh,\ Z^0Z^0, W^+W^-, f\bar{f}$
	$\phi^a W^a_{\mu\nu}B^{\mu\nu}$	$\gamma\gamma,\ Z^0\gamma,\ Z^0Z^0$
	$\phi^a\bar{L}E\sigma^a H$	$h\ell^+\ell^-,\ Z^0\ell^+\ell^-,\ W^\pm\ell^\mp\nu,\ \ell^+\ell^-$
	$\phi^a\bar{Q}U\sigma^a\tilde{H},\ \phi^a\bar{Q}D\sigma^a H$	$hq\bar{q},\ Z^0q\bar{q},\ W^\pm q'\bar{q},\ q\bar{q}$
$(3)_1$	$\phi^a L^T\sigma^a\sigma^2 L$	$\nu\nu$

$(R_{SU(2)})_Y$	operator	final states
spin 1/2		
$(1)_0$	$\tilde{H}\bar{L}\psi$	$\nu h,\ \nu Z^0,\ \ell^\pm W^\mp$
$(2)_{1/2}$	$\tilde{H}\bar{\psi}E$	$\nu h,\ \nu Z^0,\ \ell^\pm W^\mp$
$(3)_0$	$H\bar{L}\sigma^a\psi^a$	$\nu h,\ \nu Z^0,\ \ell^\pm W^\mp$
spin 1		
$(0)_0$	$\bar{f}\gamma_\mu V'^\mu f$	$f\bar{f}$
	$B_{\mu\nu}F'^{\mu\nu}/2$	$f\bar{f}$

Cohen, Murase, Rodd, Safdi, Soreq,PRL 2017

Neutrinophilic Dark Matter model

Chianese, Miele, M, Peinado, JCAP 2018

	L	ℓ_R	H	Δ	ν_R
$\mathrm{SU}(2)_L$	2	1	2	3	1
$\mathrm{U}(1)_Y$	$-1/2$	-1	$1/2$	1	0
$\mathrm{U}(1)_L$	1	1	0	-2	1

Preserved in order to have a neutrino line

$$\mathcal{L}_\nu = \frac{1}{2}\lambda_{ij} L_i^T C^{-1} i\tau_2 \Delta\, L_j + \text{h.c.}$$

$$\Delta = \sum_{i=1}^{3} \delta_i \tau_i = \begin{pmatrix} \Delta^+ & \sqrt{2}\Delta^{++} \\ \sqrt{2}\Delta^0 & -\Delta^+ \end{pmatrix}$$

- Does not aquire a VEV
- Neutrino are Dirac

Reheating temperature below DM freeze-out temperature

$$T_F < T_{RH}$$

$$\Omega_\chi h^2 \simeq 7.3 \times 10^{-11} \frac{1}{g_*^{1/2}(T_{\rm F,std})} \frac{\mathrm{GeV}^{-2}}{\langle\sigma v\rangle\, x_{\rm F,std}^{-1}}$$

$$x_{\rm F,std} \simeq \ln\left[0.038 \frac{g_\chi\, m_\chi\, M_{\rm Pl}\, x_{\rm F,std}^{1/2}}{g_*^{1/2}(T_{\rm F,std})}\langle\sigma v\rangle\right]$$

$$T_{\rm F,std} = m_\chi / x_{\rm F,std}$$

$$\langle\sigma v\rangle \simeq 2.8\times 10^{-26}\ \mathrm{cm}^3/\mathrm{s} \rightarrow$$ DM about 2TeV

Larger DM mass overclose Universe

$$T_{RH} < T_F$$

$$\Omega_\chi h^2 \simeq 2.3 \times 10^{-11} \frac{g_*^{1/2}(T_{\rm RH})}{g_*(T_{\rm F,rh})} \frac{T_{\rm RH}^3\, \mathrm{GeV}^{-2}}{m_\chi^3\, \langle\sigma v\rangle\, x_{\rm F,rh}^{-4}}$$

$$x_{\rm F,rh} \simeq \ln\left[0.015 \frac{g_\chi\, g_*^{1/2}(T_{\rm RH})}{g_*(T_{\rm F,rh})} \frac{M_{\rm Pl}\, T_{\rm RH}^2\, x_{\rm F,rh}^{5/2}}{m_\chi}\langle\sigma v\rangle\right]$$

Giudice, Kolb, Riotto PRD 2001

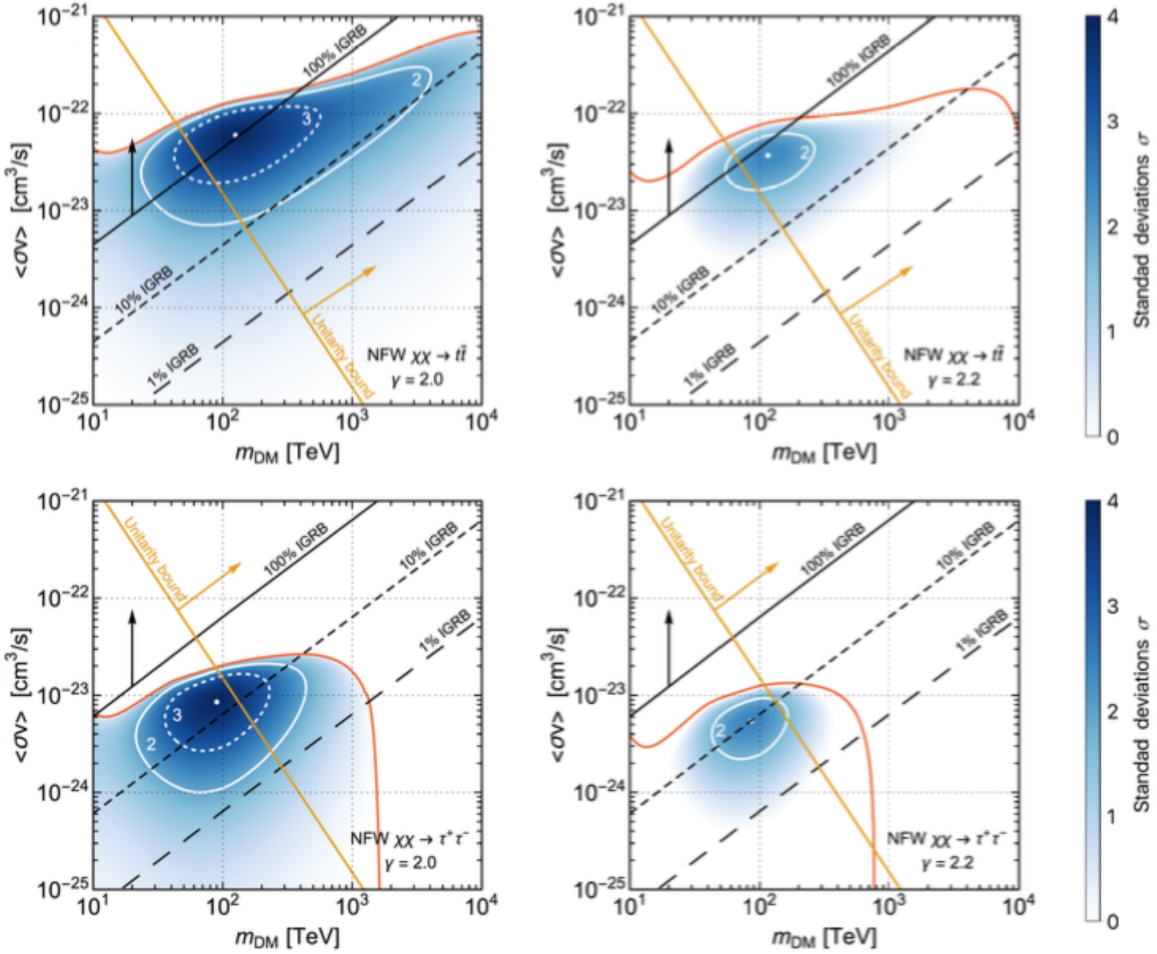
Reheating temperature become a free parameter (lower limit from BBN)

$$T_{\rm RH} \simeq 660 \left(\frac{m_\chi}{100\ \mathrm{TeV}}\right)^{1/2} \mathrm{GeV}$$

Conclusions

- Astrophysical exces at hundred TeV?
- Decaying (annihilating seems disadvantaged) Dark Matter could be a possible explanation
- Multimessenger analysis can strongly constraint the decay channel
- A rigorous angular distribution (an time) analysis will discriminate DM hypotesis

THANKS



100% IGRB
10% IGRB
1% IGRB
Unitarity bound
NFW $\chi\chi \to t\bar{t}$
γ = 2.0
NFW $\chi\chi \to t\bar{t}$
γ = 2.2
NFW $\chi\chi \to \tau^+\tau^-$
γ = 2.0
NFW $\chi\chi \to \tau^+\tau^-$
γ = 2.2
$<\sigma v>$ [cm^3/s]
m_{DM} [TeV]
Standard deviations σ