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Results and Prospects on TeV Dark Matter at the Galactic Center

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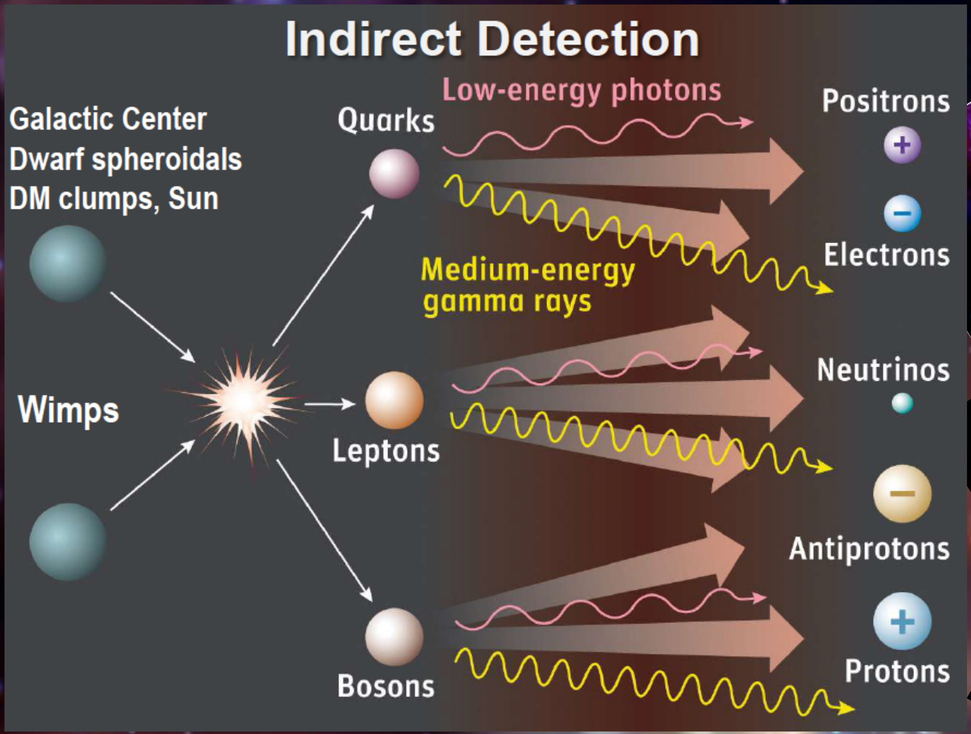
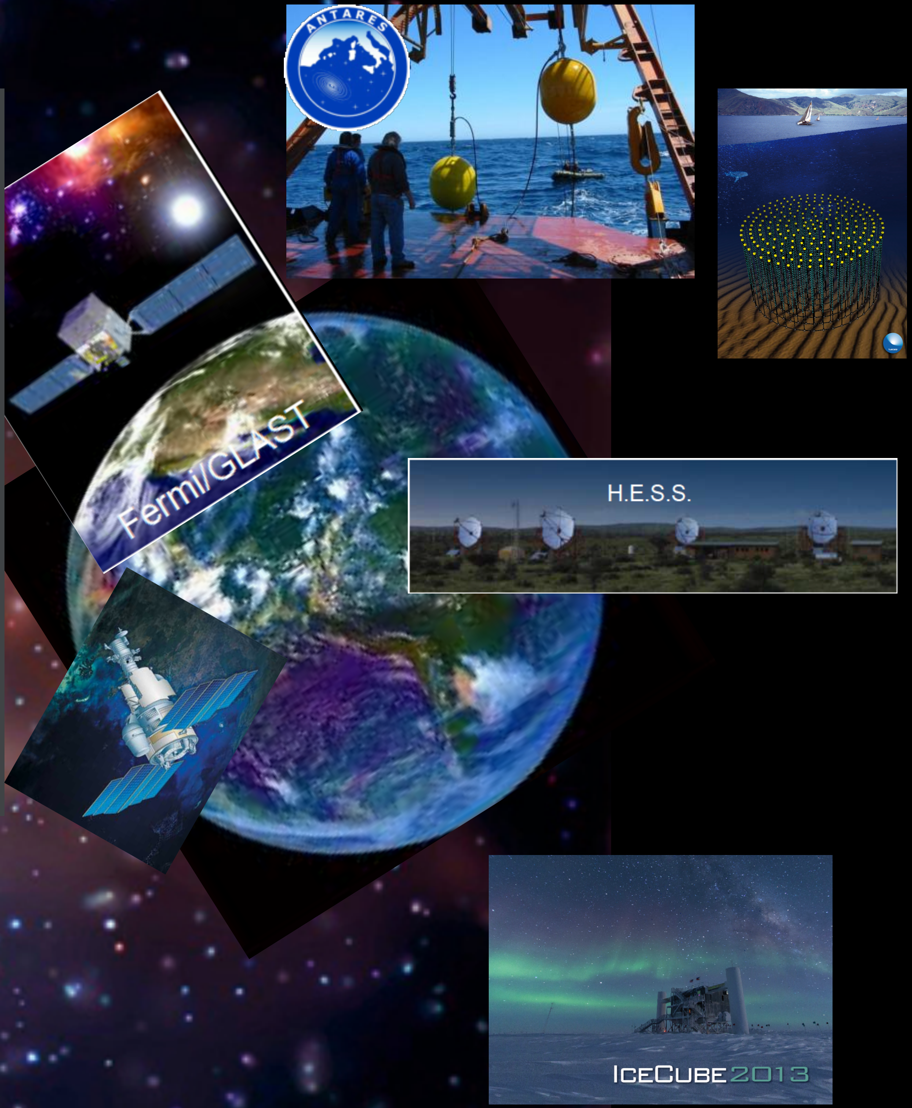
J. A. R Cembranos, V. G., A. L. Maroto [arXiv:1204.0655v1], PRD 86, 103506 (2012); [arXiv:1302.6871v2][astro-ph.CO], JCAP04 (2013) 051, [arXiv:1403.6018], PRD 90, 043004 (2014); , A. de la Cruz-Dombriz, R. A. Lineros [arXiv:1404.2067] TAUP 2013 Proceedings, JHEP 1309 (2013) 077, arXiv:1305.2124v3 [hep-ph]

Outline

- Dark Matter (DM) Indirect Search
- The Galactic Center (GC):
  - Gamma-rays
  - Neutrinos
  - Antiprotons
- Conclusions and Prospects

Indirect search





Indirect search

Single equation for multimessenger detection of cosmic-ray fluxes at the Earth from DM annihilating (a=2, $\zeta_i^{(2)} = \langle \sigma_i v \rangle$) and/or decay (a=1, $\zeta_i^{(1)} = 1/\tau_i^{\text{decay}}$) in Galactic sources:

$$\frac{d\Phi_{\text{cr-DM}}}{dE} = \eta_{\text{cr}} \cdot \sum_{a=1}^{2} \sum_{i}^{\text{SM channels}} \frac{\zeta_i^{(a)}}{a} \frac{dN_i^{(\text{cr})}}{dE} \cdot \frac{\kappa_{\text{cr}}^{(a)}}{4\pi\ m_{\text{DM}}^a}$$

	gamma-rays	neutrinos	antiprotons
η_{cr}	1	$\sum_{p=1}^{3} P_{fp}$	$v_{\bar{p}} (\rho_\odot)^a$
κ_{cr}	$\langle J_{(a)} \rangle_{\Delta\Omega}$	$\langle J_{(a)} \rangle_{\Delta\Omega}$	$R_{\bar{\text{cr}}}(r_\odot, E)$

Galactic Center

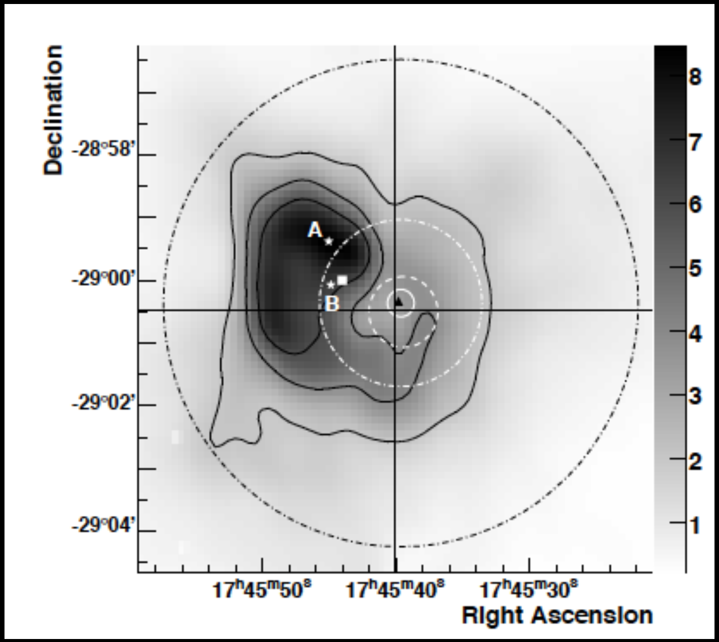
- Possible DM distribution close to the Earth but embedded in a very complex region due to the presence of multiple sources.

- Multiple sources observed (Radio flux, Sgr A* black hole, SNR Sgr A East, pulsar candidate, gamma emission).

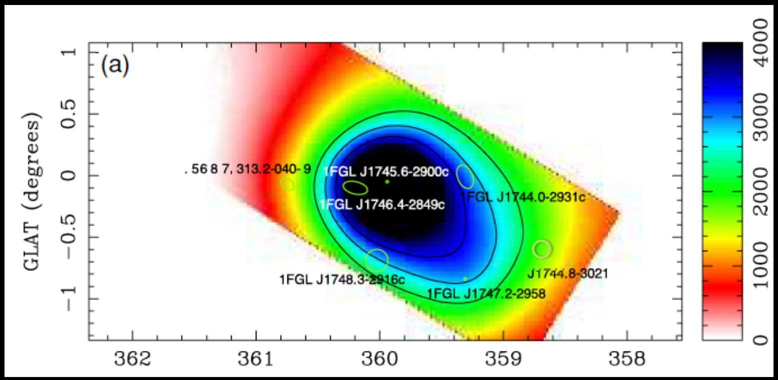
- Variability in Radio and X,

  but not in gamma flux

HESS J1745-290



1FGL J1745.6-2900c

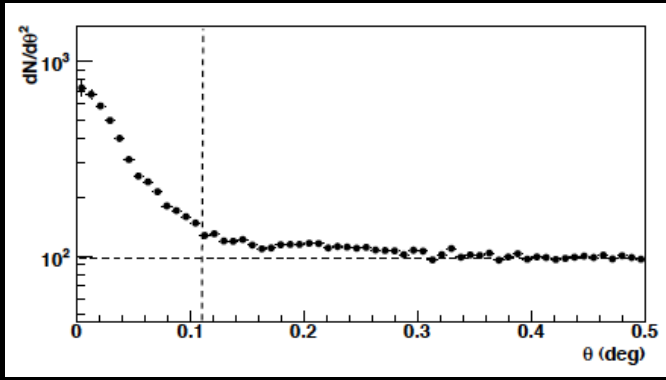


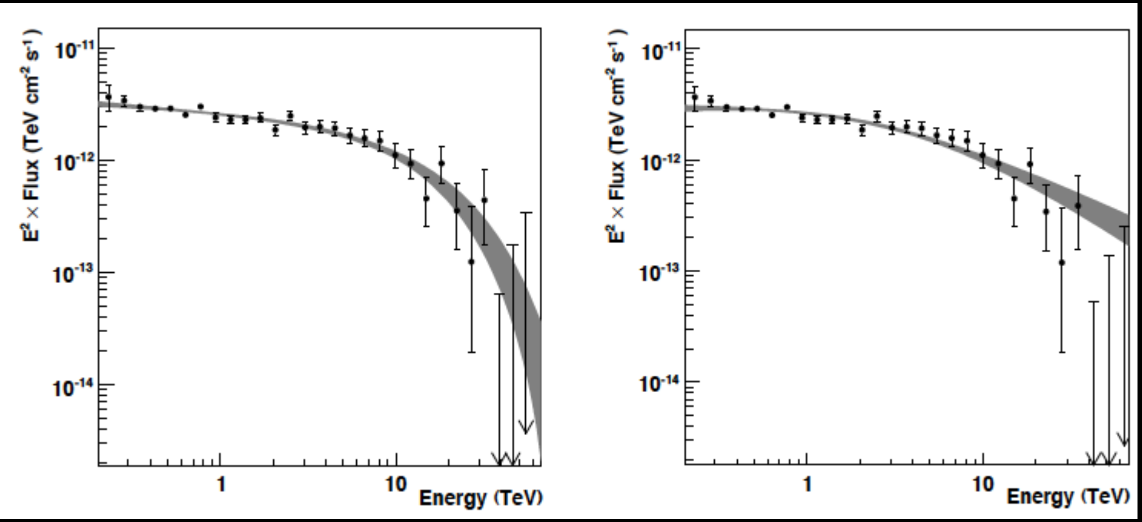
Gamma-rays from the Galactic Center

By HESS:

270 GeV-70 TeV

$\Theta < 0.1^{o}$

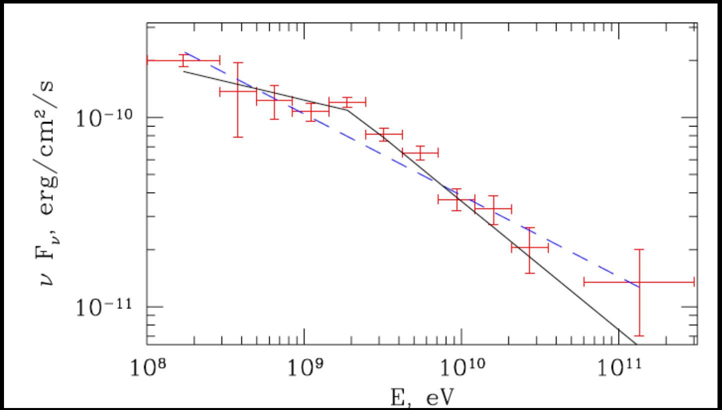




F. Aharonian et al. A&A 503, 817-825 (2009) F. Prada et al. Phys. Rev. Lett. 95, 241301 (2004)

By Fermi-LAT:

100 MeV-300 GeV



$$E > E_{br}$$

$$\chi^2/d.o.f. = 0.81$$

$$\Gamma = 2.68 \pm 0.05$$

M. Cherenyakova et al. ApJ 726, 60 (2011)

Gamma-rays from the Galactic Center

Background component: $$\frac{d\Phi_{Bg}}{dE} = B^2 \cdot \left(\frac{E}{\mathrm{GeV}}\right)^{-\Gamma}$$

$$\frac{d\Phi_{Tot}}{dE} = \frac{d\Phi_{Bg}}{dE} + \frac{d\Phi_{DM}}{dE}$$

4 free parameters:

$$B, \Gamma, A, M$$

DM contribution: $$\frac{\mathrm{d}\,\Phi_{\mathrm{DM}}}{\mathrm{d}\,E} = \sum_i \frac{\langle \sigma_i v \rangle}{2} \frac{\mathrm{d}\,N_i}{\mathrm{d}\,E} \times \underbrace{\frac{\Delta\Omega \, \langle J_{(2)} \rangle_{\Delta\Omega}}{4\pi M^2}}_{A}$$

Gamma-rays from the Galactic Center

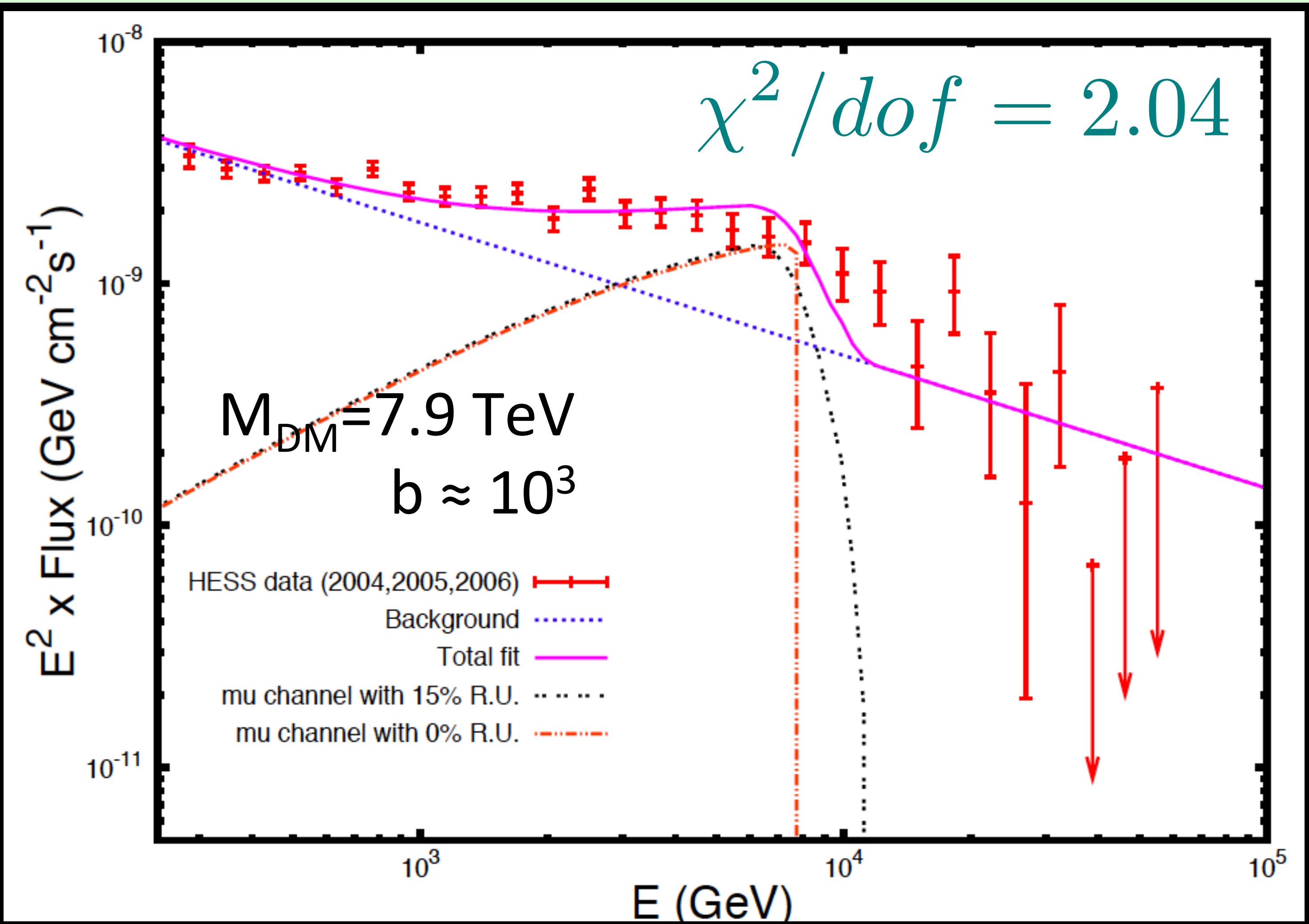
Channel	M (TeV)	$A\,(10^{-7}\,\mathrm{cm}^{-1}\mathrm{s}^{-1/2})$	$B\,(10^{-4}\,\mathrm{GeV}^{-1/2}\mathrm{cm}^{-1}\mathrm{s}^{-1/2})$	Γ	χ^2/dof	$\Delta\chi^2$	b
e^+e^-	7.51 ± 0.11	8.12 ± 0.73	2.78 ± 0.79	2.55 ± 0.06	2.09	32.6	111 ± 20
$\mu^+\mu^-$	7.89 ± 0.21	21.2 ± 1.92	2.81 ± 0.53	2.55 ± 0.06	2.04	31.4	837 ± 158
$\tau^+\tau^-$	12.4 ± 1.3	7.78 ± 0.69	3.17 ± 0.62	2.59 ± 0.06	1.59	20.6	278 ± 76
$u\bar{u}$	27.9 ± 1.8	6.51 ± 0.46	9.52 ± 9.47	3.08 ± 0.35	0.78	1.2	987 ± 189
$d\bar{d}$	42.0 ± 4.4	4.88 ± 0.48	8.26 ± 7.86	3.03 ± 0.34	0.73	0.0	1257 ± 361
$s\bar{s}$	53.9 ± 6.2	4.85 ± 0.57	6.59 ± 5.43	2.92 ± 0.29	0.90	4.1	2045 ± 672
$c\bar{c}$	31.4 ± 6.0	6.90 ± 1.06	53.0 ± 157	3.70 ± 1.07	1.78	25.0	1404 ± 689
$b\bar{b}$	82.0 ± 12.8	3.69 ± 0.61	6.27 ± 6.07	2.88 ± 0.35	1.32	14.2	2739 ± 1246
$t\bar{t}$	87.7 ± 8.2	3.68 ± 0.34	6.07 ± 3.34	2.86 ± 0.19	0.88	3.6	3116 ± 820
W^+W^-	48.8 ± 4.3	4.98 ± 0.40	5.18 ± 2.23	2.80 ± 0.15	0.84	2.6	1767 ± 419
ZZ	54.5 ± 4.9	4.73 ± 0.40	5.38 ± 2.45	2.81 ± 0.16	0.85	2.9	1988 ± 491

$$A^2 = \frac{\langle \sigma v \rangle \, \Delta\Omega \, \langle J_{(2)} \rangle_{\Delta\Omega}}{8\pi M^2} \qquad \langle \sigma v \rangle = 3 \cdot 10^{-26}\ \mathrm{cm}^3\mathrm{s}^{-1} \qquad \Delta\Omega \simeq 10^{-5}$$

$$b \equiv \langle J_{(2)} \rangle / \langle J_{(2)}^{\mathrm{NFW}} \rangle \qquad \langle J_{(2)}^{\mathrm{NFW}} \rangle \simeq 280 \cdot 10^{23}\ \mathrm{GeV}^2\mathrm{cm}^{-5}$$

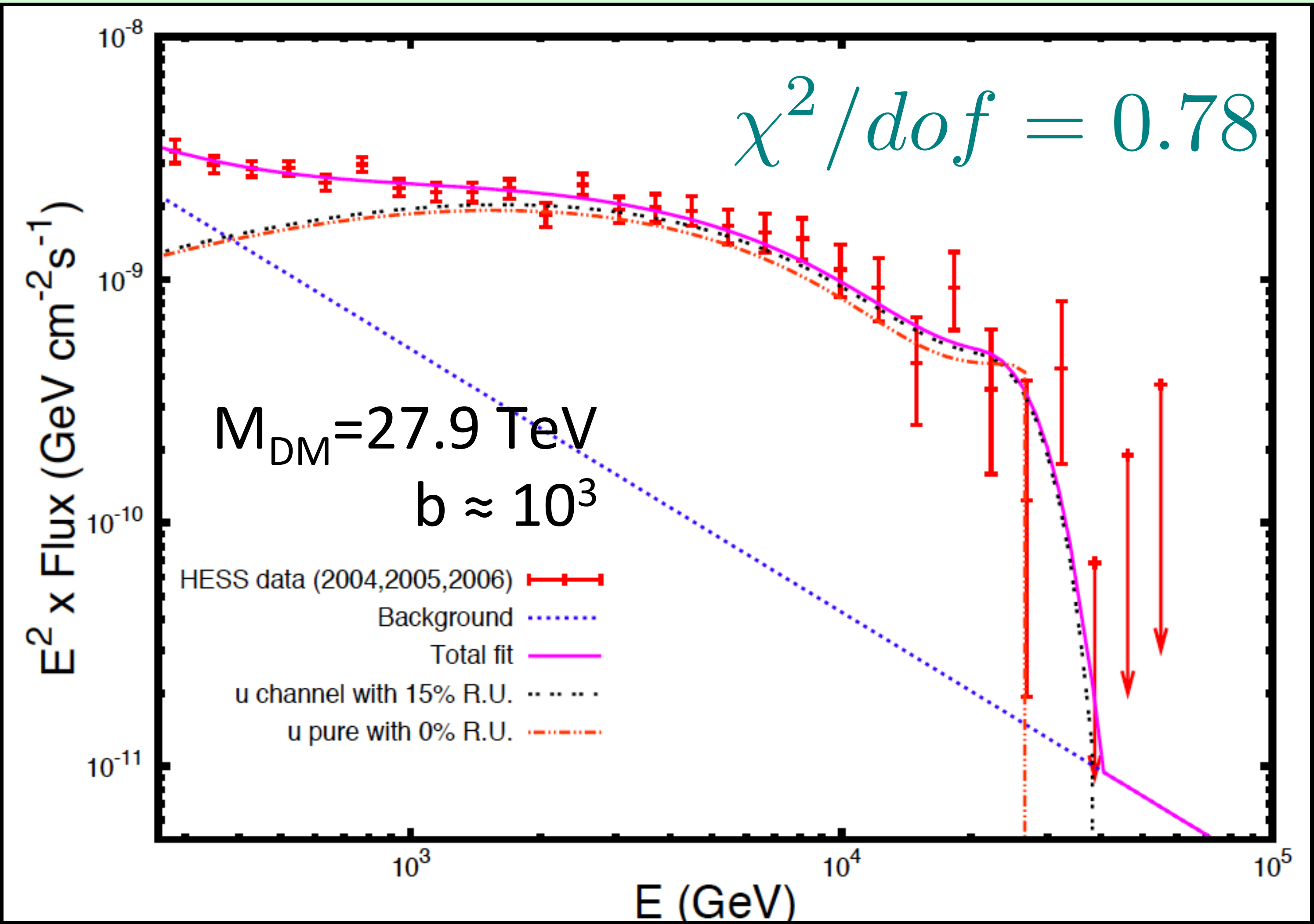
J. A. R Cembranos, V. G., A. L. Maroto arXiv [1204.0655v1], [Phy. Rev. D 85, 043505] ; [arXiv: 1302.6871v2][astro-ph.CO], JCAP04 (2013) 051

$\mu^+\mu^-$ channel



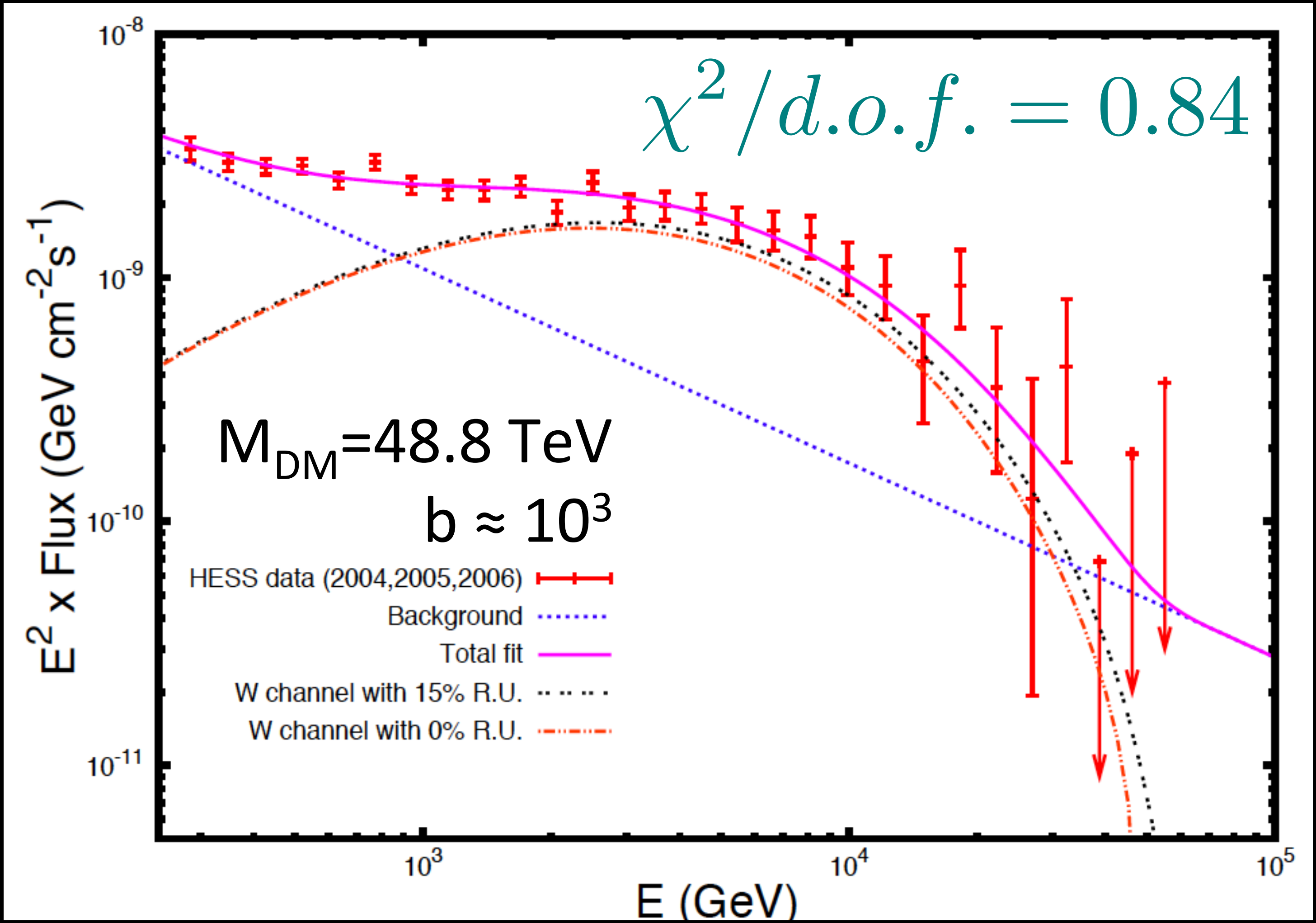
J. A. R Cembranos, V. G., A. L. Maroto arXiv [1204.0655v1], PRD 86, 103506 (2012); [arXiv:1302.6871v2][astro-ph.CO], JCAP04 (2013) 051

u-ubar channel



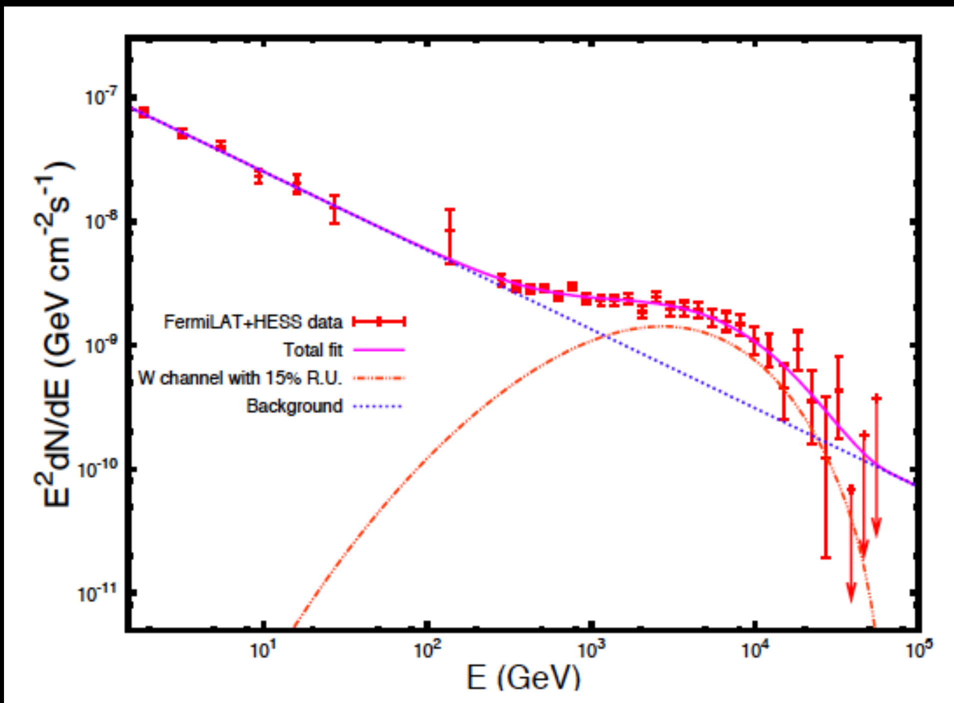
J. A. R Cembranos, V. G., A. L. Maroto arXiv [1204.0655v1], PRD 86, 103506 (2012); [arXiv:1302.6871v2][astro-ph.CO], JCAP04 (2013) 051

W^+W^- channel



J. A. R Cembranos, V. G., A. L. Maroto arXiv [1204.0655v1], PRD 86, 103506 (2012); [arXiv:1302.6871v2][astro-ph.CO], JCAP04 (2013) 051

Gamma-rays from the Galactic Center



M_{DM}>10 TeV

Boost factor $=\langle J\rangle/\langle J\rangle_{NFW} \approx 10^3$

Bg compatible with Fermi-LAT

(Fermi-LAT Data)	W^+W^-
M	51.7 ± 5.2
A	4.44 ± 0.34
B	3.29 ± 1.03
Γ	2.63 ± 0.02
$\chi^2/\,\mathrm{dof}$	0.75

J. A. R Cembranos, V. G., A. L. Maroto arXiv [1204.0655v1], PRD 86, 103506 (2012); [arXiv:1302.6871v2][astro-ph.CO], JCAP04 (2013) 051

Neutrinos from the Galactic Center

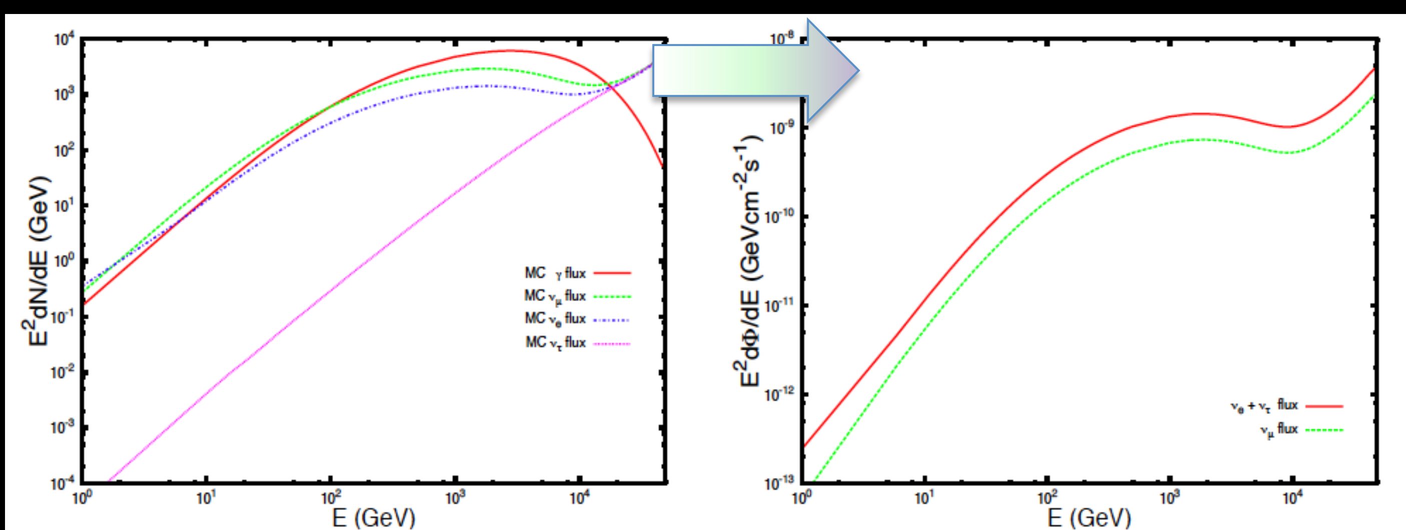
$$\frac{d\Phi_{\nu_f}}{dE} = \sum_{p=1}^{3}\sum_{a=1}^{2}\sum_{i}^{\text{channels}} \boxed{P_{fp}} \cdot \frac{\zeta_i^{(a,\nu_p)}}{a}\frac{dN_i^{(\nu_p)}}{dE} \cdot \frac{\Delta\Omega \langle J_{(a)}\rangle_{\Delta\Omega}}{4\pi M^a}$$

1. W^+W^- boson channel parameters from gamma-rays fit:

$M_{DM} \approx 50$ TeV

Neutrinos flux at the Earth needs to account for:

2. neutrino oscillation

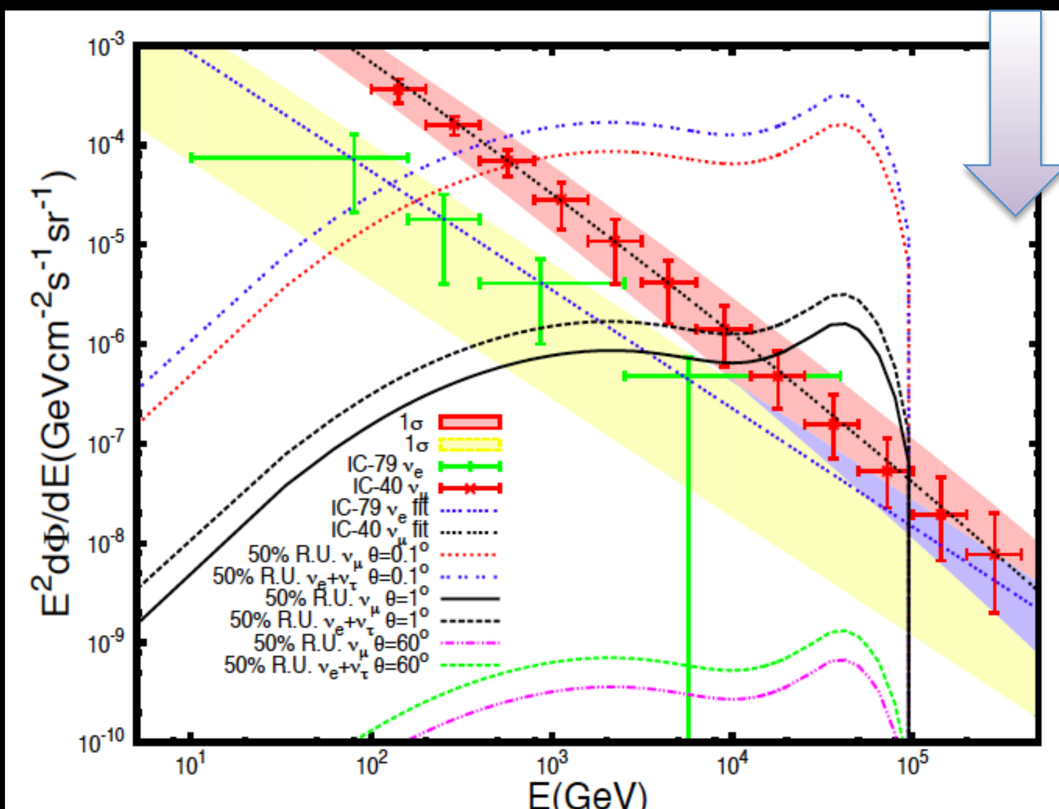


3. detector different (in)sensitivity to neutrinos flavors and antineutrinos

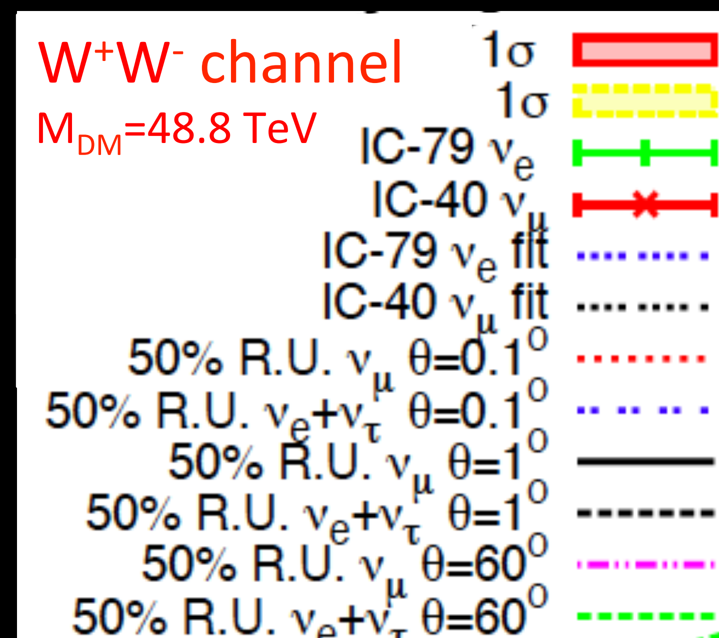
J. A. R Cembranos, V. G., A. L. Maroto arXiv [1403.6018], PRD 90, 043004 (2014); [arXiv:1404.2067]TAUP 2013 Proceedings

Neutrinos from the Galactic Center

$$\frac{d\Phi_{\nu_f}}{dE} = \sum_{p=1}^{3}\sum_{a=1}^{2}\sum_{i}^{\text{channels}} P_{fp}\cdot \frac{\zeta_i^{(a,\nu_p)}}{a}\frac{dN_i^{(\nu_p)}}{dE}\frac{\Delta\Omega\langle J_{(a)}\rangle_{\Delta\Omega}}{4\pi M^a}$$



$$\Delta\Omega = 2\pi(1-\cos\theta)$$



J. A. R Cembranos, V. G., A. L. Maroto arXiv [1403.6018],PRD 90, 043004 (2014); [arXiv:1404.2067]TAUP 2013 Proceedings

Neutrinos from the Galactic Center

$$\chi_{\nu_i} = \frac{\Phi_{\nu_i}\sqrt{A_{\rm eff}\, t_{\rm exp}\, \Delta\Omega}}{\sqrt{\Phi_{\nu_i} + \Phi_{\nu_i}^{\rm Atm}}} = 5\,(3,\,2)$$

$$N_{\nu_f}^{t_{exp}} = \int_{E_{\rm min}^{\nu}}^{\infty} dE_\nu \; \frac{d\Phi_{\nu_f}}{dE} \times A_{\rm eff}\, t_{\rm exp}$$

Effective Area and Resolution Angle depend on:

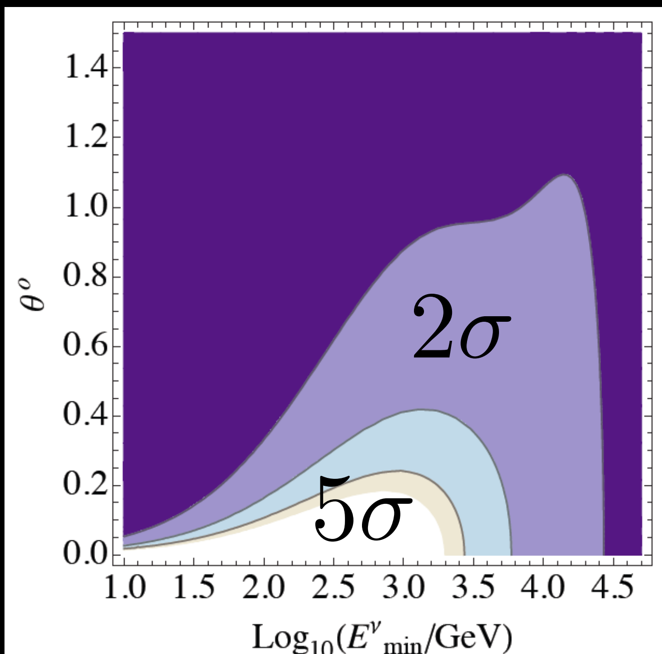
- Energy range;
- Neutrino flavor and background;
- Position of the source with respect to the detector (Northern or Southern sky);
- Number of strings in the configuration of observation.

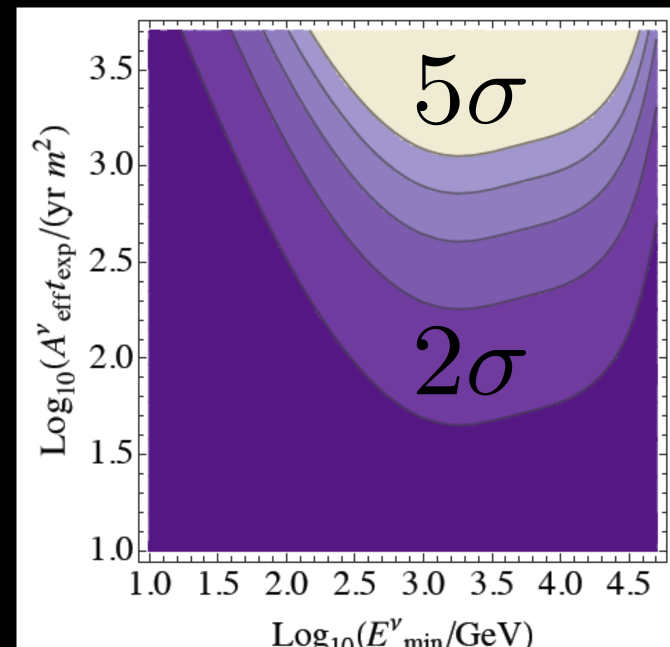
J. A. R Cembranos, V. G., A. L. Maroto arXiv [1403.6018] , PRD 90, 043004 (2014); [arXiv:1404.2067]TAUP 2013 Proceedings

Neutrinos from the Galactic Center

$$Af = A_{\rm eff} \times t_{\rm exp} = 100\,{\rm m}^2\,{\rm yr}$$

$$\theta = 0.6^\circ$$





W^+W^- channel, with θ = 0.6º, $E_{min} \approx$ 1 TeV and 5 years we need:

$A_{eff} \approx 40\ m^2$ to get ≈2σ signal;

$A_{eff} \approx 200\ m^2$ to get a ≈5σ signal;

J. A. R Cembranos, V. G., A. L. Maroto arXiv [1403.6018] , PRD 90, 043004 (2014); [arXiv:1404.2067]TAUP 2013 Proceedings

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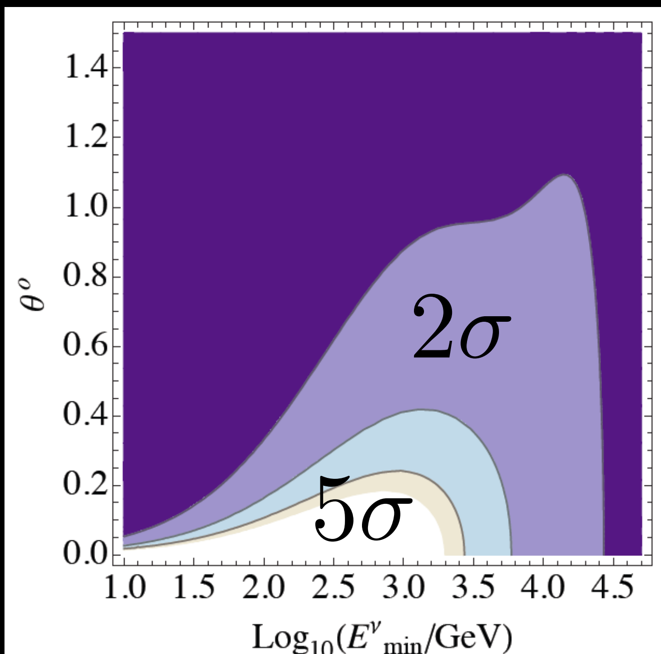
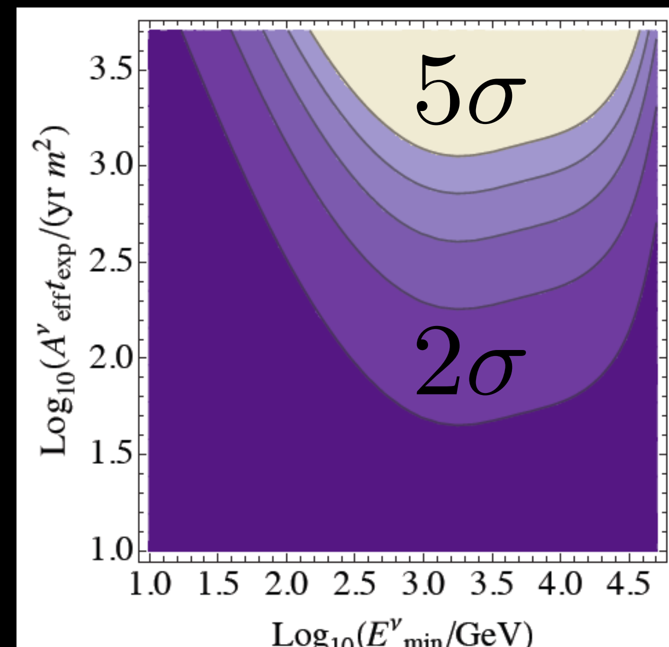


<u>Example:</u>

IC-79 ν_μ
Southern Sky at
≈ 30-100 TeV:

A_{eff} ≈ 5-20 m^2
θ ≥ 0.5º;



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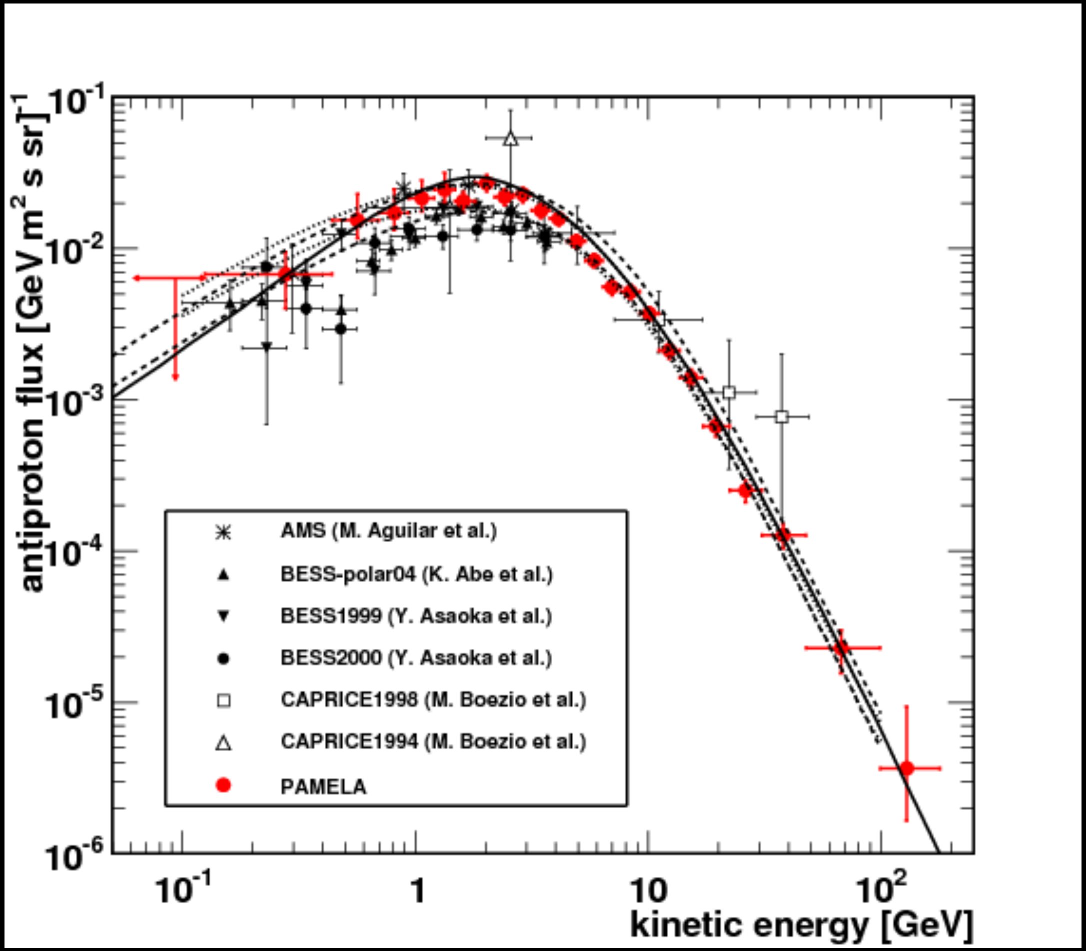
J. A. R Cembranos, V. G., A. L. Maroto arXiv [1403.6018] , PRD 90, 043004 (2014); [arXiv:1404.2067]TAUP 2013 Proceedings

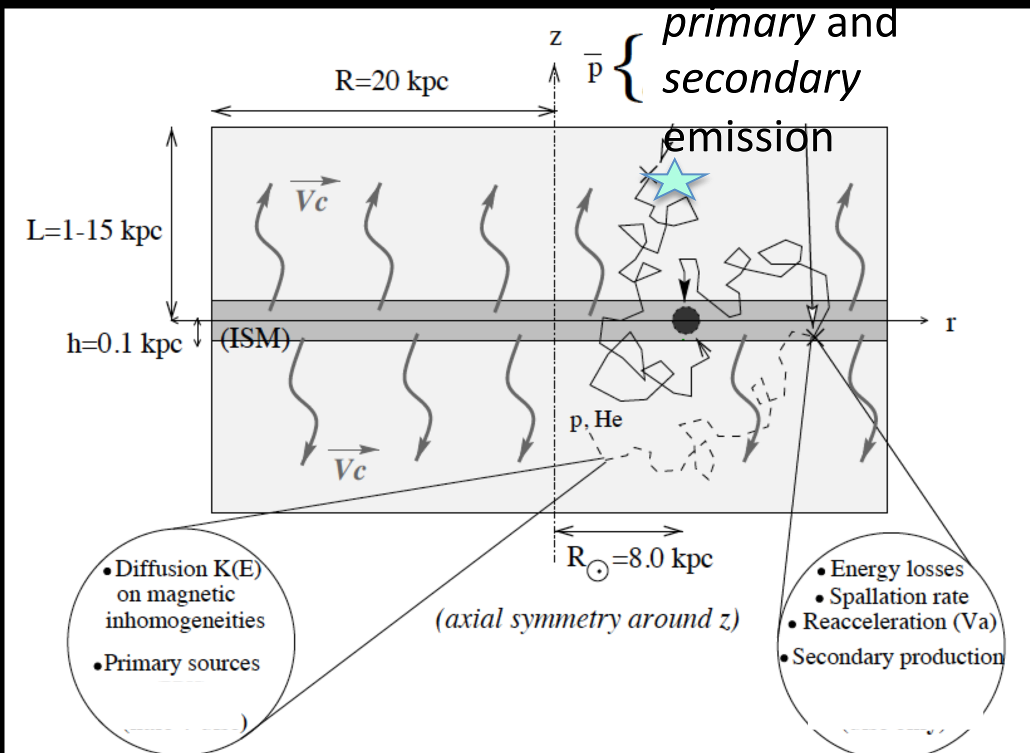
PAMELA antiproton data



- Compatible with antiproton *secondary* emission
- Any astroparticles source needs to be compatible with such antiproton flux.

Phys. Rev. Lett. 105, 121101 – Adriani et al. arXiv:1007.0821v1

Antiprotons from the Galactic Center



- V_c convective velocity
- $K(E_{\bar{p}})$ pure diffusion
- p-$\bar{p}$ annihilations (secondary) and ISM interactions (tertiary)
- $Q(E_{\bar{p}}, x, t)$ is the primary source

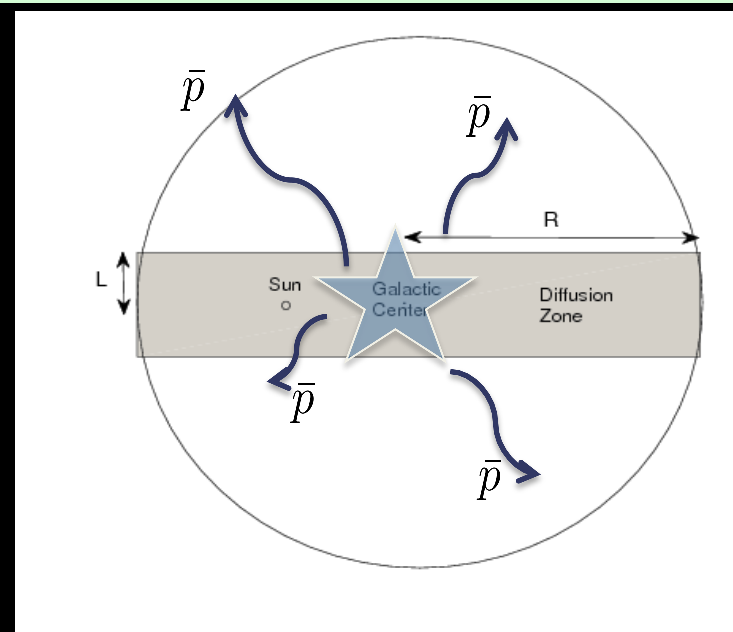
A&A 388, 676-687 (2002) Barrau et al. , arXiv:0112486v2

$$\frac{d\Phi_{\bar{p}}}{dE_{\bar{p}}} = \sum_{a=1}^{2} \sum_{i}^{\text{channels}} \frac{\zeta^{(a)}}{a} \frac{dN_i^{(a,\bar{p})}}{dE_{\bar{p}}} \cdot \frac{v_{\bar{p}}}{4\pi} \left(\frac{\rho_\odot}{M}\right)^a \boxed{R_{(a)}(E_{\bar{p}})}$$

Antiprotons from the Galactic Center

$$R^{\delta}(E_{\bar{p}}) = \frac{2}{R^2}\sum_{m=1}^{\infty}\frac{J_0\left(\zeta_1 \frac{r_\odot}{R}\right)}{A_m J_1^2(\zeta_m)} \times Const$$

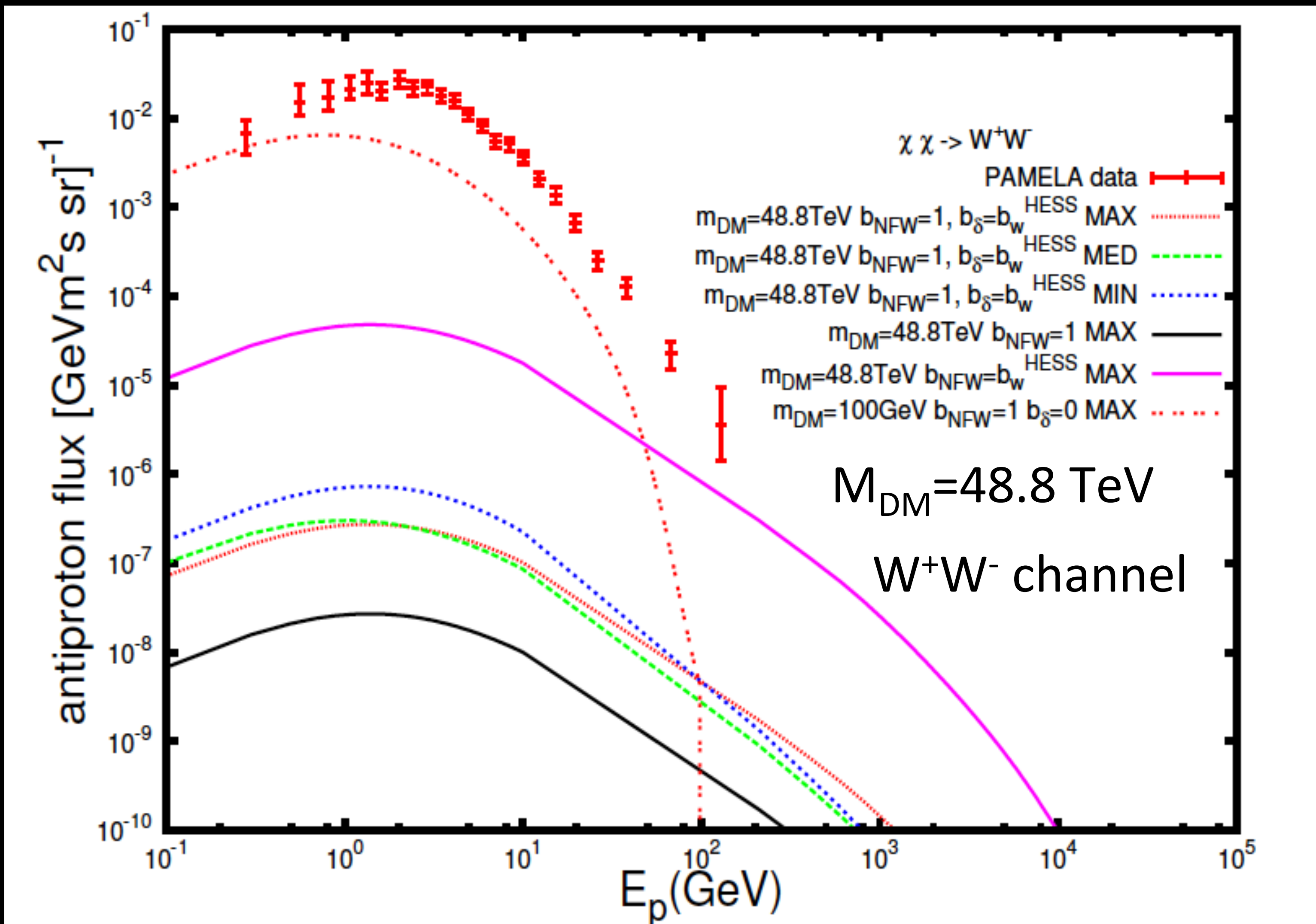
$$Const = \langle J \rangle_{\Delta\Omega}^{NFW} \Delta\Omega_{\mathrm{HESS}} \left(\frac{D_\odot}{\rho_\odot}\right)^2 \simeq 2.13 \cdot 10^{60}\, m^3$$



Model	δ	K_0 [kpc^2/Myr]	V_c [km/s]	L [kpc]
MIN	0.85	0.0016	13.5	1
MED	0.70	0.0112	12	4
MAX	0.46	0.0765	5	15

$$\frac{d\Phi_{\bar{p}}}{dE_{\bar{p}}} = \frac{v_{\bar{p}}}{4\pi}\frac{1}{2}\left(\frac{\rho_\odot}{m_{DM}}\right)^2 \sum_j \langle \sigma v \rangle_j \frac{dN_{\bar{p}}^j}{dE_{\bar{p}}}\left(b_{NFW}^j \times R^{NFW}(E_{\bar{p}}) + b_\delta^j \times C_1 \times R^{\delta}(E_{\bar{p}})\right)$$

Antiprotons from the Galactic Center



J. A. R Cembranos, V. G., A. L. Maroto arXiv [1204.0655v1], JCAP03(2015)041

Conclusions

- gamma-ray HESS data of the J1745-290 point-like source in the GC is well fitted by TeV DM annihilating into boson and some quark-antiquarks channels, with 10^3 boost factor.
- Fermi-LAT gamma-rays data from the same region are compatible with a power-law background component.
- Next generation of neutrino experiment with improved effective area and angular resolution will set more constraints on such DM hypothesis.
- PAMELA antiprotons data are compatible with a NFW TeV DM distribution with a 10^3 enhancement factor at the GC.

Prospects

- TeV DM candidate unconstrained by direct search.
- Branons could be a prospective model for TeV DM.
- 10^3 boost factor: local enhancement or no thermal DM?
- Next generation of experiments with improved effective area and angular resolution will set more constraints on such DM hypothesis.
- Search in progress….

¡Thank you!