Galactic antiprotons as a Dark Matter probe

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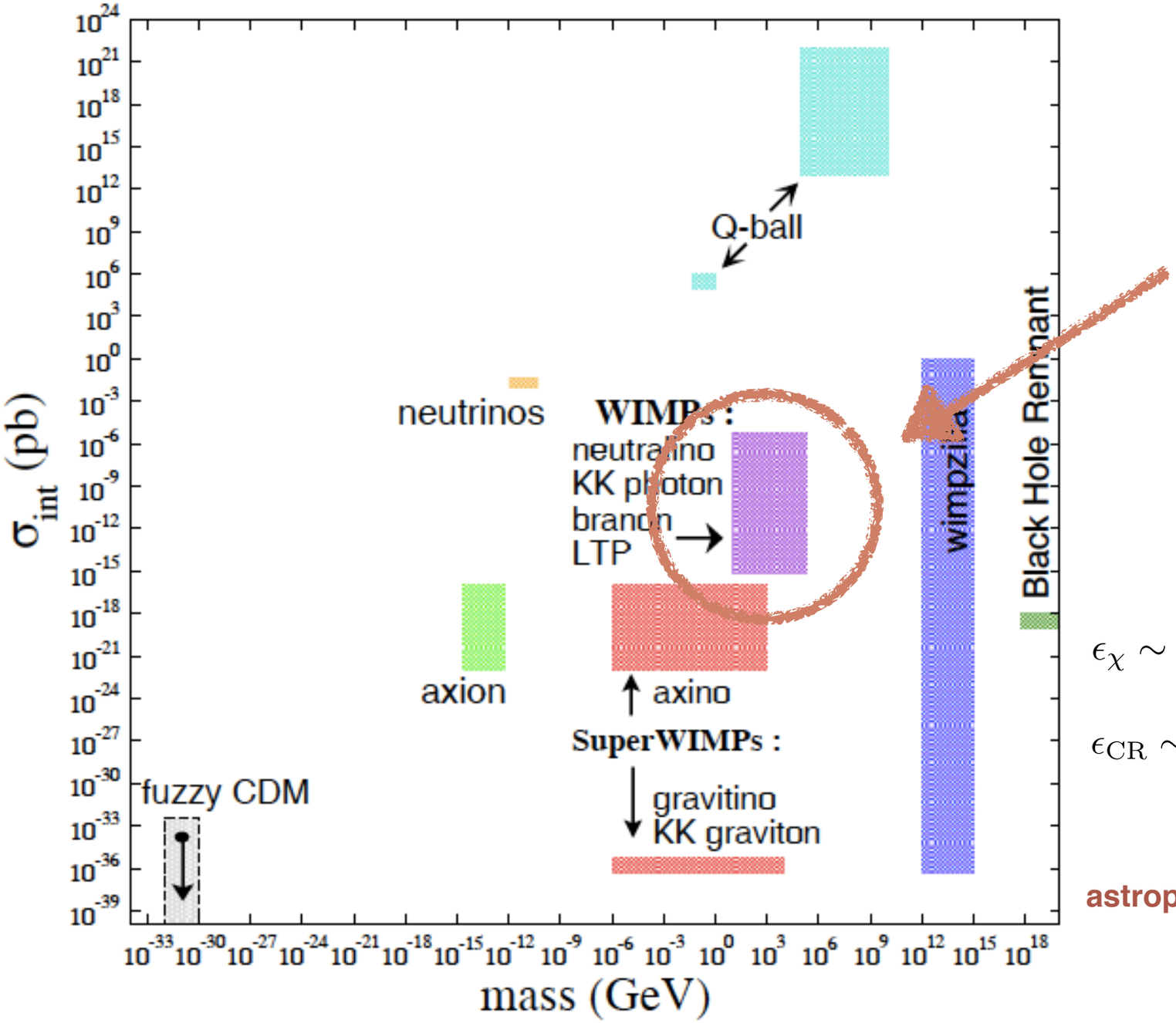
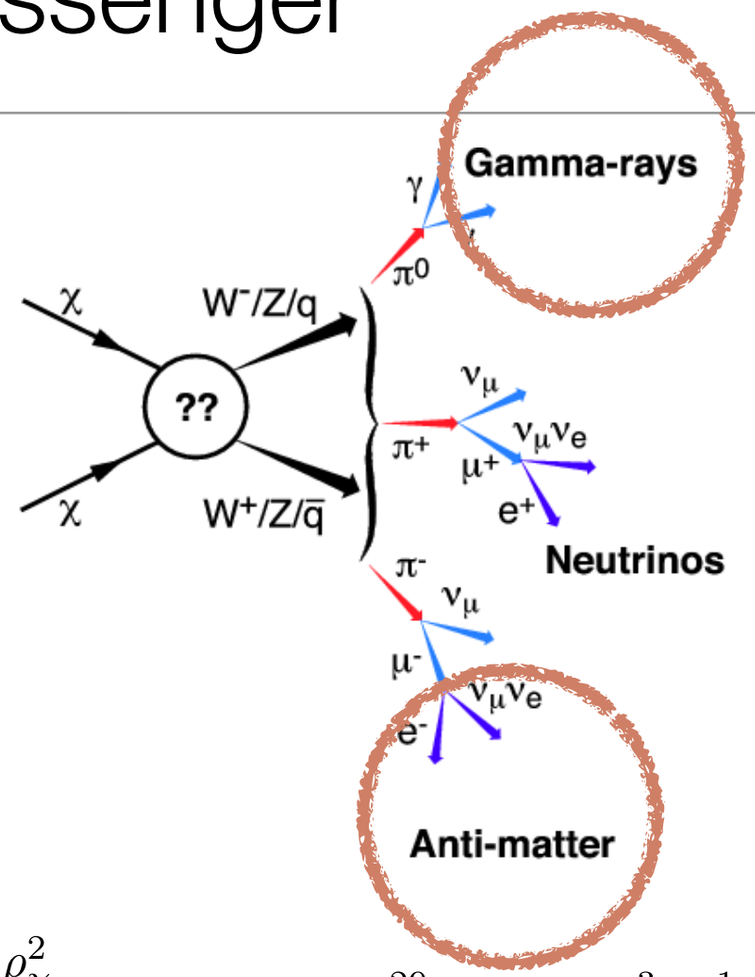
in collaboration with Daniele Gaggero (GRAPPA) and Dario Grasso (INFN)

Obergurgl-Hochgurgl | γ-rays and Dark Matter | 10th of December 2015

The importance of being multi-messenger





$$\epsilon_\chi \sim \frac{\rho_\chi^2}{m_\chi}\langle\sigma v\rangle \sim 5\times10^{-29}\,\mathrm{GeV\,cm^{-3}\,s^{-1}}$$

$$\epsilon_{\rm CR} \sim E^2\phi_{\rm CR}\,n_{\rm ISM}\,\sigma_{pp} \sim 5\times10^{-25}\,\mathrm{GeV\,cm^{-3}\,s^{-1}}$$

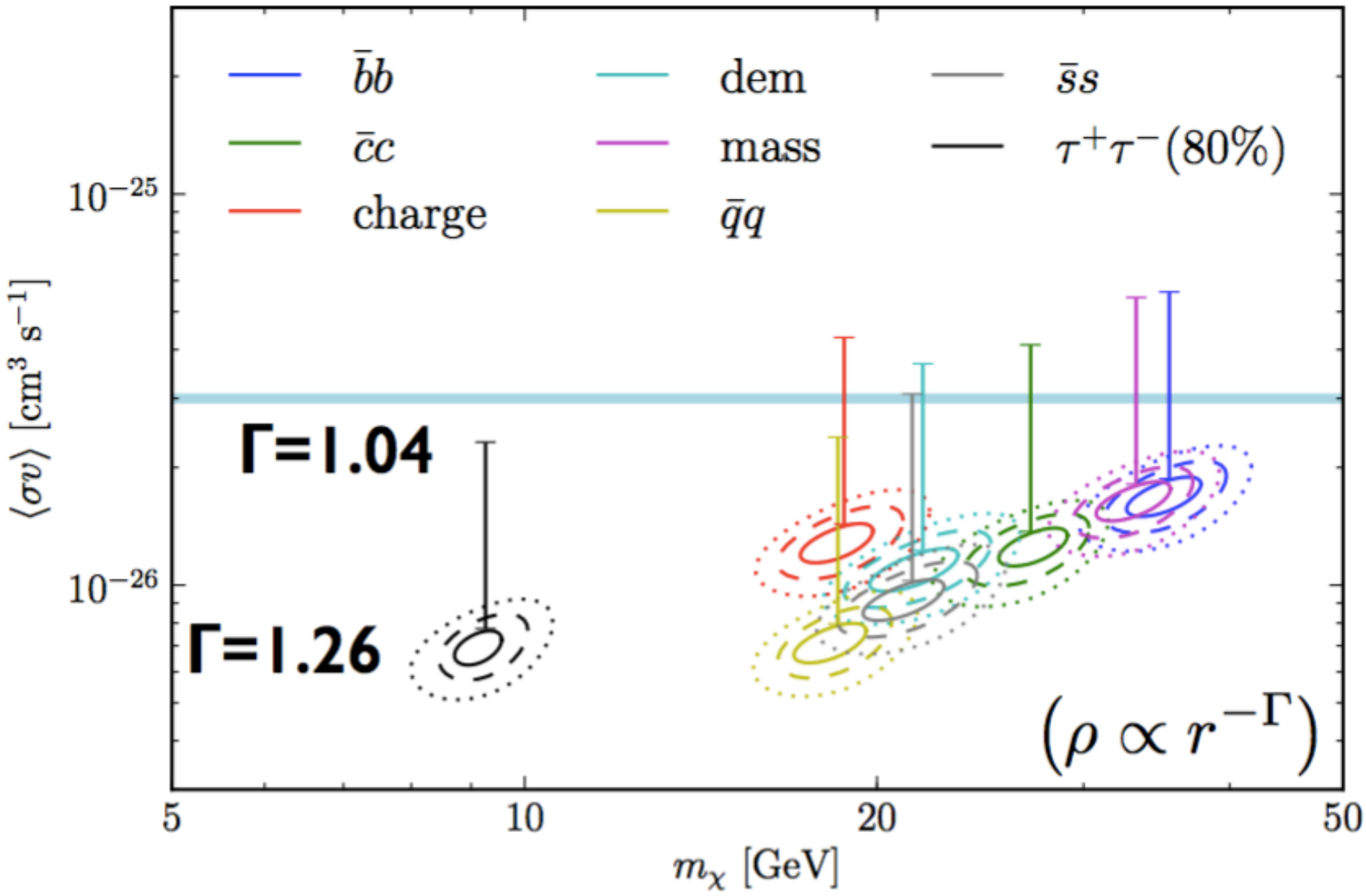
problem!

astrophysical emissivity is much larger than Dark one

A signal from the GC?

T. Bringmann, M. Vollmann & C. Weniger, 1406.6027

see Dan's talk for a complete list of references

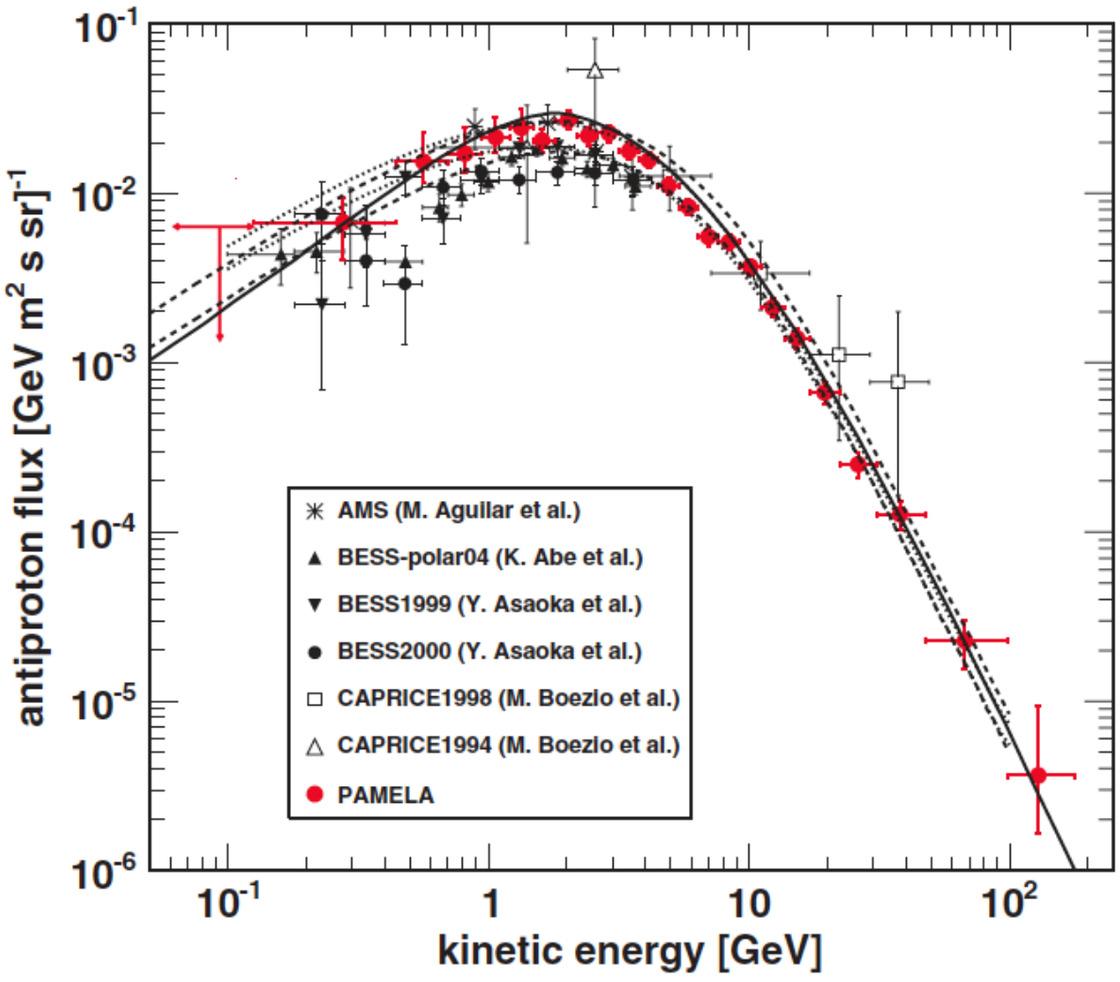


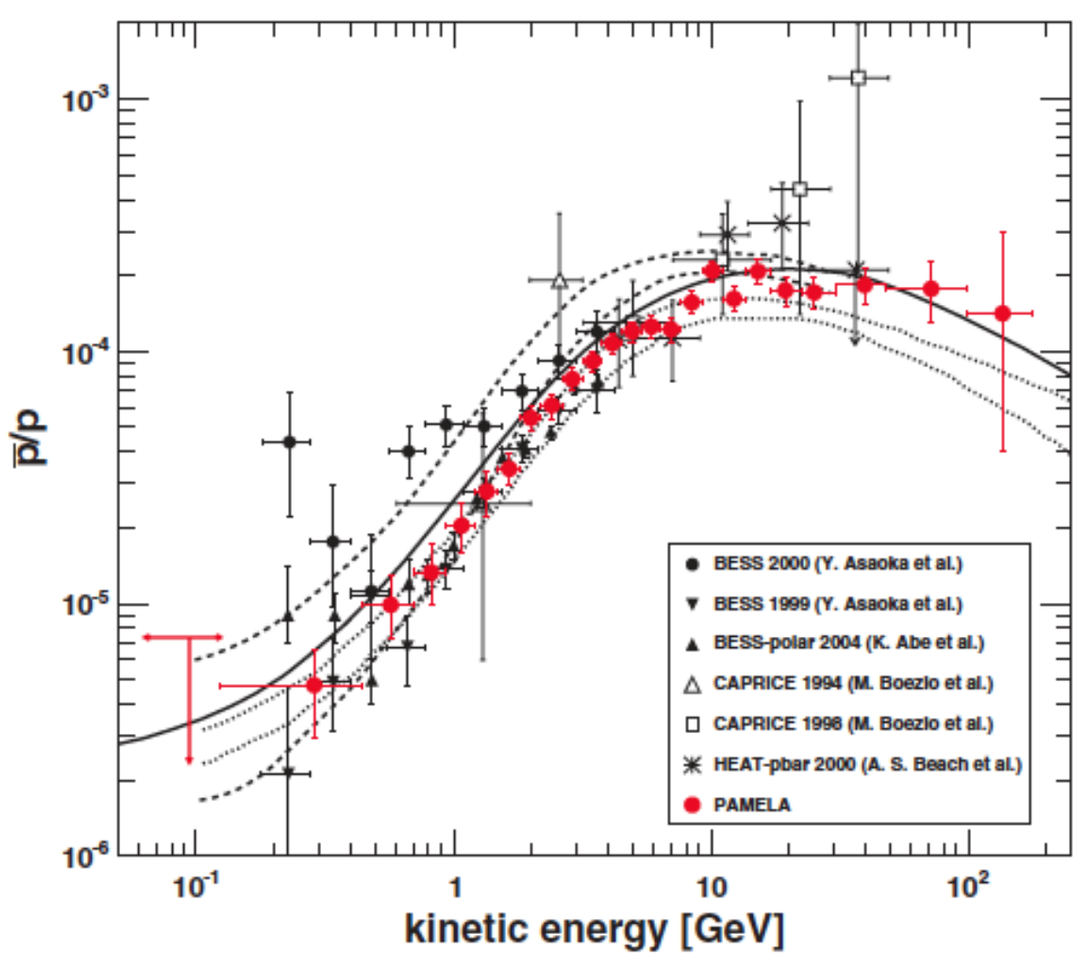
Quark final states and gNFW profile provide excellent spectral and morphological fits

→ *can galactic antiprotons rule out this interpretation?*

The experimental situation

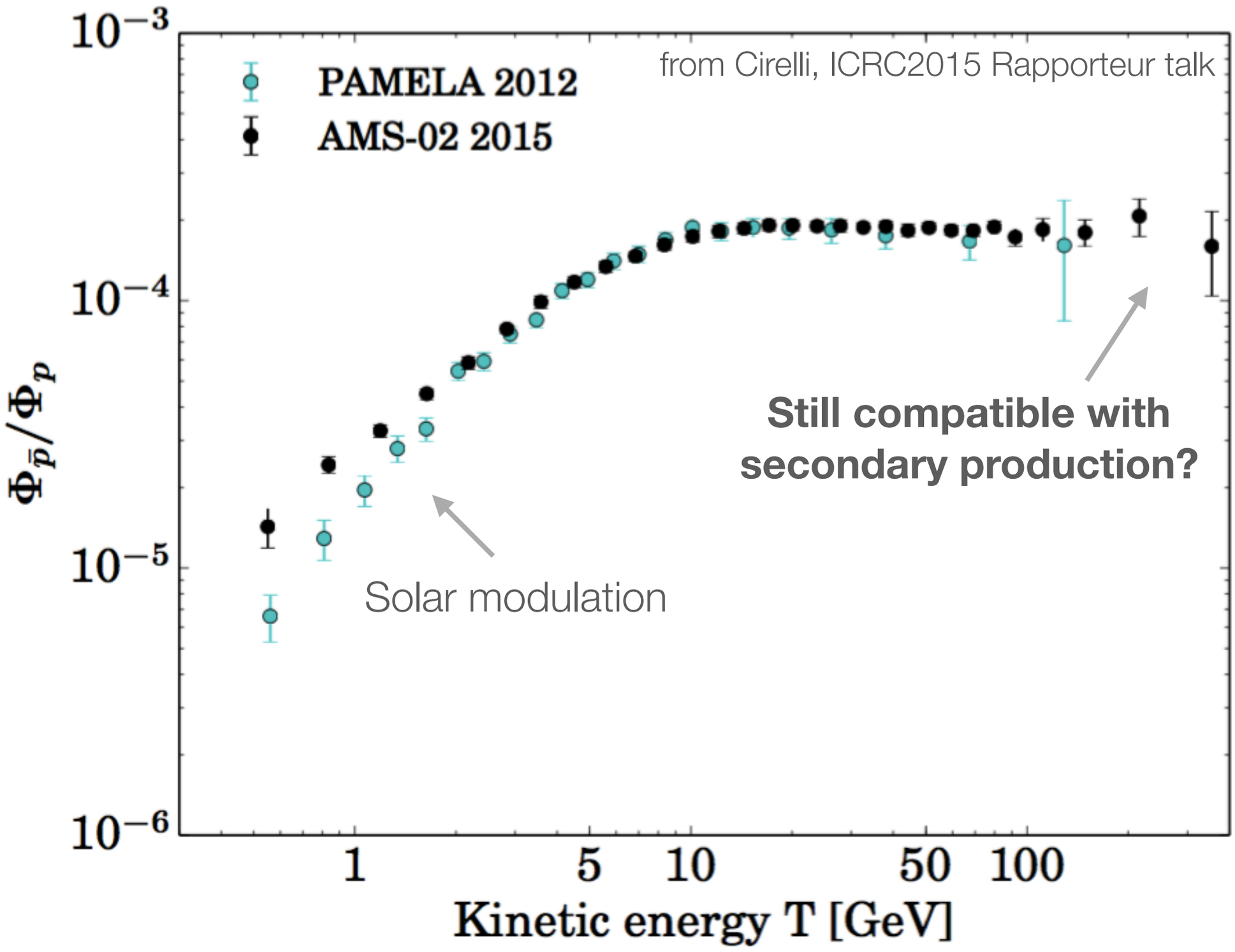
PAMELA, *PRL* 105, 121101 (2010)





- ~1.500 antiprotons identified by Pamela
- Spectrum ~ 0.06-180 GeV
- *Compatible with secondary production (Di Bernardo, CE, et al., 2010)*

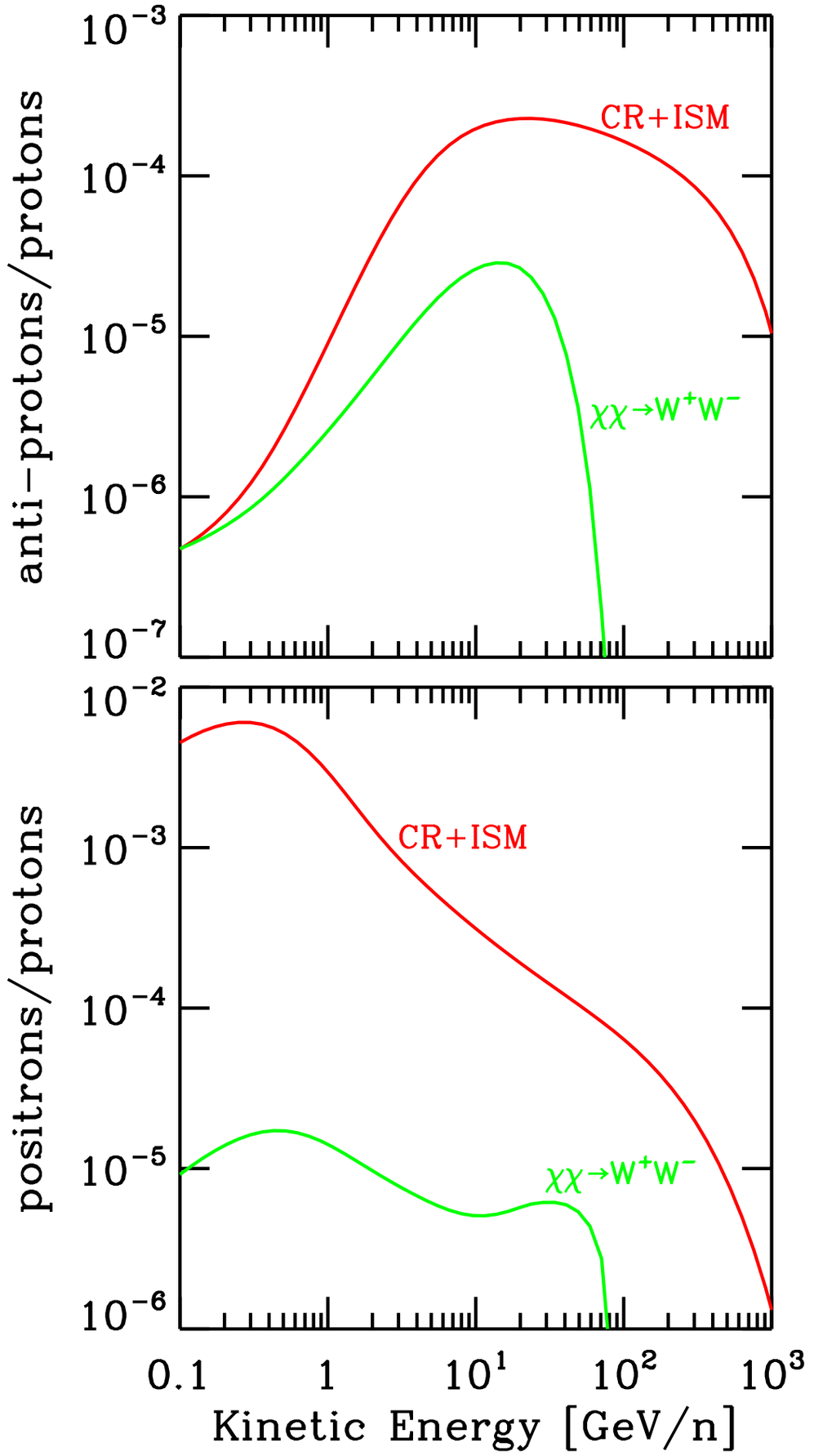
New (preliminary) data at higher energies!



Why antiprotons?

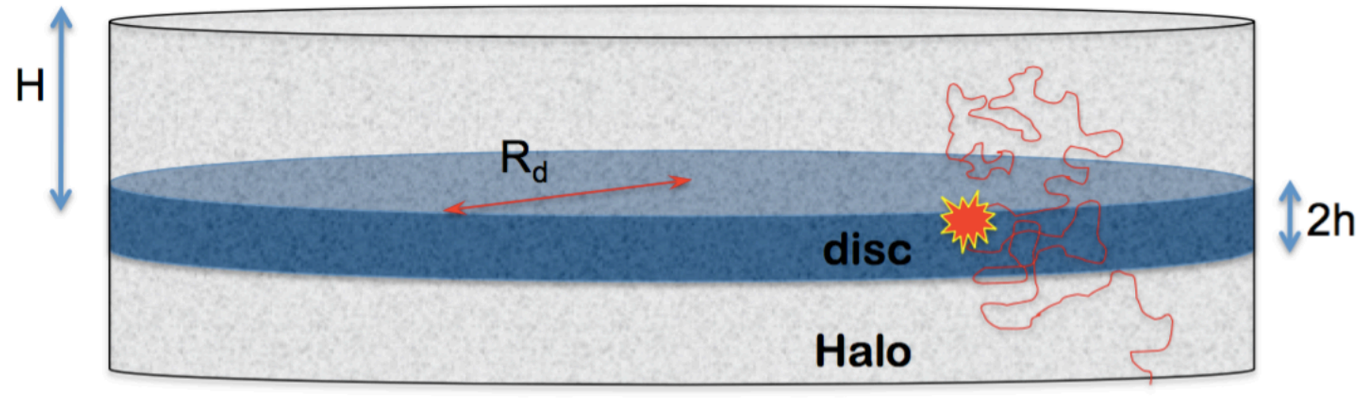
- we know the **background** with good accuracy

- in a **democratic** WIMP model the ratio between DM signal and background from standard astrophysical sources is usually much larger in the **antiproton** channel with respect to all other indirect detection methods.



Galactic CR propagation in a nutshell

see Stefano and Ralf talks for a longer introduction



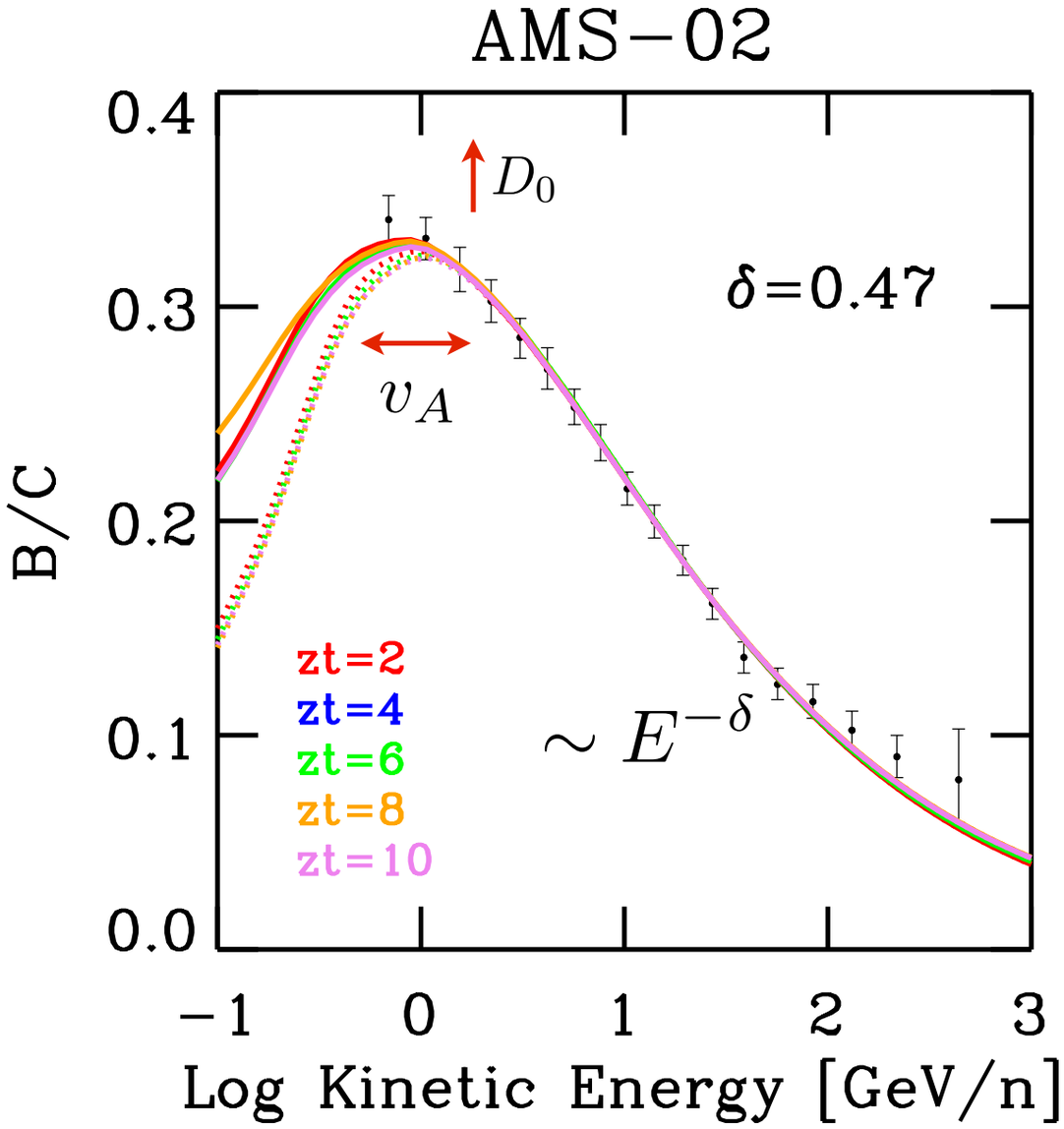
$$\cancel{\frac{\partial n}{\partial t}} = Q - \frac{n}{t_{\rm esc}} \quad \longrightarrow \quad n = Q \times t_{\rm esc} \sim Q \times \frac{H^2}{D} \sim Q \times \frac{H^2}{D_0} E^{-\delta}$$

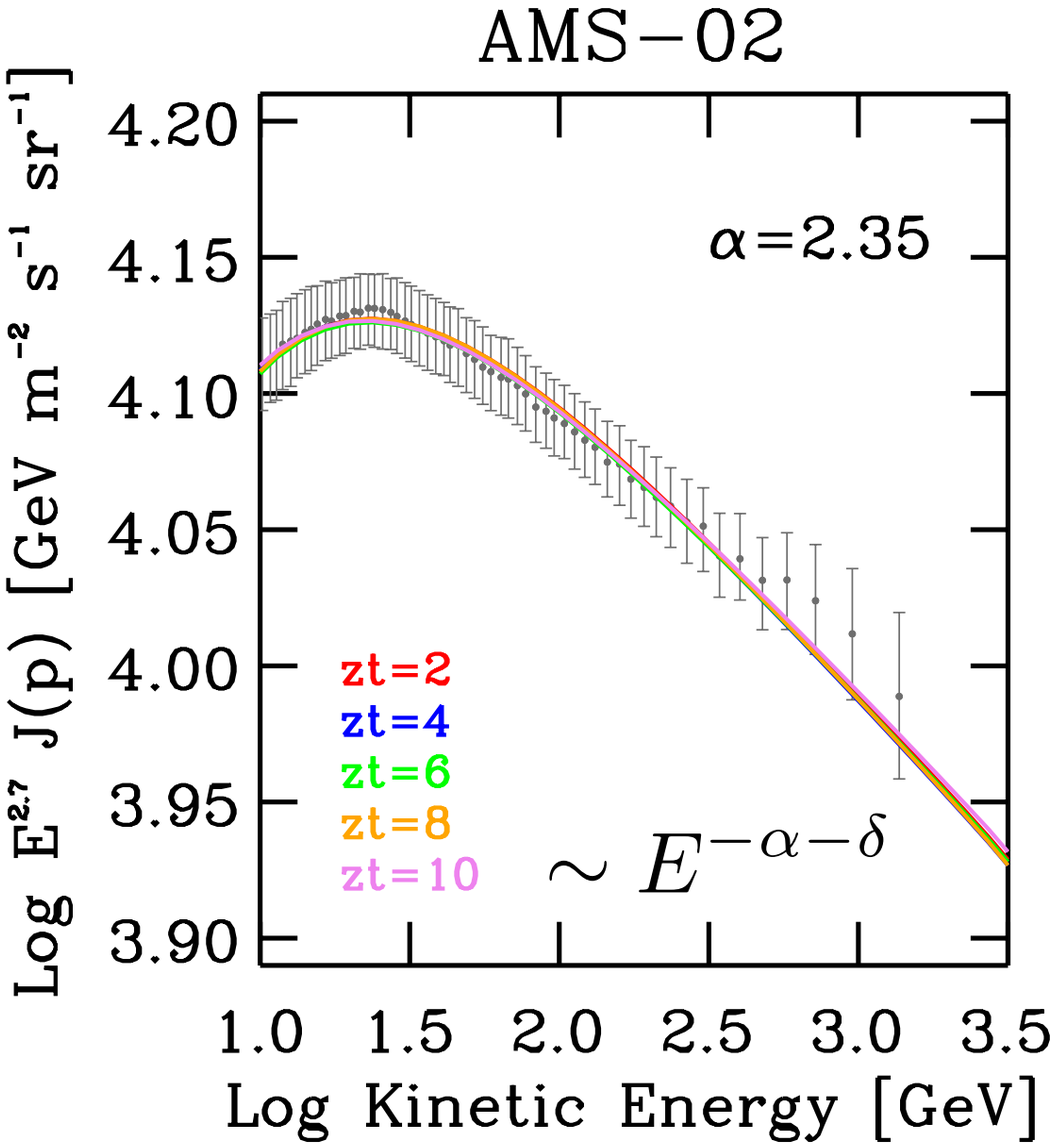
$$Q_p \sim \delta(z) E^{-\alpha} \quad \longrightarrow \quad n_p \sim \frac{H^2}{D_0} E^{-(\alpha+\delta)}$$

$$Q_s \sim n_p \bar{n}_{\rm gas} c\sigma \quad \longrightarrow \quad n_s \sim n_p \bar{n}_{\rm gas} c\sigma t_{\rm esc} \quad \longrightarrow \quad \frac{n_s}{n_p} \sim X \sim \frac{H}{D_0} E^{-\delta}$$

$$\bar{n}_{\rm gas} = n_{\rm disk} \frac{h}{H}$$

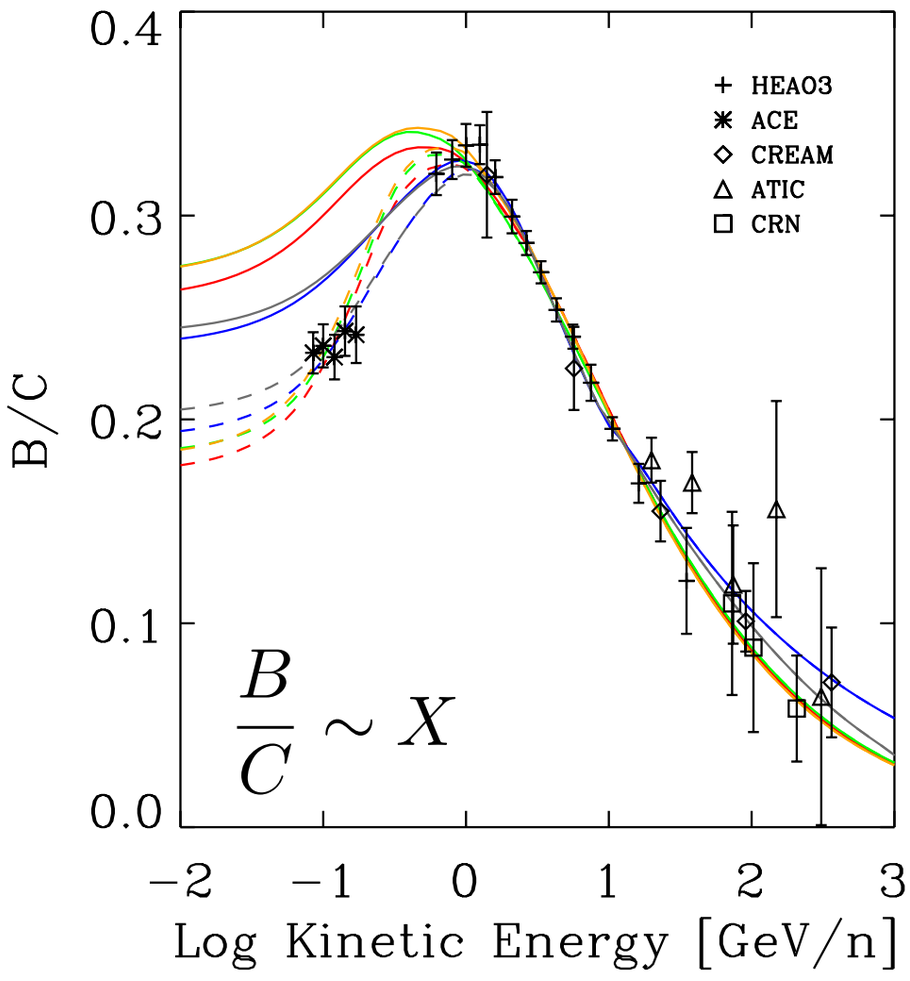
Fitting local observables

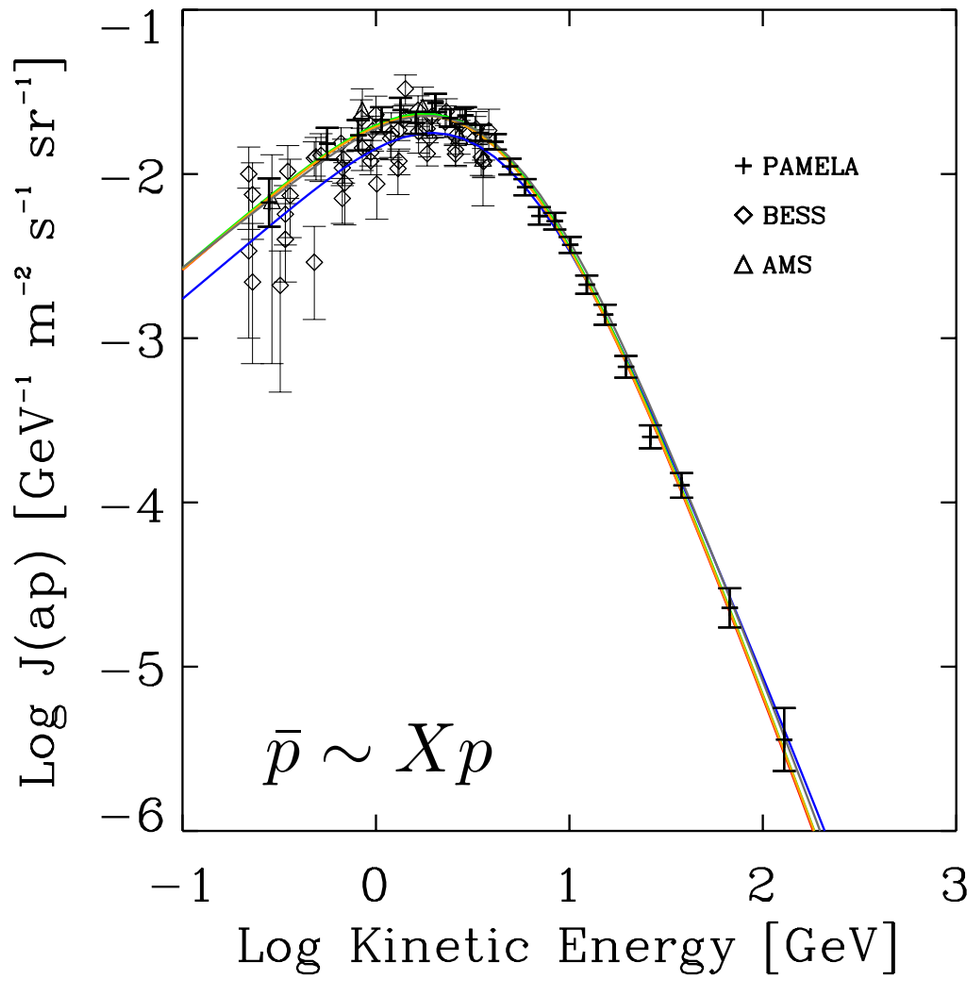




Anti-protons: secondary vs Dark Matter

CE, I.Cholis, D.Grasso, L.Maccione & P.Ullio, PRD, 2012, 1108.0664





Model	z_t (kpc)	δ	$D_0(10^{28}$ cm^2/s)	η	v_A (km/s)	γ	dv_c/dz (km/s/kpc)	$\chi^2_{B/C}$	χ^2_p	Φ (GV)	$\chi^2_{\bar{p}}$	Color in Figs.
KRA	4	0.50	2.64	−0.39	14.2	2.35	0	0.6	0.47	0.67	0.59	Red
KOL	4	0.33	4.46	1.	36.	1.78/2.45	0	0.4	0.3	0.36	1.84	Blue
THN	0.5	0.50	0.31	−0.27	11.6	2.35	0	0.7	0.46	0.70	0.73	Green
THK	10	0.50	4.75	−0.15	14.1	2.35	0	0.7	0.55	0.69	0.62	Orange
CON	4	0.6	0.97	1.	38.1	1.62/2.35	50	0.4	0.53	0.21	1.32	Gray

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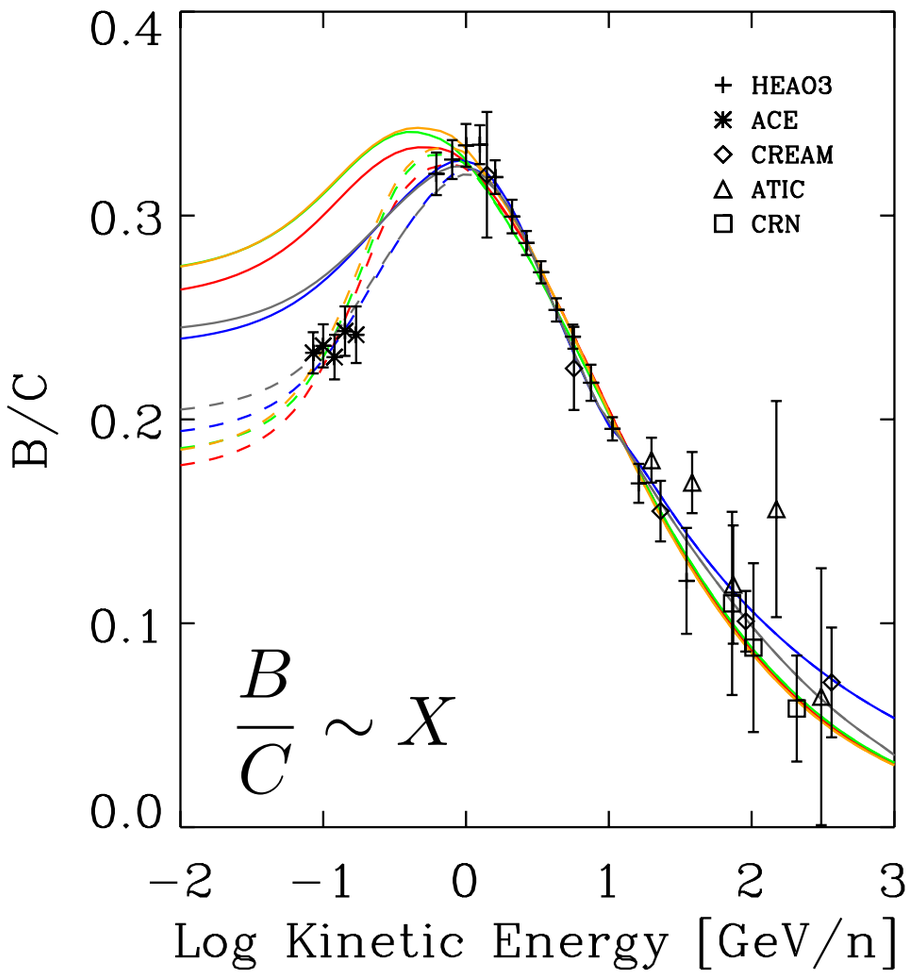
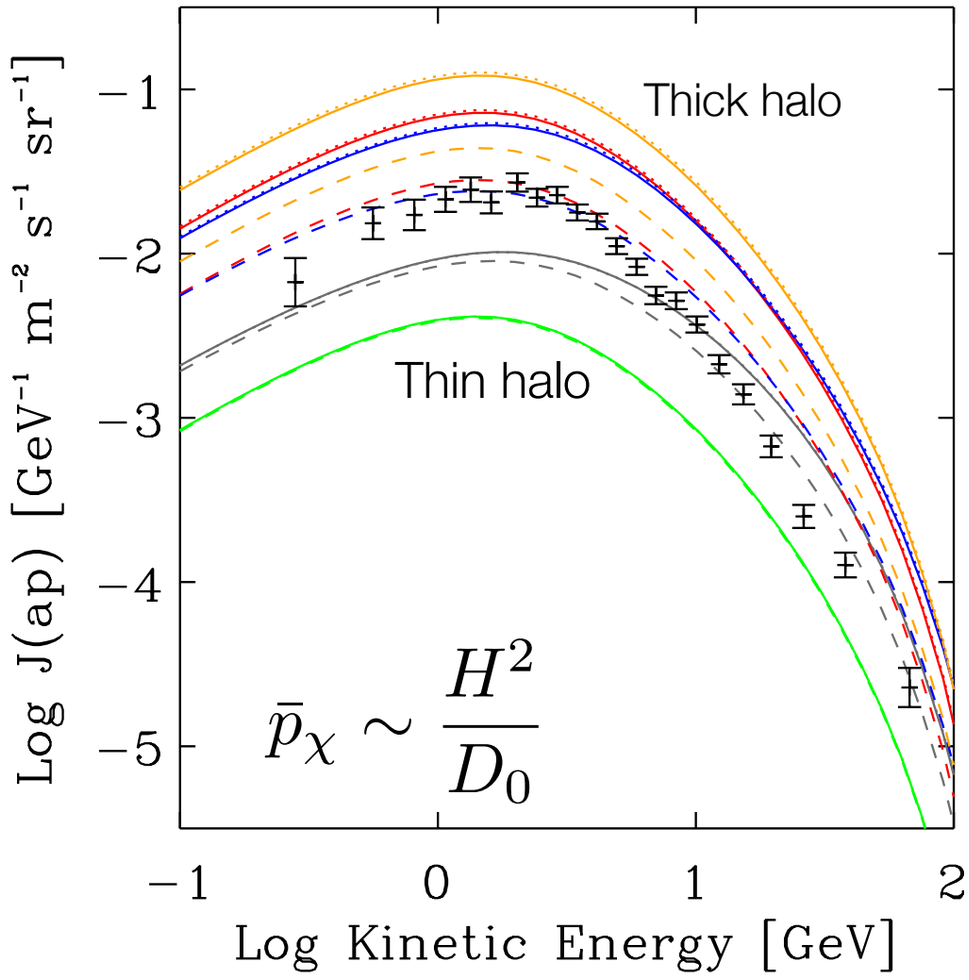
CE, I.Cholis, D.Grasso, L.Maccione & P.Ullio, PRD, 2012, 1108.0664





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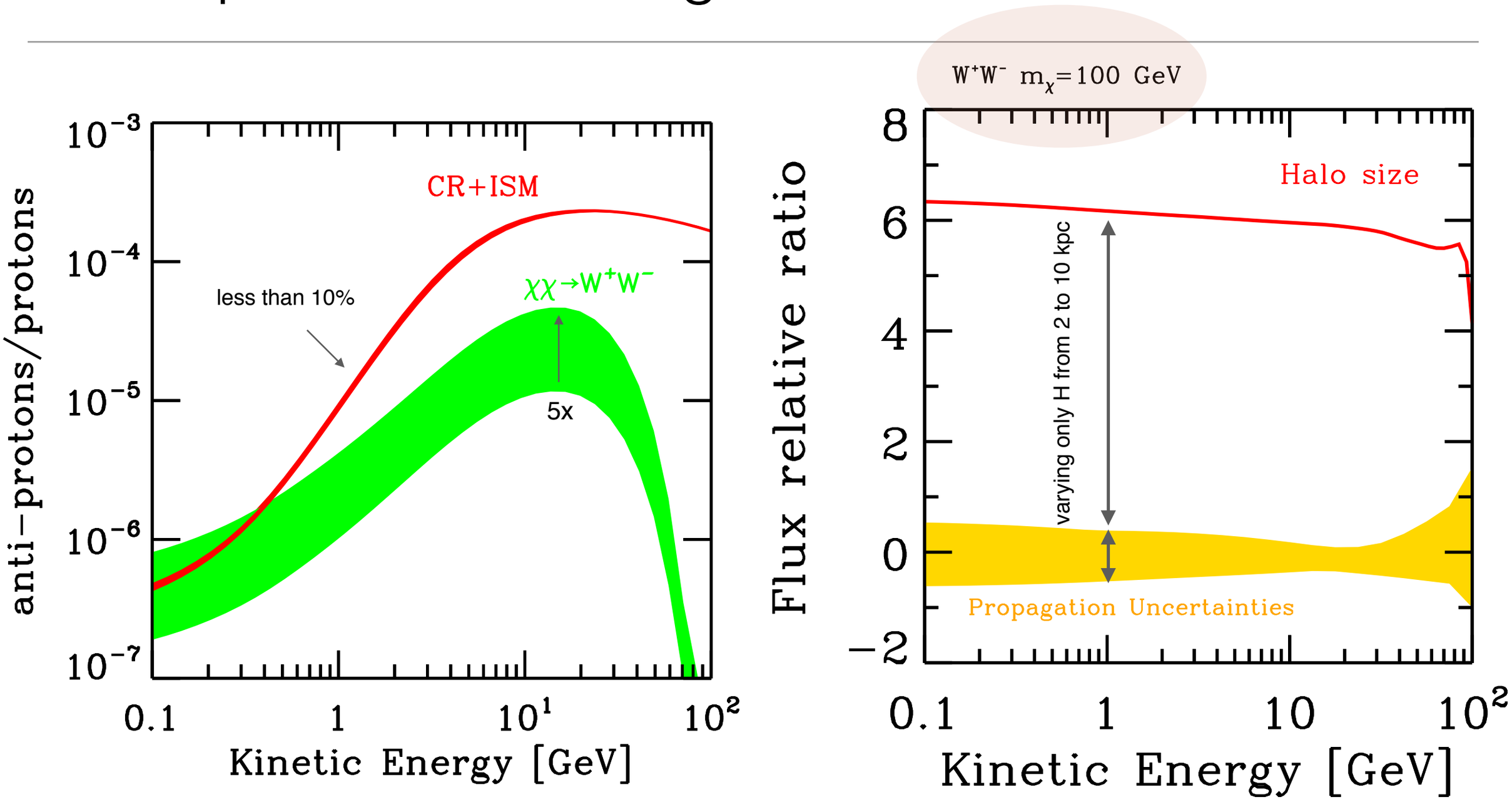
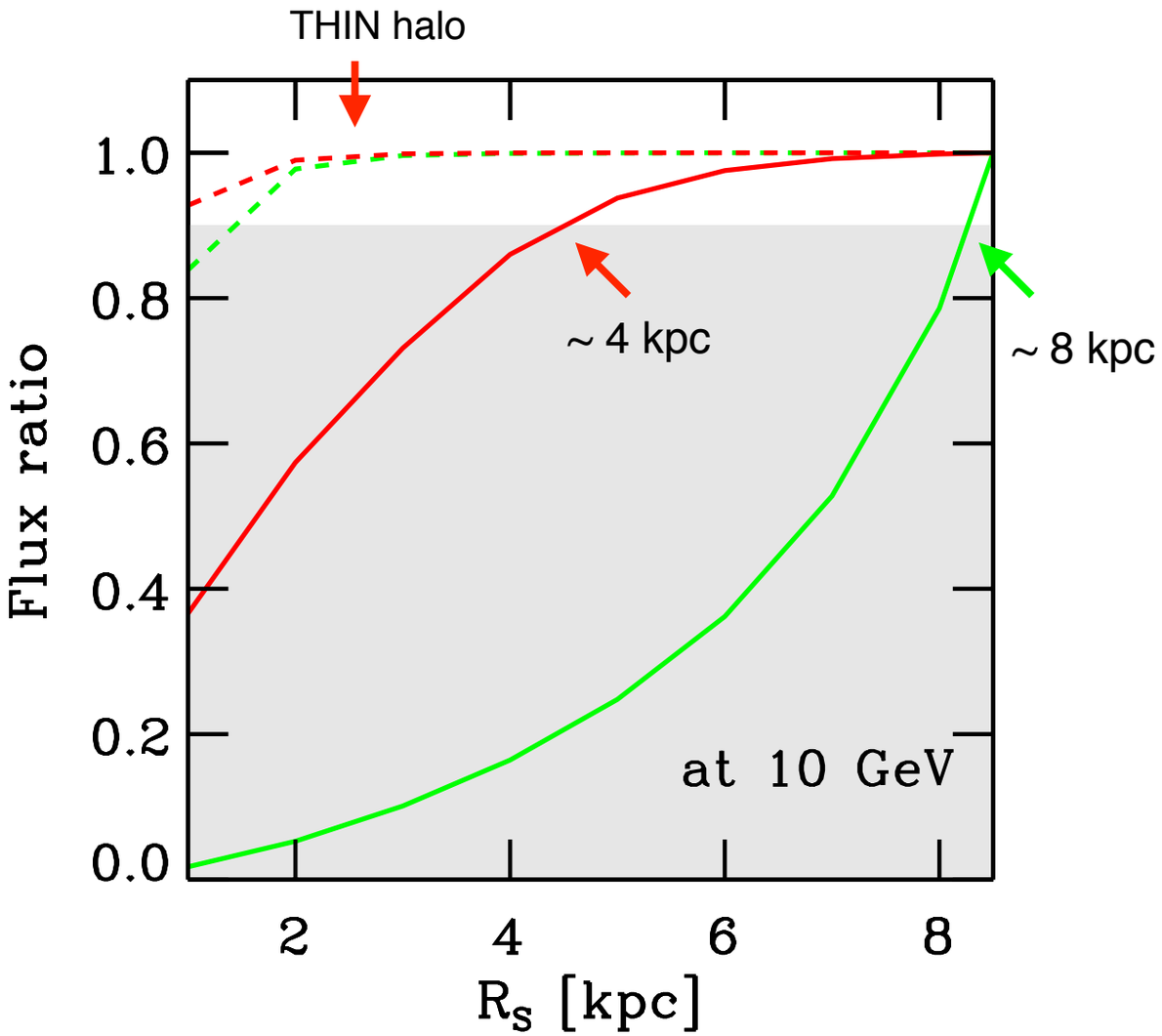
The importance of being thin



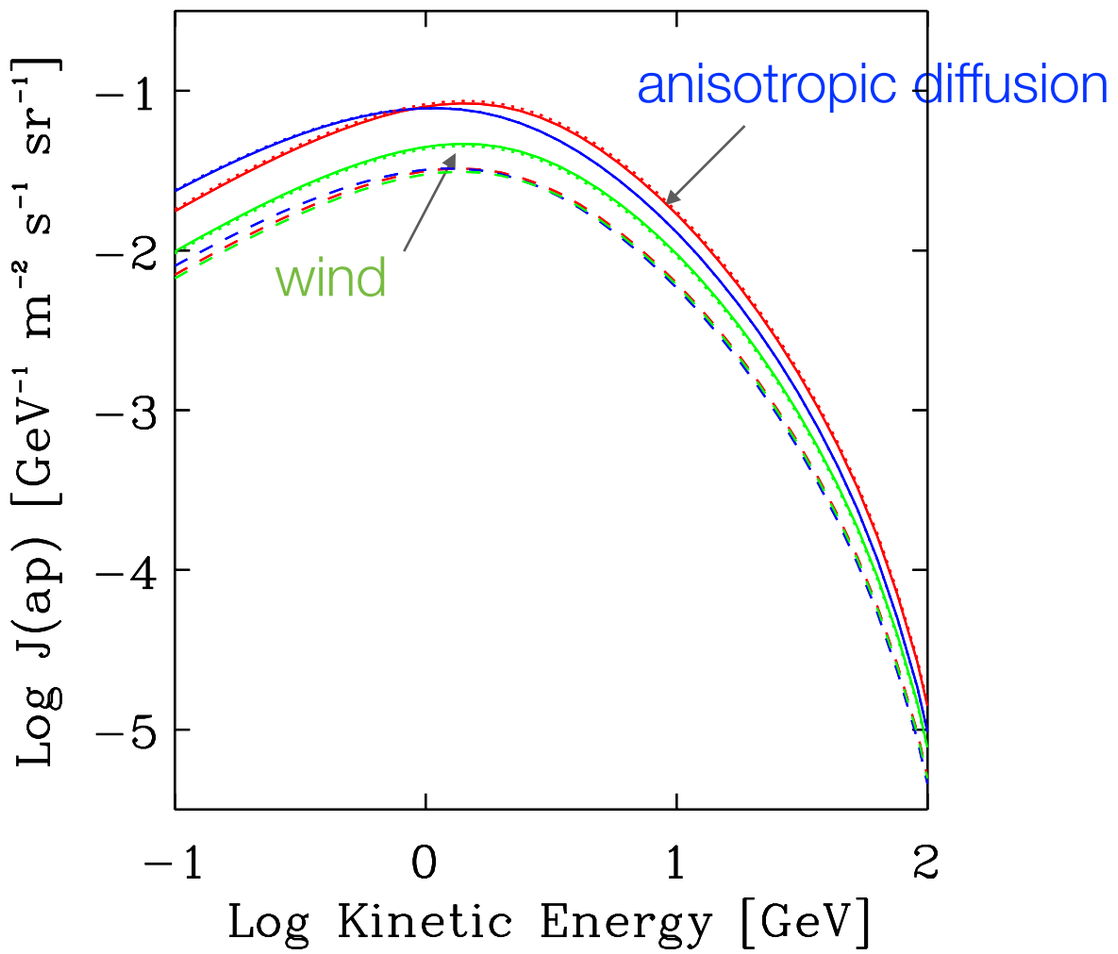
Constraints on the halo scale height (H > *2 kpc*) are obtained from the galactic diffuse synchrotron emission and positron fraction (G.Di Bernardo, CE, D.Gaggero, D.Grasso and L.Maccione, JCAP, 2013). See also J. Lavalle, D. Maurin and A. Putze, PRD, 2014.

Antiprotons locality

CE, I.Cholis, D.Grasso, L.Maccione & P.Ullio, PRD, 2012, 1108.0664



The ratio of the local flux obtained considering sources with distance smaller than R_S to that obtained with $R_S = \infty$ (see also R. Taillet & D. Maurin, A&A, 2003)

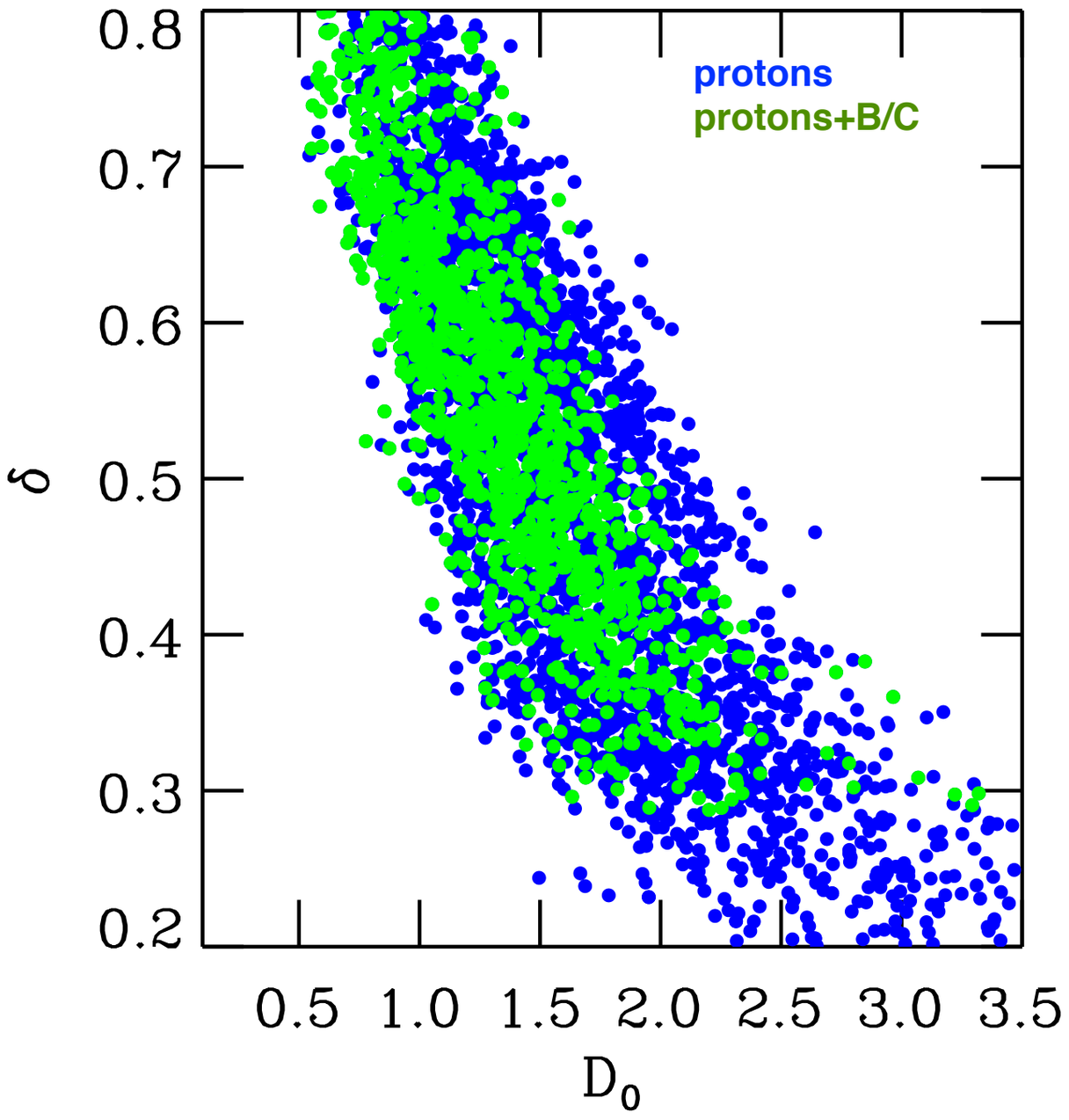


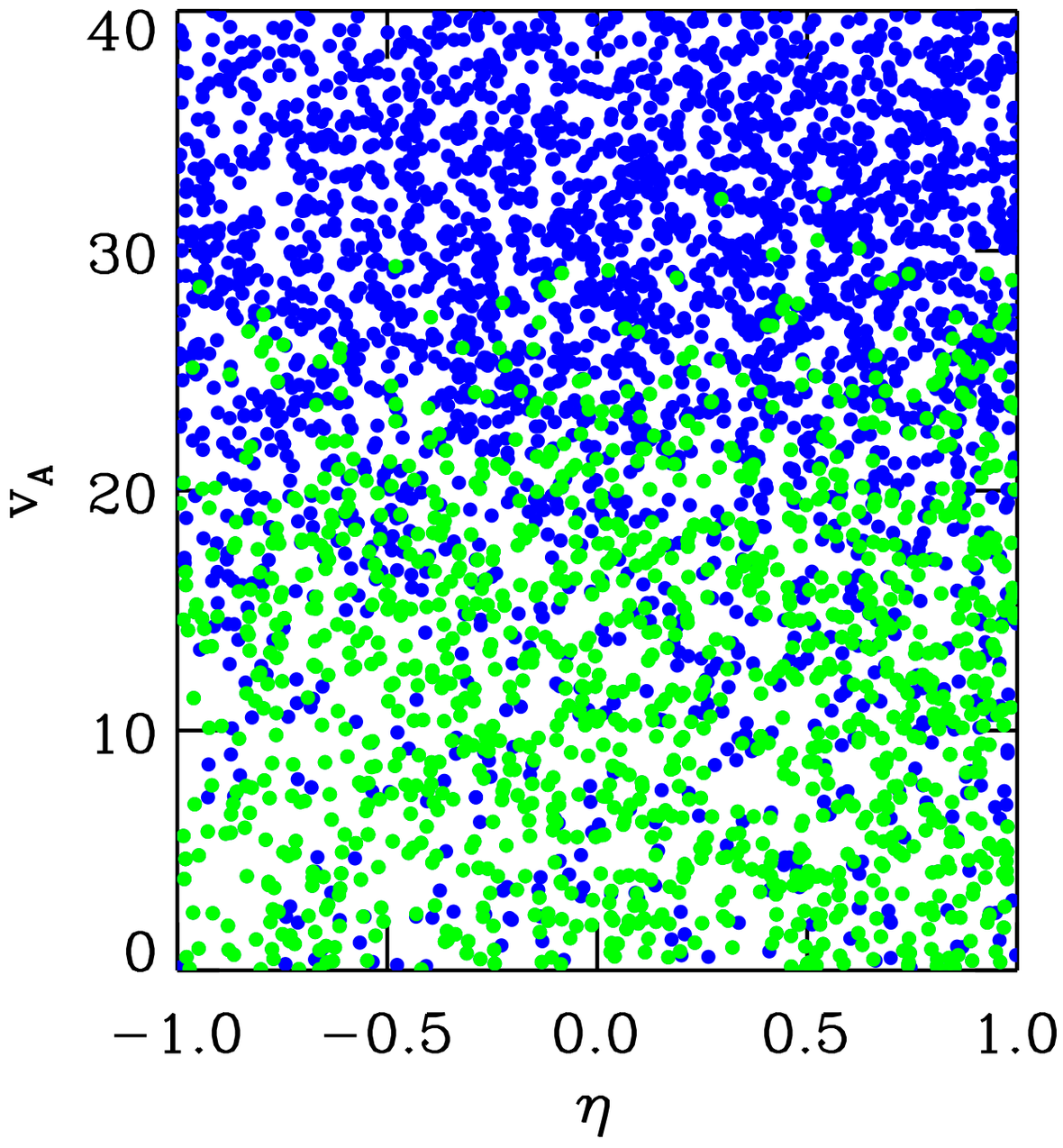
Changing diffusion conditions in the inner Galaxy gives significant effect on the DM contribution without affecting the local observables.

Unavoidable uncertainties?

Bracketing the propagation uncertainties with PAMELA

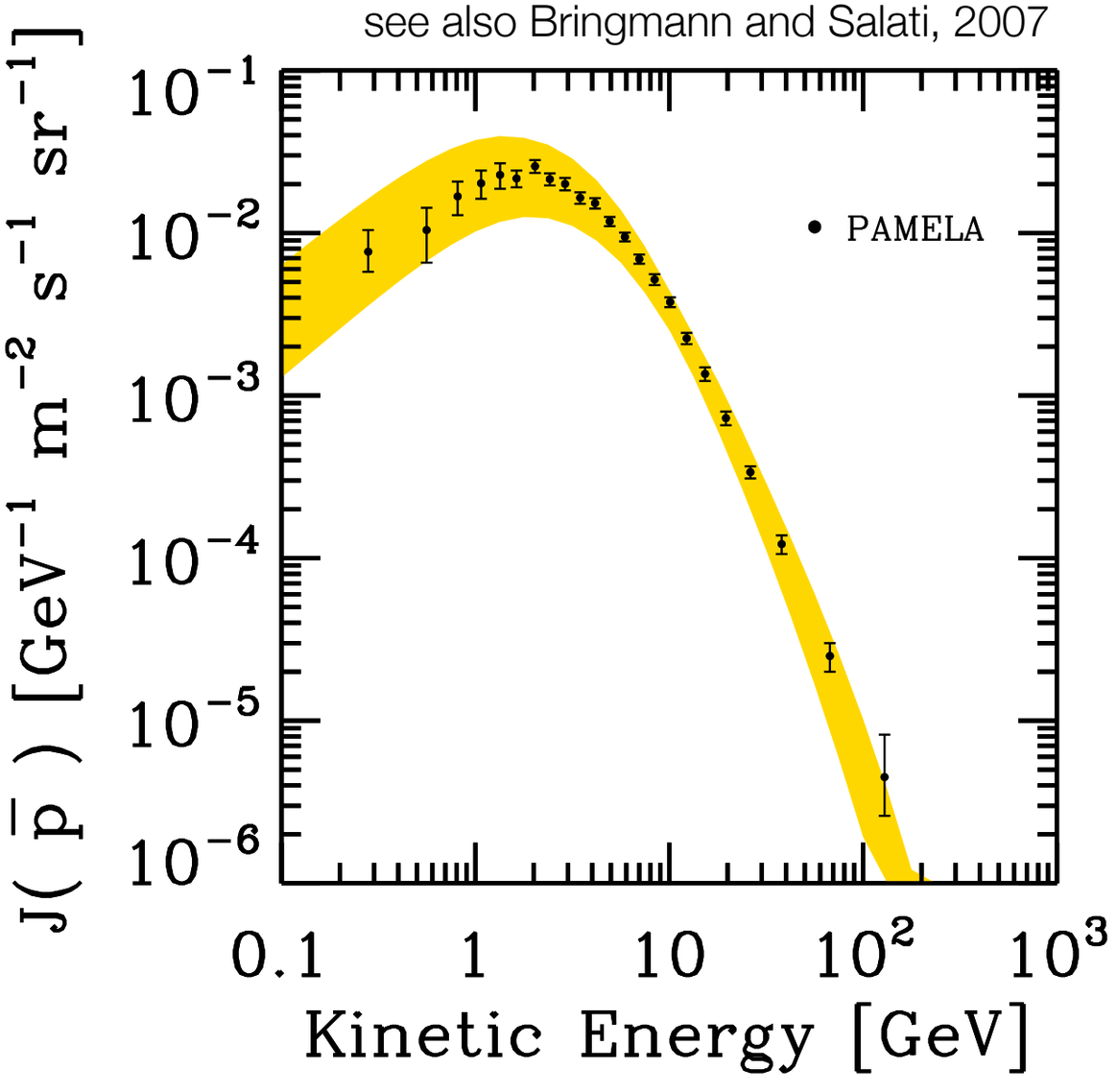
CE, D.Gaggero & D.Grasso, 1504.05175





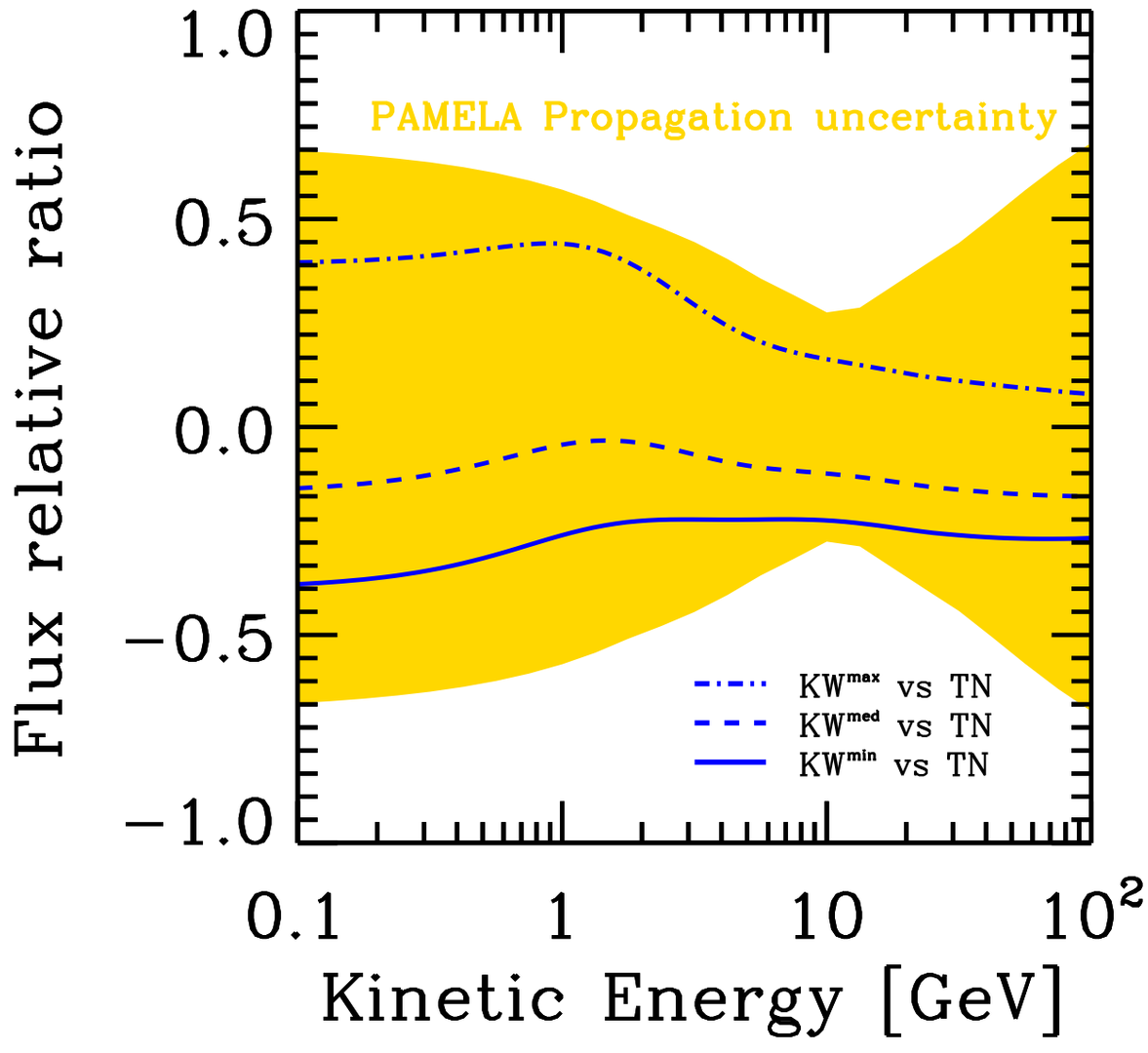
Bracketing the propagation uncertainties with PAMELA

see also Bringmann and Salati, 2007



Secondary Minimum and Maximum flux as the envelop of all the *good* models

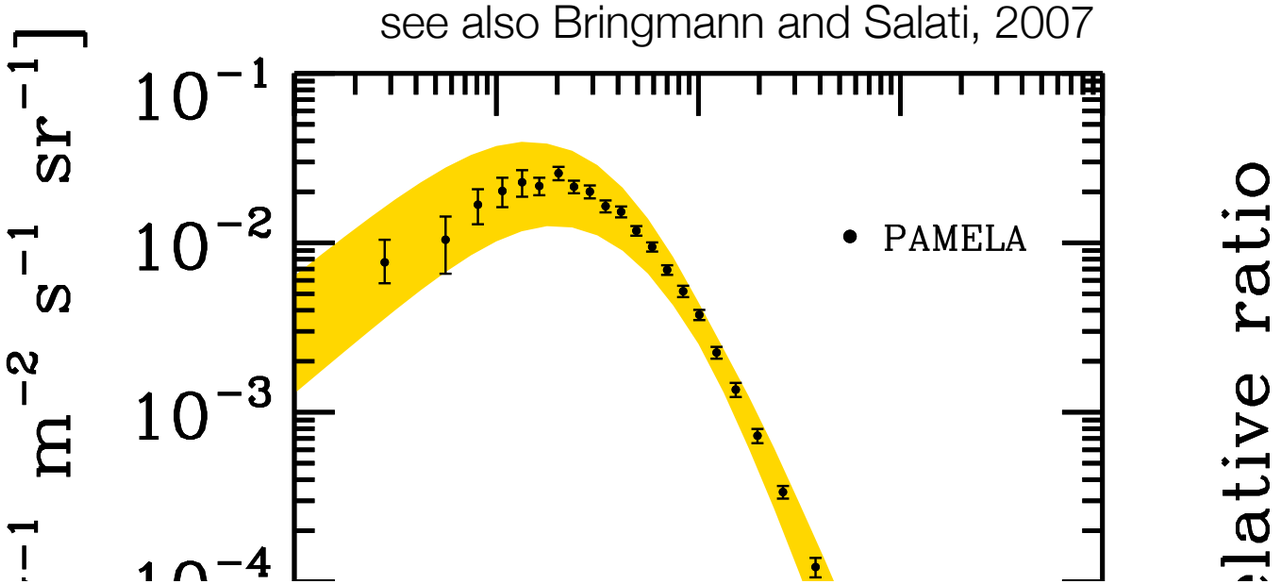
see also Di Mauro *et al.*, 2014



Upcoming CR measurements will reduce significantly propagation uncertainties.
What about nuclear ones?

Bracketing the propagation uncertainties with PAMELA

see also Bringmann and Salati, 2007

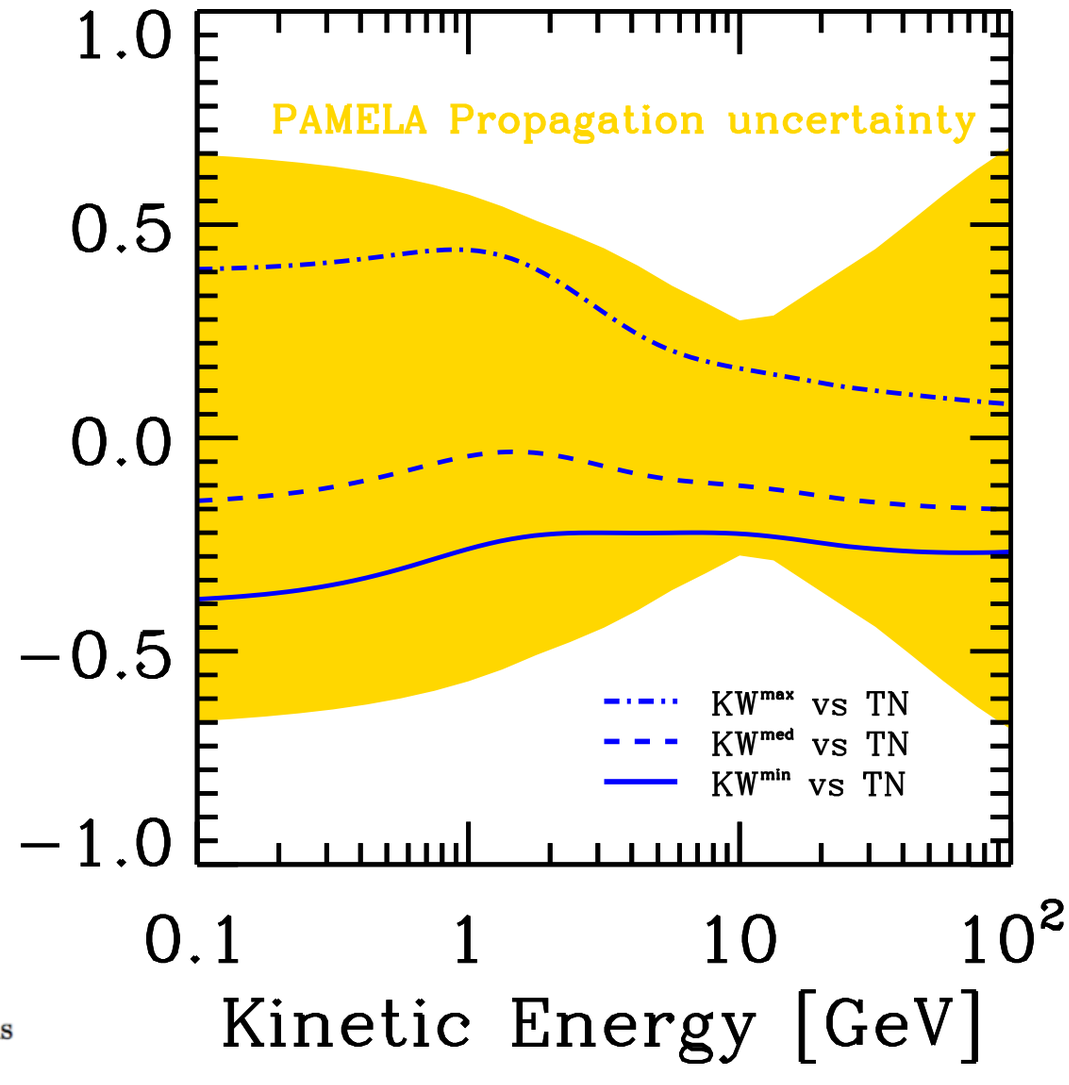


E_k [GeV]	η	D_0 units	δ	v_A [km/s]	dV_C/dz [km/s/kpc]	γ_p	q_C [$\times 10^3$]	γ_C	ϕ [GV]
Min models									
1	0.30	3.32	0.30	32.2	0.04	2.58	2.74	2.53	0.77
10	0.68	2.85	0.38	28.6	0.03	2.54	2.83	2.48	0.86
100	-0.16	1.17	0.75	9.31	6.78	2.38	3.40	2.17	0.57
Max models									
1	0.84	0.85	0.74	0.52	5.65	2.40	3.80	2.18	0.53
10	-0.92	0.83	0.68	7.71	4.05	2.44	4.03	2.22	0.54
100	0.60	2.85	0.23	27.4	6.88	2.62	2.95	2.59	0.75

Table 3. Model parameters giving the minimum (maximum) contribution of secondary anti-protons at energy $E = 1$, 10, 100 GeV.

Secondary Minimum and Maximum flux as the envelop of all the *good* models

see also Di Mauro *et al.*, 2014

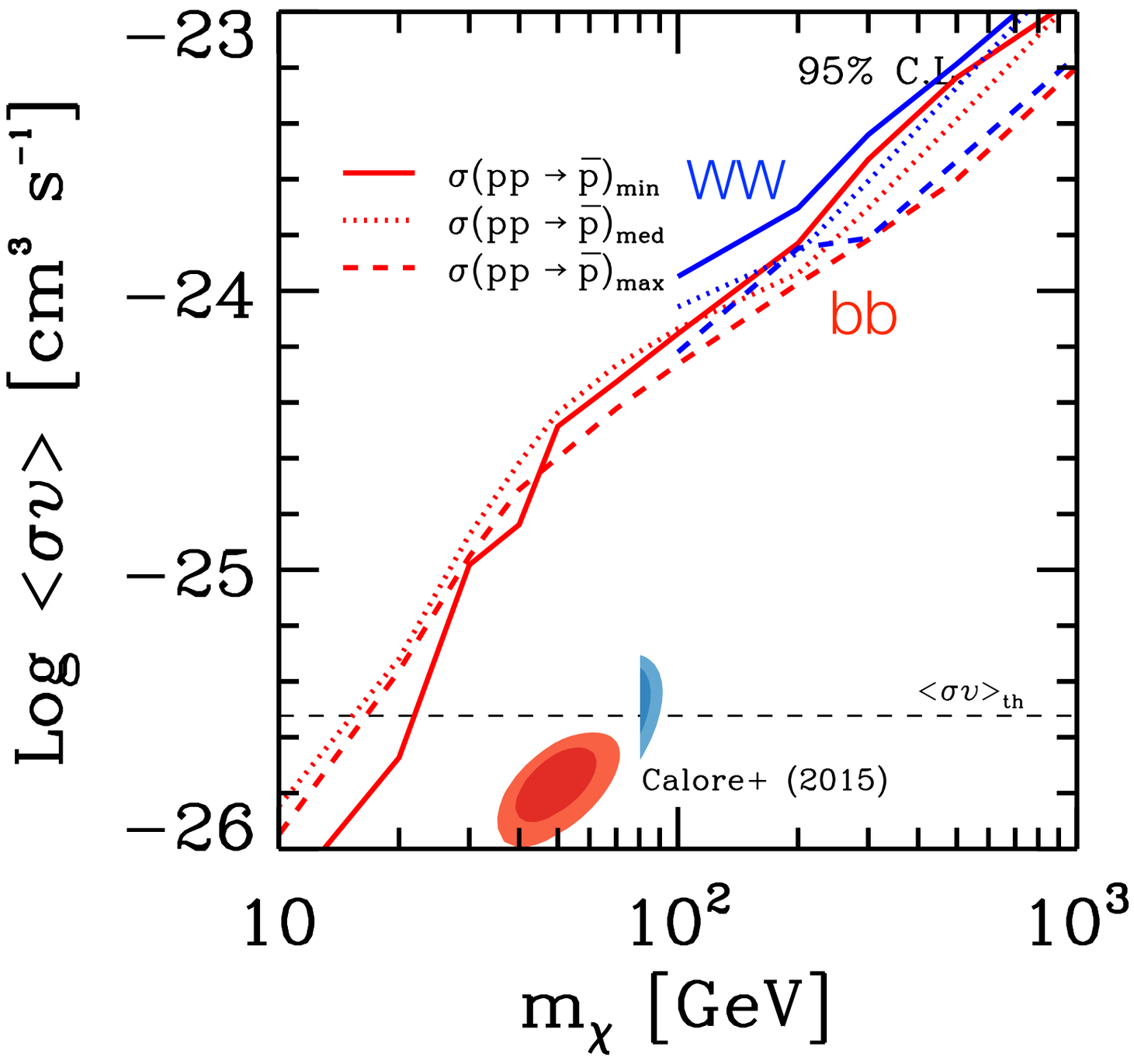


Upcoming CR measurements will reduce significantly propagation uncertainties.
What about nuclear ones?

DM bounds after PAMELA data

CE, D.Gaggero & D.Grasso, JCAP, *1504.05175*

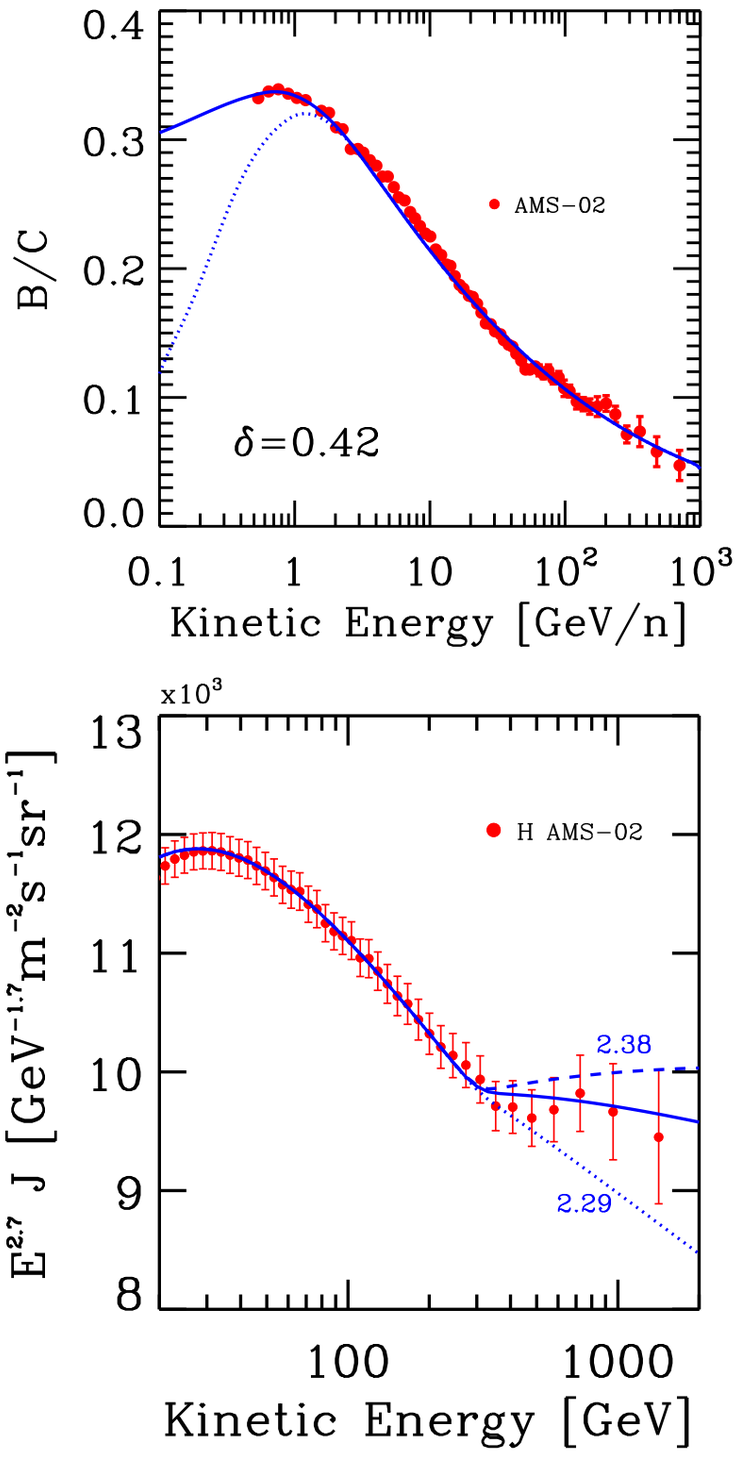
see also M. Boudaud, et al., JCAP, 2015

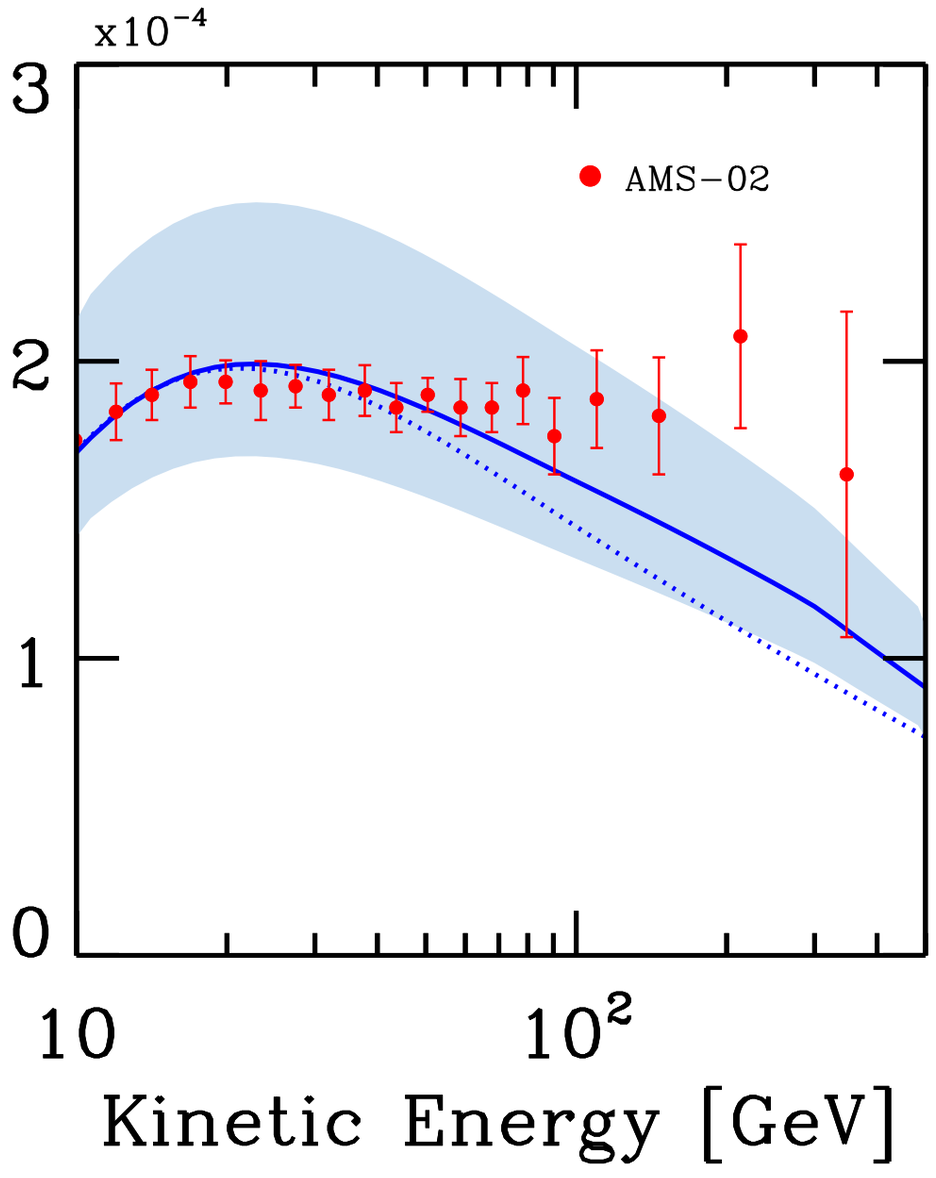


Testing the AMS-02 high-energy data

CE, D.Gaggero & D.Grasso, JCAP, *1504.05175*

see also Giesen *et al.*, 1504.04276
Kappl, Reinert and Winkler, 1506.04145





} production cross-sections

Conclusions

- Whether or not **dark matter** contributes to the observed CR fluxes is one of the most important open problem in Cosmology.

- Antiprotons promise to be an extremely useful tool to search or constraint WIMP hadronic channels.

- Astrophysical and nuclear uncertainties on the background predictions are at the moment comparable limiting factors in achieving competitive bounds

- Multi-Wavelength and multi-messenger studies in combination with more precise measurements will allow us to reduce enormously the astrophysical uncertainties. What about nuclear ones?