Galactic Cosmic Rays and Multimessenger Astronomy

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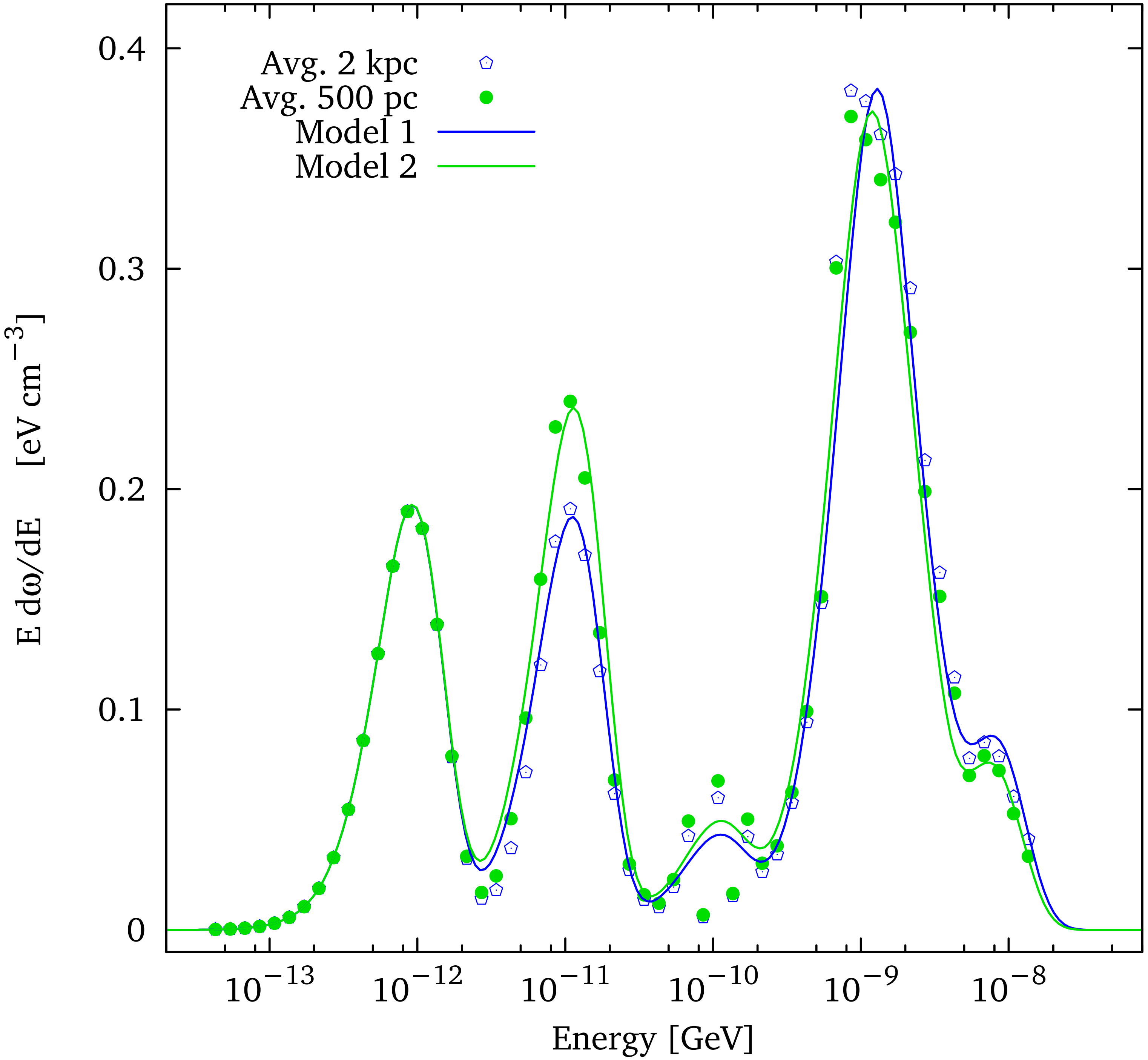
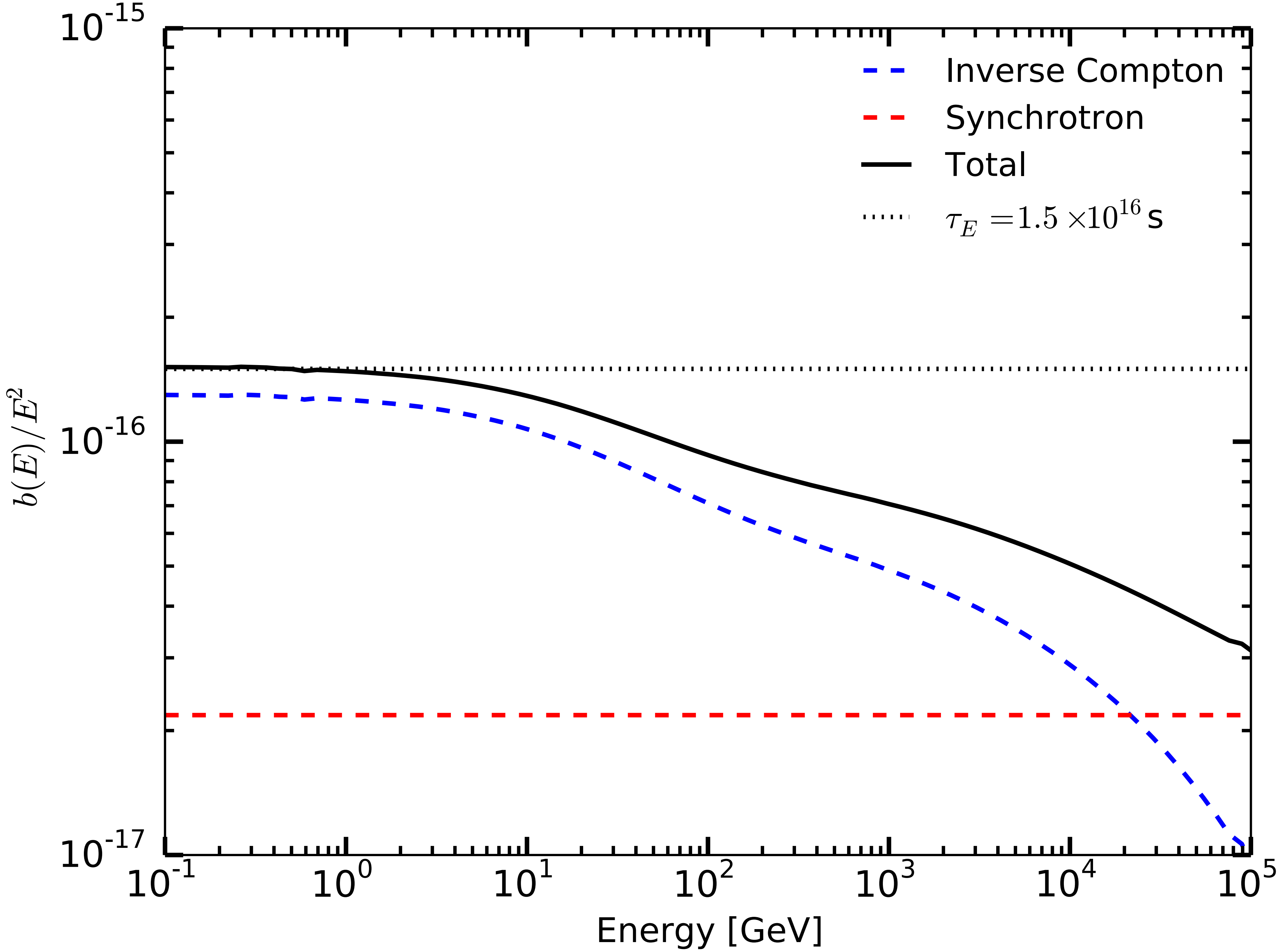
The Interstellar Radiation Field

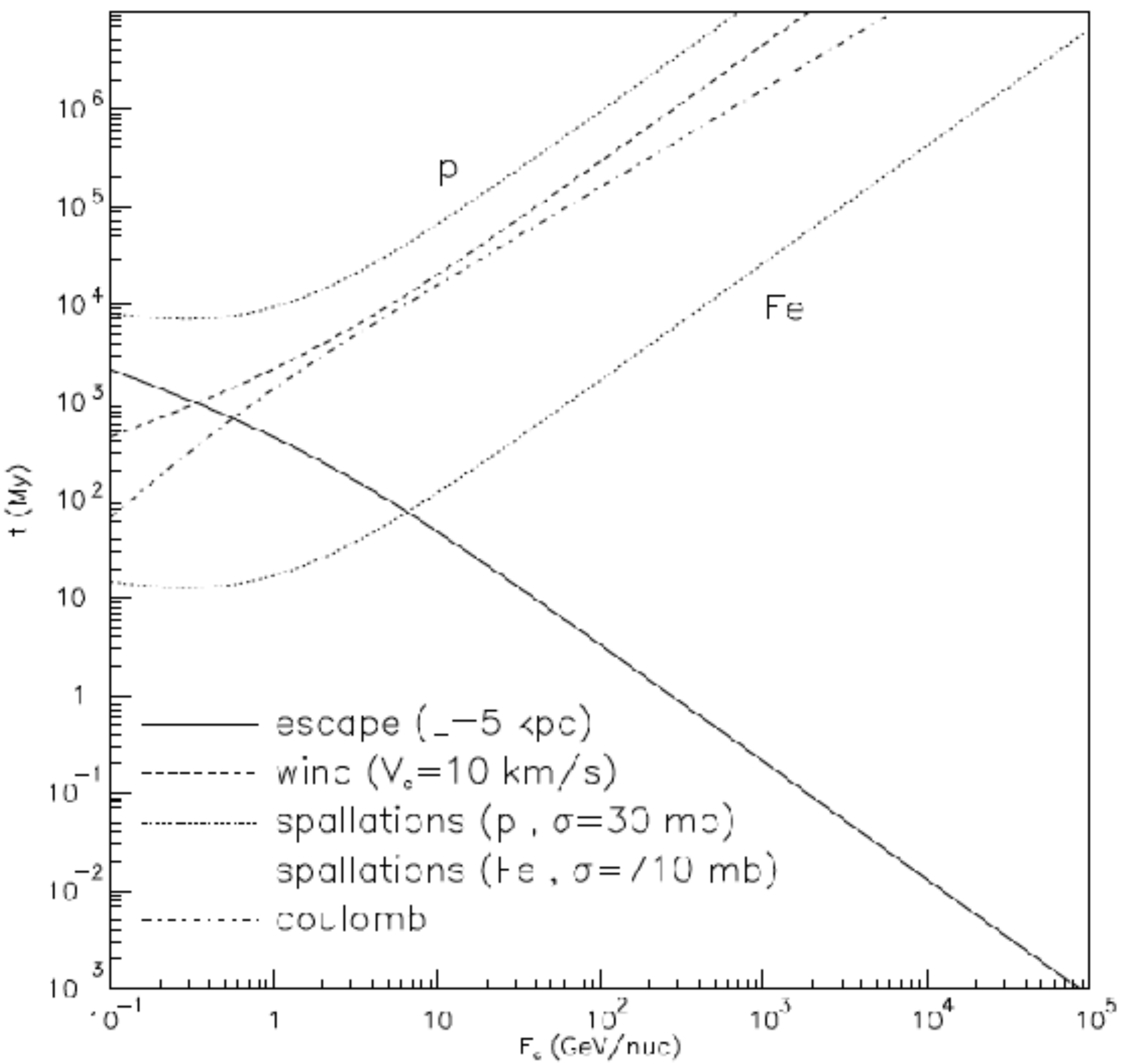
Delahaye, Lavalle, Lineros, Donato & Fornengo (2010)



Energy losses for electrons

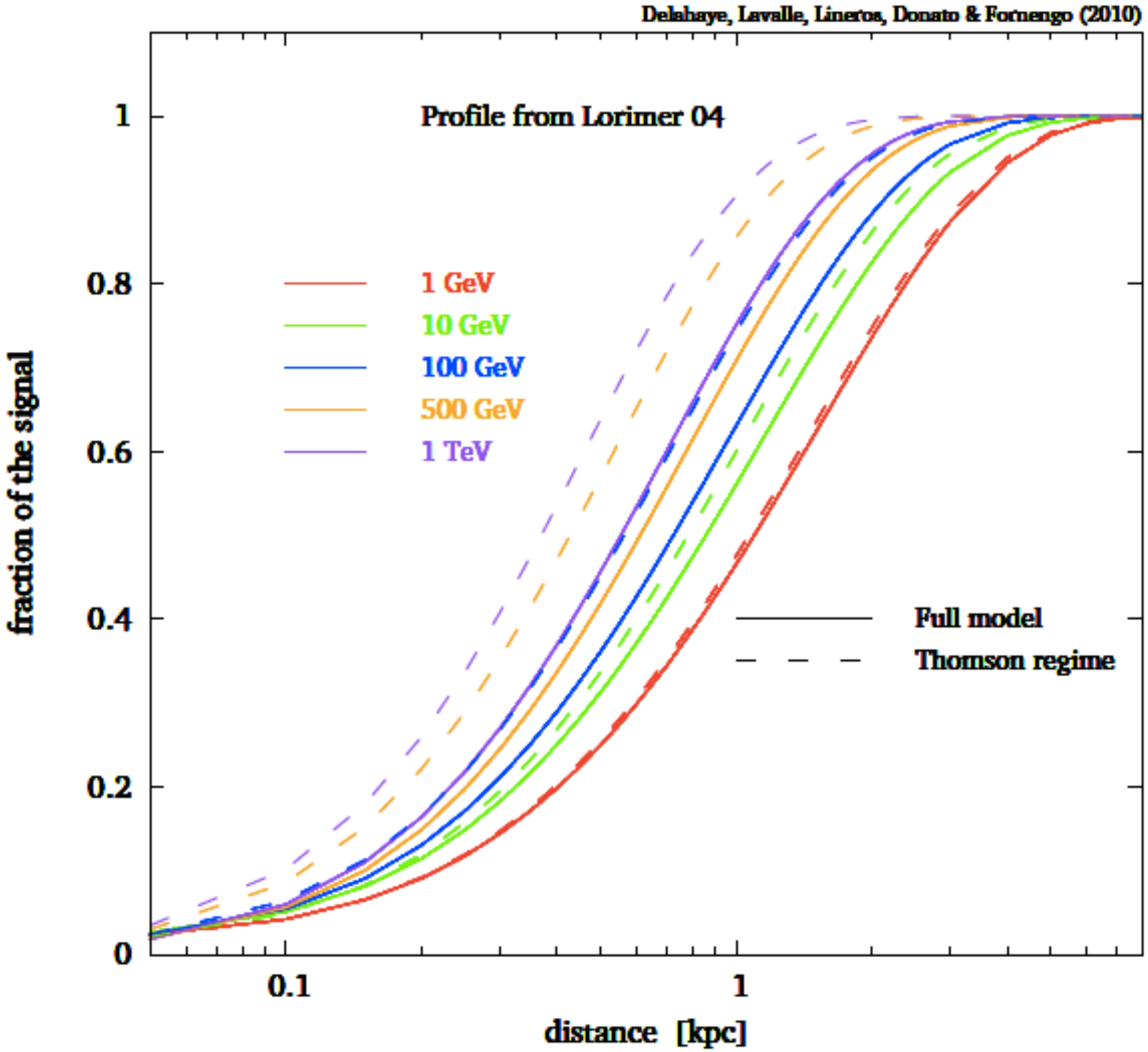


Characteristic times/losses for nuclei

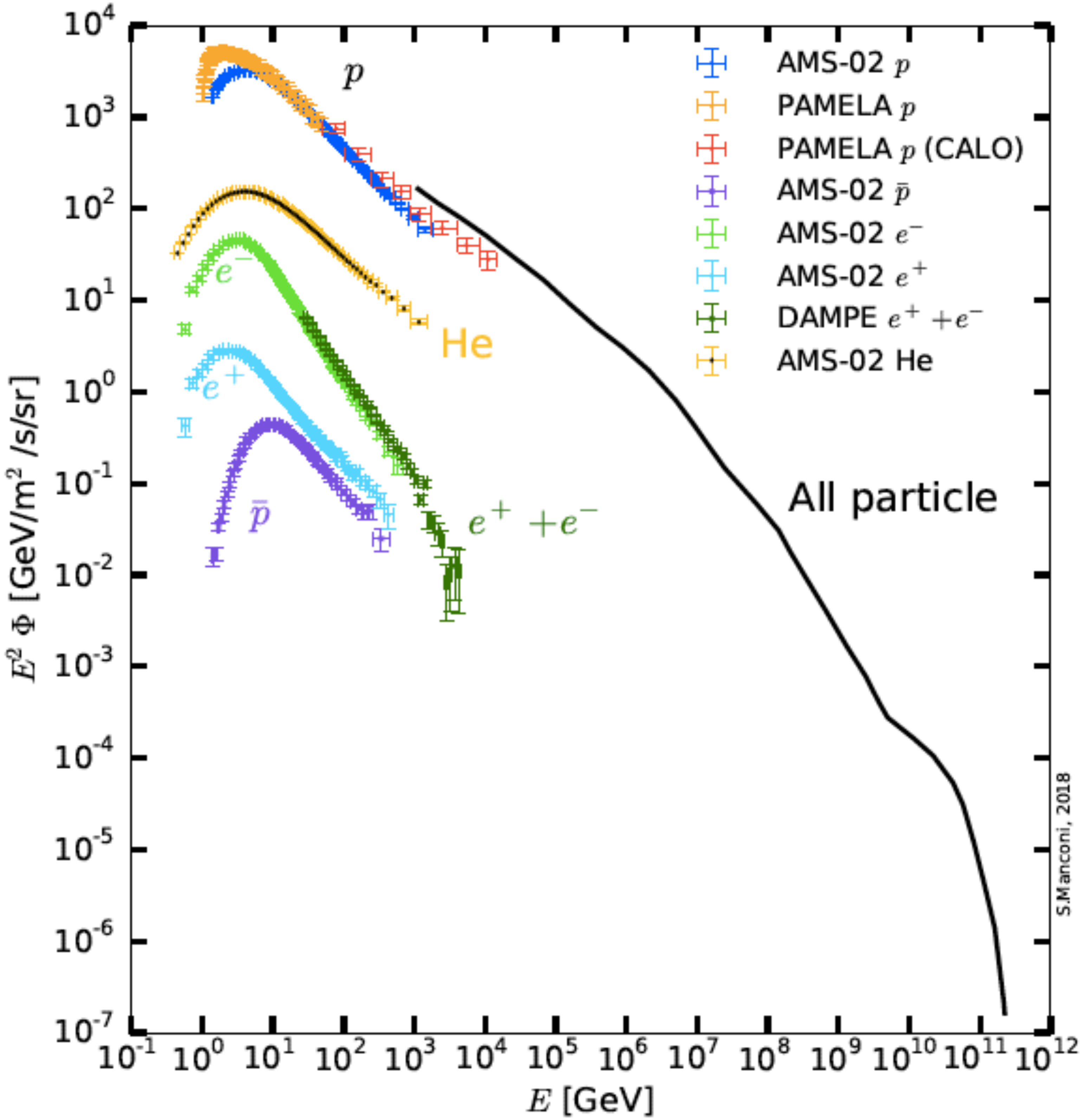


The smaller the time, the more efficient the process

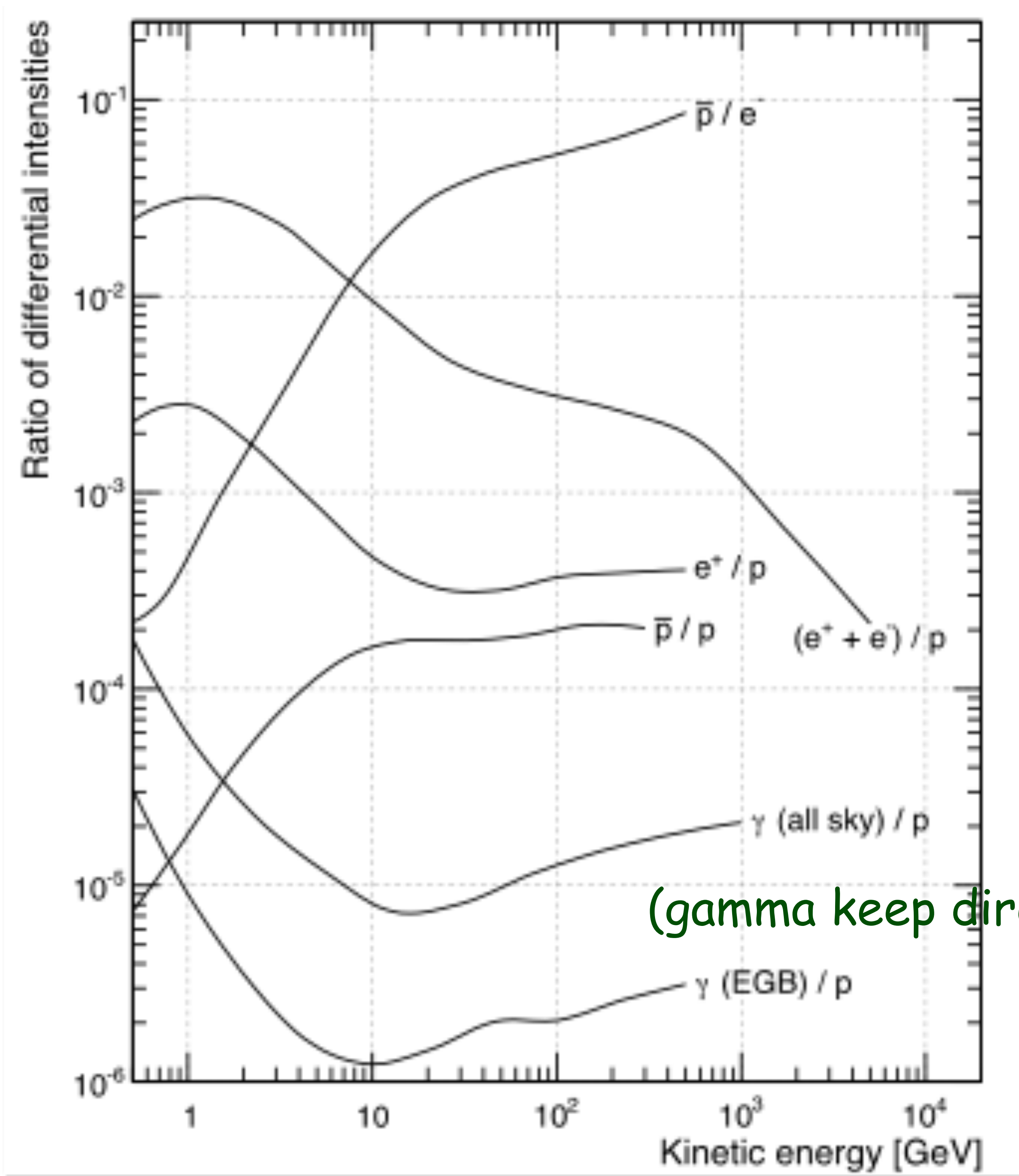
Effect of energy losses on electrons



The flux of cosmic rays



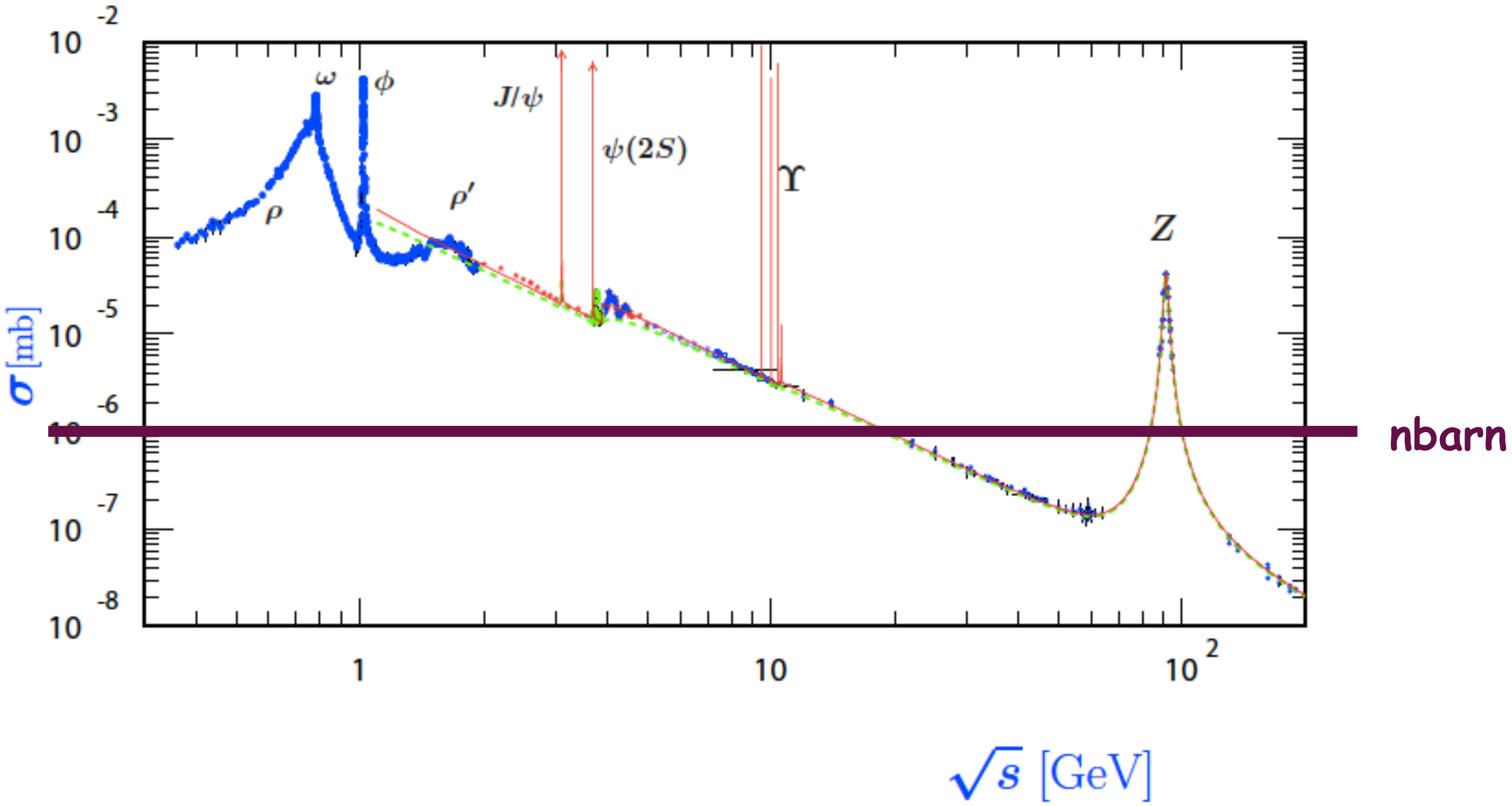
The rare CRs



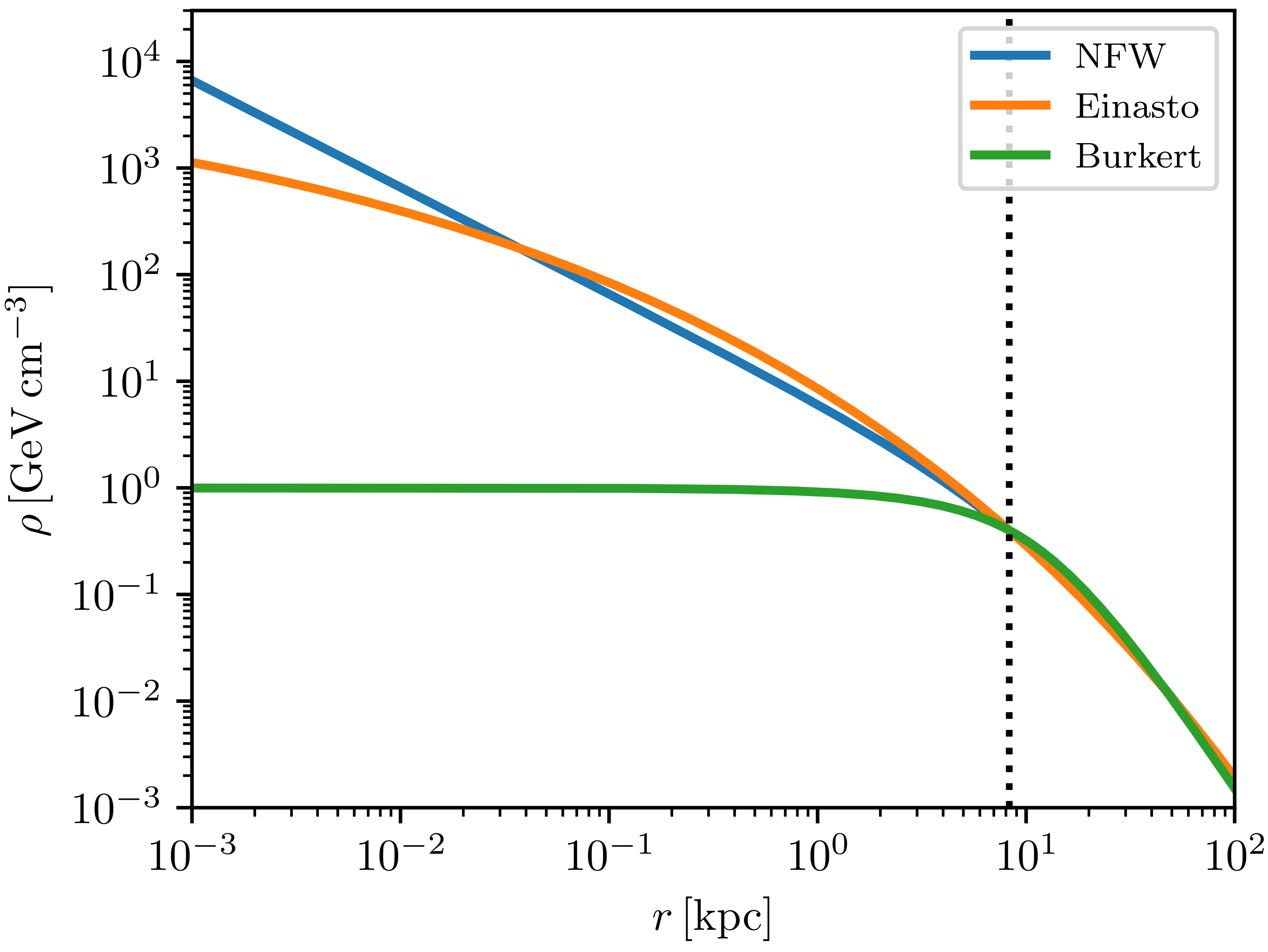
(gamma keep direction)

Weak cross sections

e+e- total cross section

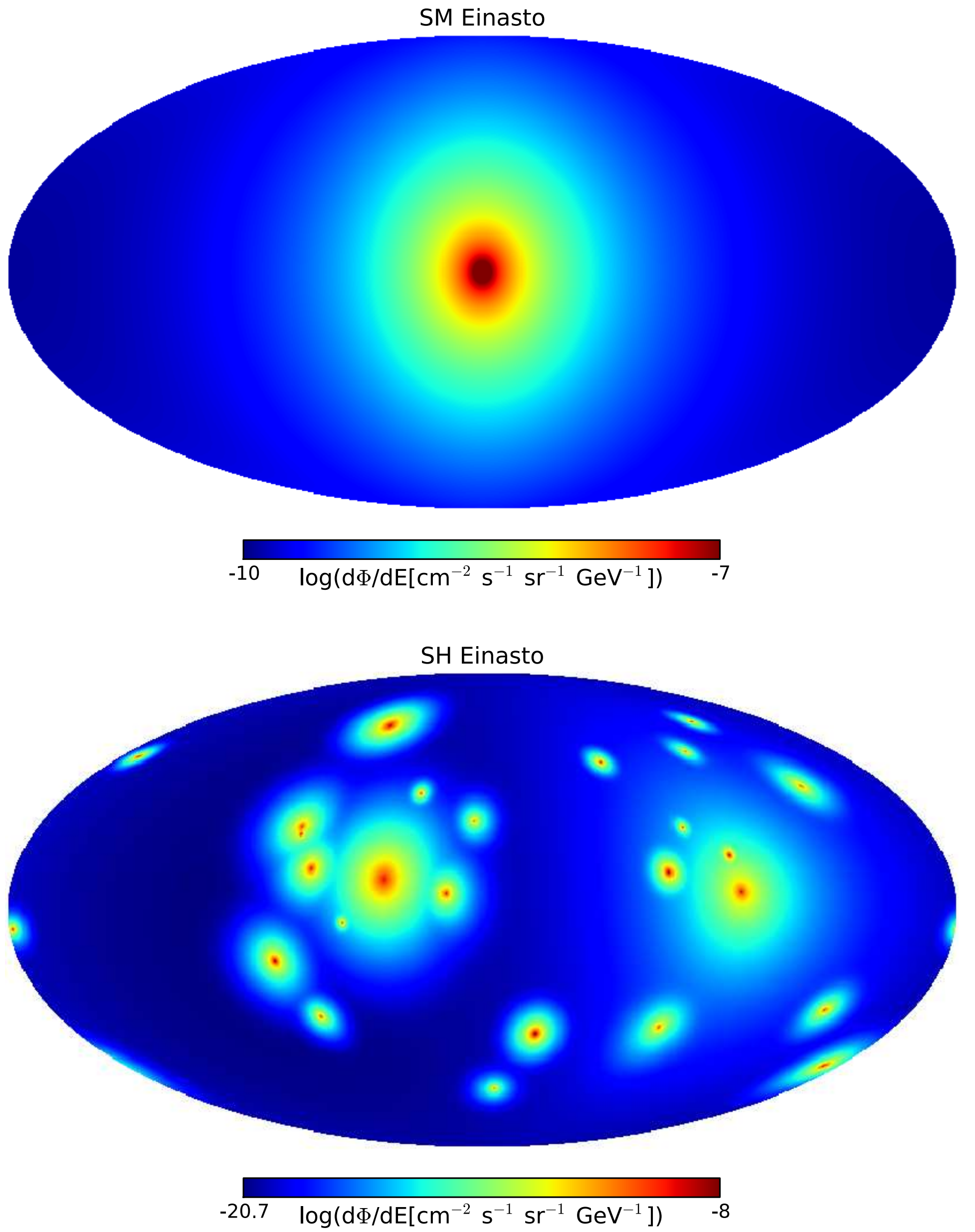


The galactic dark matter profiles

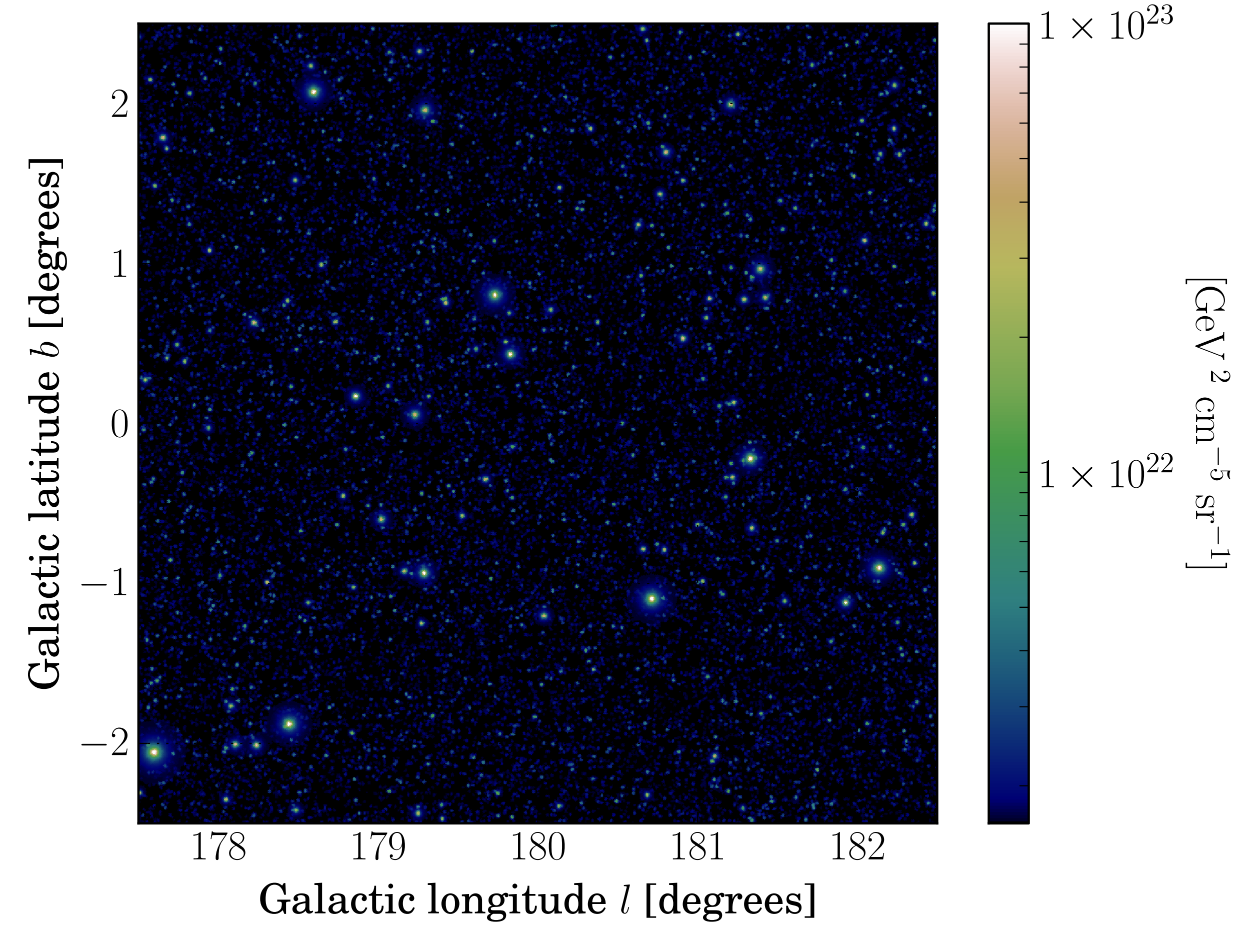


The J-factor

Calore+ 2014



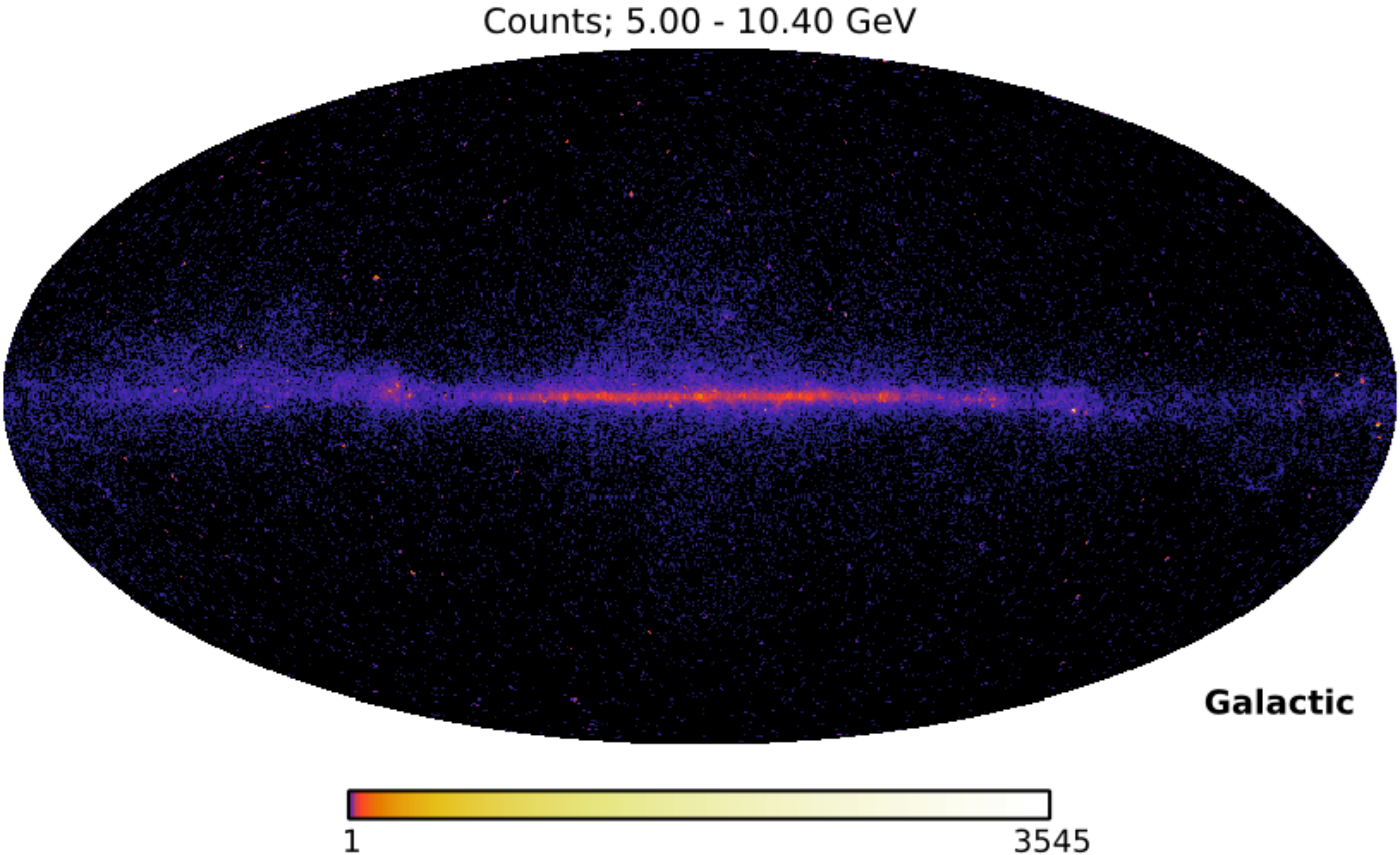
Bonnivard et al. 2016



5x5 deg towards anticenter

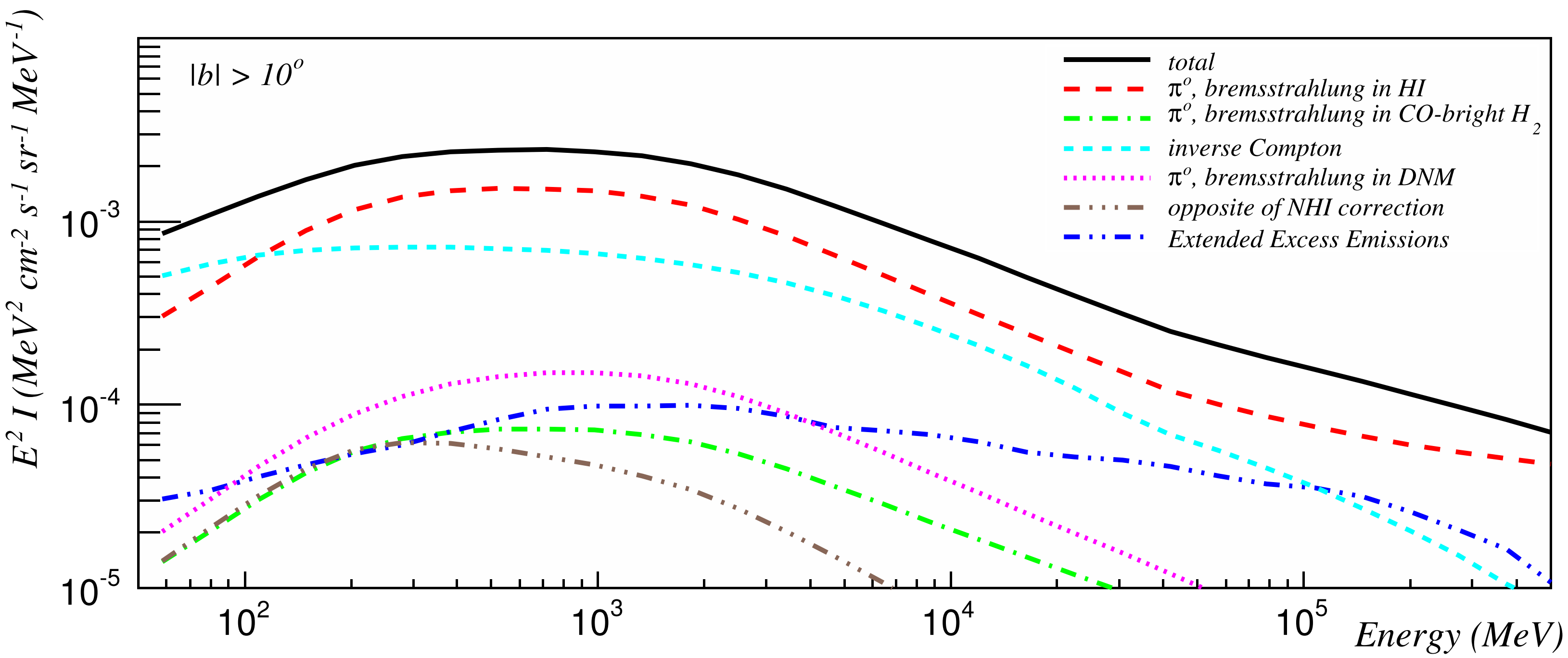
E = 4 GeV, m_{DM}=200GeV

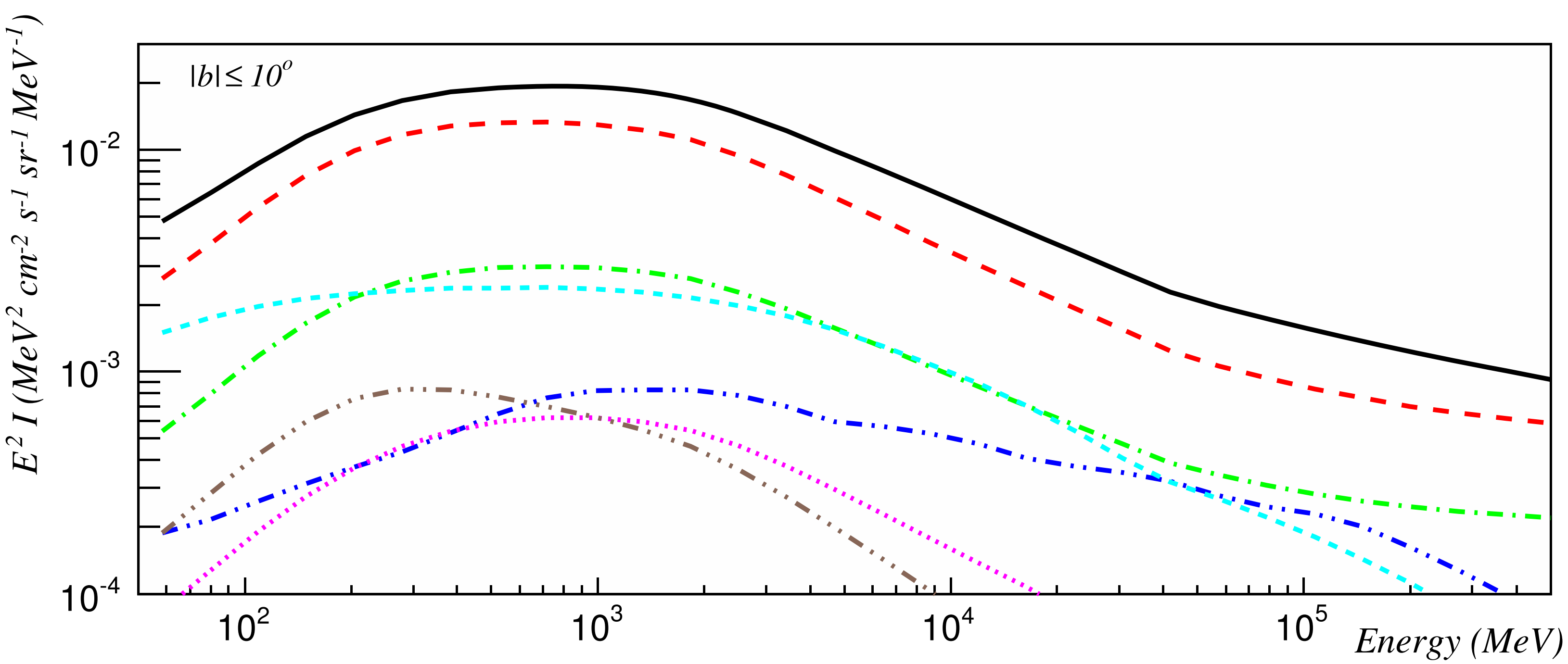
The invaluable gamma-ray sky



The diffuse emission of the Galaxy

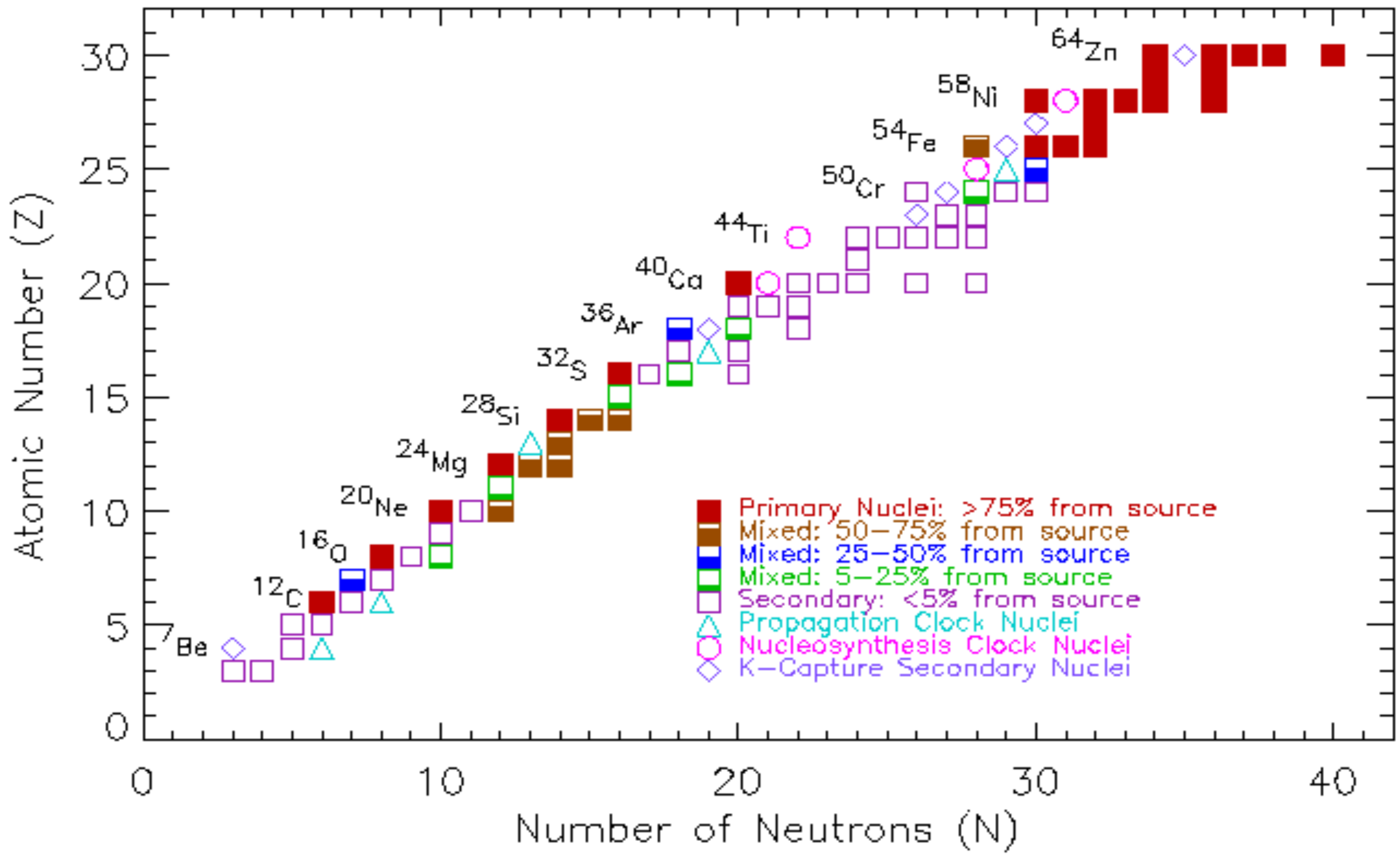
Fermi-LAT Coll. ApJS 2016





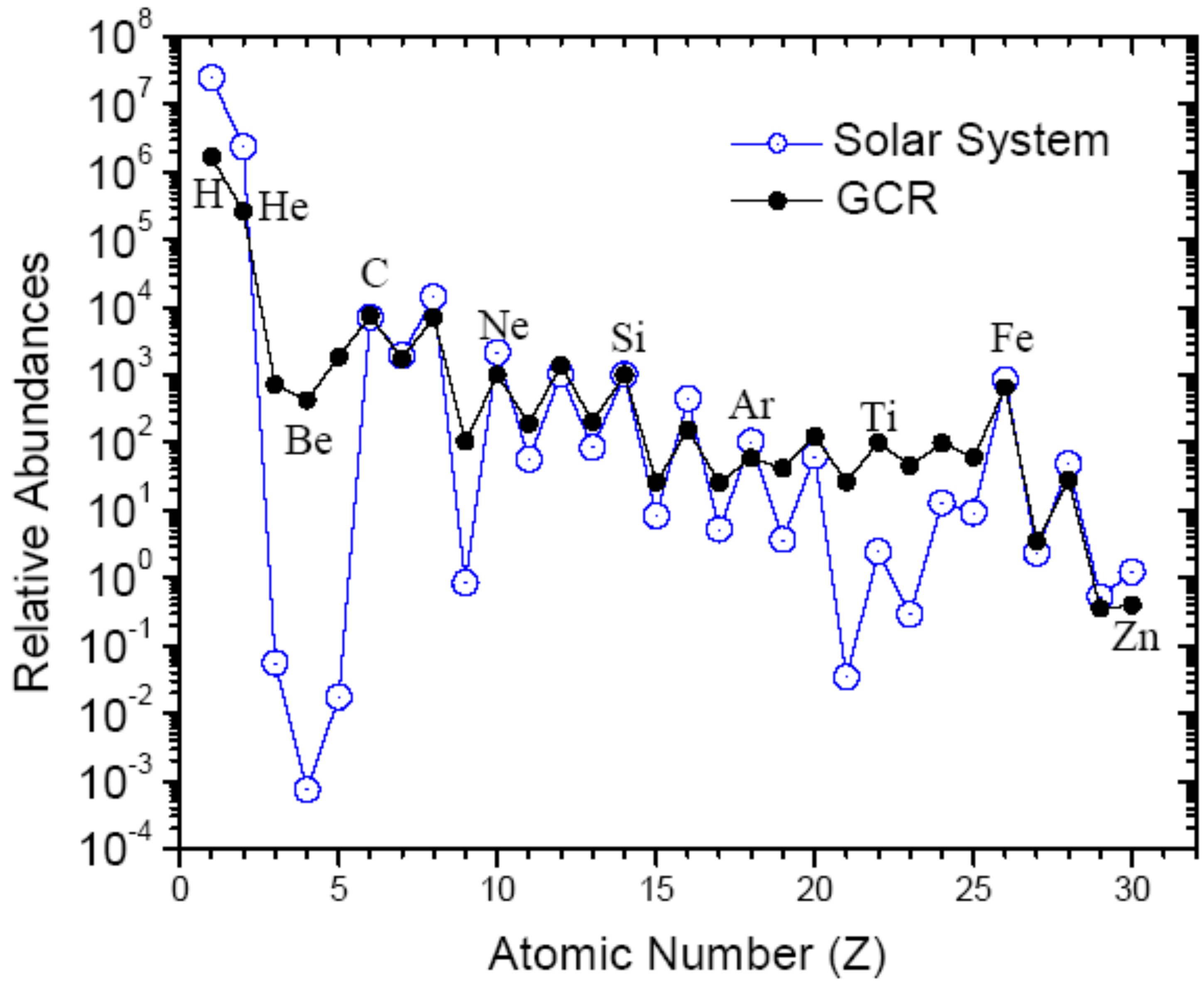
- Π^0 dominates
- IC is more and more relevant at increasing latitudes
- GeV is the most affected

Primary - mixed - secondary nuclei



Li - Be - B are fully secondary, ^{12}C and ^{16}O primary. Many are mixed.
Isotopes are relevant (^{10}Be)

Cosmic Ray composition



Galactic Cosmic Rays have abundances similar to the Solar System ones except for Li-Be-B and sub-Fe nuclei: They are produced by spallation (fragmentation) of heavier nuclei on the Interstellar Medium (H, He)

TABLE IV. Ranking of 1- and 2-step channels for Li at 10 GeV/n, from $f_{ij}^{1\text{-step}}$ and $f_{ijk}^{2\text{-step}}$ coefficients (A1). Channels $<0.1\%$ and higher-level channels ($>$ 2-step, contributing to $\sim 8.6\,\%$, see Table I), are not shown.

# of channels	in range	contribution [%]
15	[1%,100%]	70.2
33	[0.1%,1%]	12.7
189	[0.01%,0.1%]	6.7
430	[0.001%,0.01%]	1.5
618	[0.0001%,0.001%]	0.2
2499	[0.0%,0.0001%]	0.0

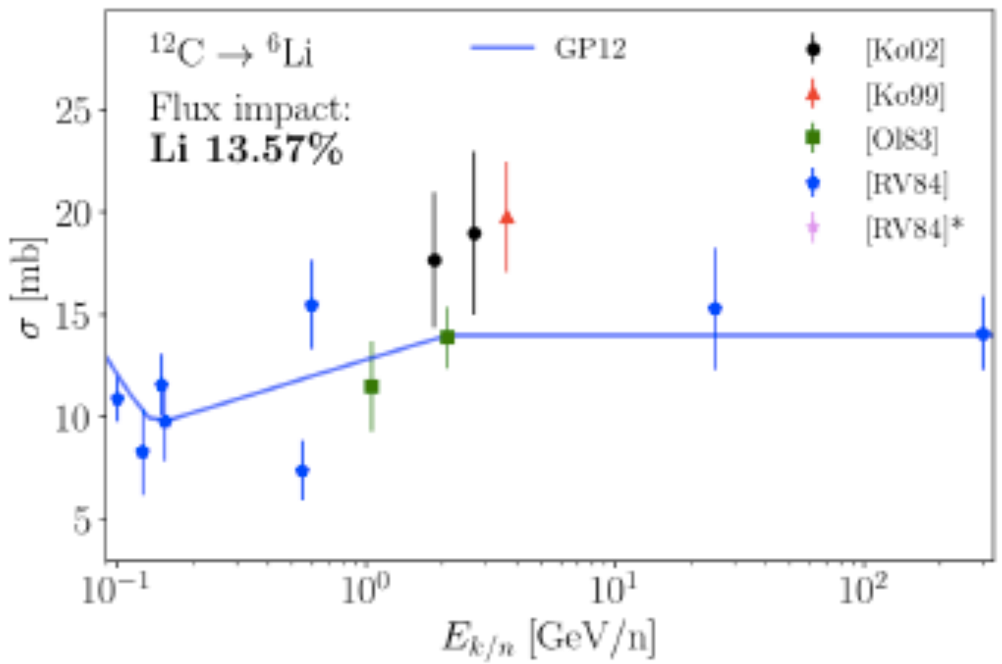
Channel	min	mean	max
^{16}O → ^{6}Li	12.8	**15.4**	17.9
^{12}C → ^{6}Li	11.7	**13.9**	16.1
^{16}O → ^{7}Li	9.99	**12.0**	14.0
^{12}C → ^{7}Li	9.50	**11.3**	13.2
^{24}Mg → ^{6}Li	1.99	**2.24**	2.48
^{16}O → ^{15}N → ^{7}Li	1.55	**1.86**	2.17
^{56}Fe → ^{6}Li	0.00	**1.79**	3.58
^{16}O → ^{13}C → ^{7}Li	1.48	**1.78**	2.08
^{12}C → ^{11}B → ^{7}Li	1.47	**1.75**	2.03
^{24}Mg → ^{7}Li	1.45	**1.74**	2.03
^{16}O → ^{13}C → ^{6}Li	1.41	**1.62**	1.84
^{16}O → ^{15}N → ^{6}Li	1.30	**1.47**	1.64
^{56}Fe → ^{7}Li	0.00	**1.27**	2.54
^{28}Si → ^{6}Li	0.00	**1.06**	2.13
^{16}O → ^{11}B → ^{7}Li	0.84	**1.01**	1.17
^{16}O → ^{12}C → ^{6}Li	0.83	**1.00**	1.16
^{16}O → ^{7}Li → ^{6}Li	0.86	**0.88**	0.90
^{12}C → ^{7}Li → ^{6}Li	0.82	**0.83**	0.84
^{16}O → ^{12}C → ^{7}Li	0.68	**0.81**	0.95
^{14}N → ^{6}Li	0.68	**0.79**	0.90
^{28}Si → ^{7}Li	0.00	**0.76**	1.52
^{20}Ne → ^{6}Li	0.00	**0.69**	1.38
^{16}O → ^{14}N → ^{6}Li	0.46	**0.64**	0.82
^{12}C → ^{10}B → ^{6}Li	0.46	**0.53**	0.61
^{16}O → ^{7}Be → ^{6}Li	0.43	**0.52**	0.60
^{20}Ne → ^{7}Li	0.00	**0.52**	1.03
^{14}N → ^{7}Li	0.44	**0.51**	0.59
^{12}C → ^{11}B → ^{6}Li	0.50	**0.51**	0.52
^{16}O → ^{10}B → ^{6}Li	0.39	**0.46**	0.52
^{12}C → ^{7}Be → ^{6}Li	0.35	**0.42**	0.49
^{16}O → ^{14}N → ^{7}Li	0.30	**0.42**	0.53
^{16}O → ^{11}B → ^{6}Li	0.28	**0.29**	0.30
^{12}C → ^{10}B → ^{7}Li	0.20	**0.24**	0.28
^{16}O → ^{10}B → ^{7}Li	0.17	**0.20**	0.24
^{13}C → ^{7}Li	0.15	**0.18**	0.21
^{13}C → ^{6}Li	0.14	**0.16**	0.18
^{32}S → ^{6}Li	0.00	**0.14**	0.27
^{24}Mg → ^{7}Li → ^{6}Li	0.13	**0.13**	0.13
^{26}Mg → ^{6}Li	0.00	**0.12**	0.25
^{25}Mg → ^{6}Li	0.00	**0.12**	0.24
^{26}Mg → ^{7}Li	0.00	**0.11**	0.23
^{54}Fe → ^{6}Li	0.00	**0.11**	0.23
^{20}Ne → ^{15}N → ^{7}Li	0.09	**0.11**	0.13
^{56}Fe → ^{7}Li → ^{6}Li	0.00	**0.11**	0.22
^{24}Mg → ^{16}O → ^{6}Li	0.09	**0.10**	0.12
^{28}Si → ^{27}Al → ^{6}Li	0.00	**0.10**	0.21
^{28}Si → ^{24}Mg → ^{6}Li	0.09	**0.10**	0.11
^{24}Mg → ^{12}C → ^{6}Li	0.08	**0.10**	0.12

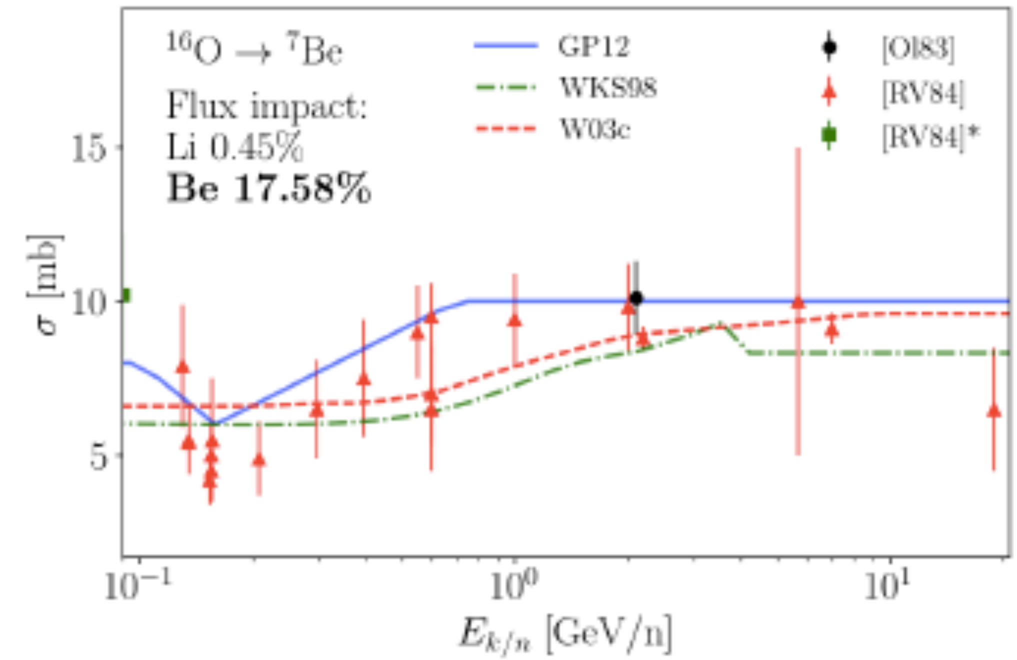
TABLE V. Ranking of 1- and 2-step channels for Be at 10 GeV/n, from $f_{ij}^{1\text{-step}}$ and $f_{ijk}^{2\text{-step}}$ coefficients (A1). Channels $<0.1\%$ and higher-level channels ($>$ 2-step, contributing to $\sim 6.8\,\%$, see Table I), are not shown.

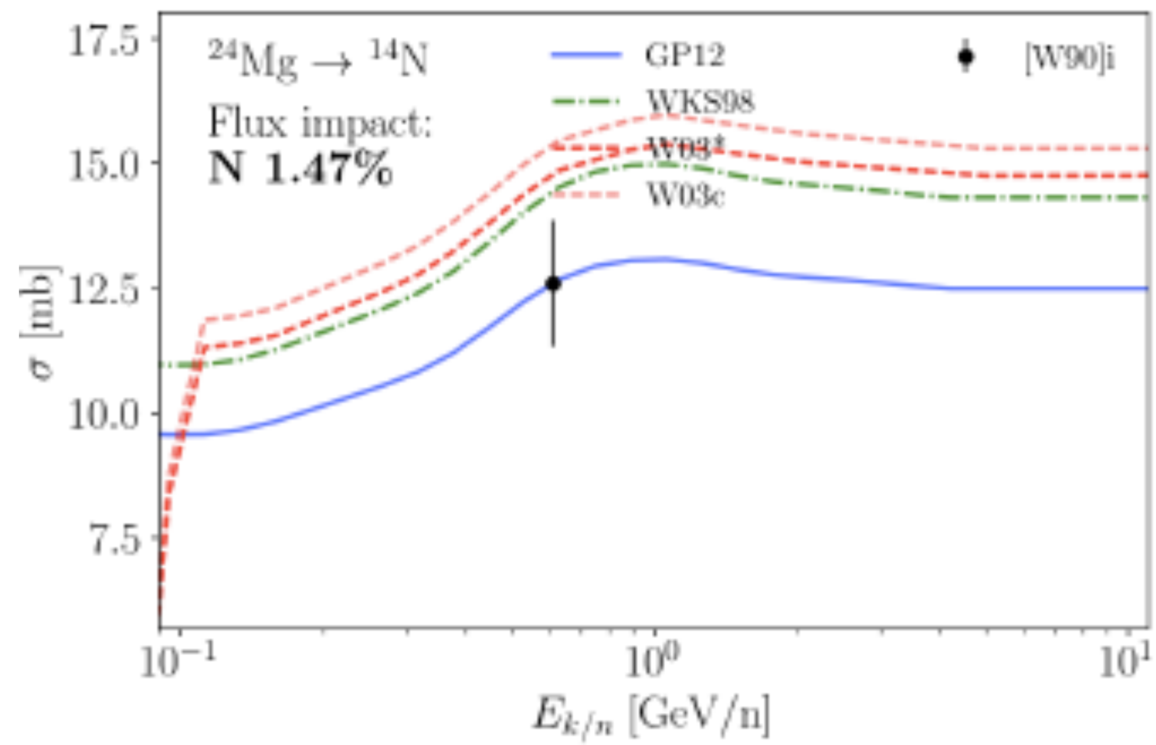
# of channels	in range	contribution [%]
17	[1%,100%]	71.5
46	[0.1%,1%]	13.4
207	[0.01%,0.1%]	6.1
532	[0.001%,0.01%]	1.8
879	[0.0001%,0.001%]	0.3
3624	[0.0%,0.0001%]	0.0

Channel	min	mean	max
^{16}O → ^{7}Be	17.6	**18.9**	20.9
^{12}C → ^{7}Be	15.3	**17.1**	18.9
^{12}C → ^{9}Be	7.12	**8.34**	9.64
^{16}O → ^{9}Be	5.78	**6.18**	6.48
^{28}Si → ^{7}Be	2.70	**3.18**	3.63
^{24}Mg → ^{7}Be	2.53	**2.99**	3.78
^{20}Ne → ^{7}Be	1.63	**2.10**	2.99
^{56}Fe → ^{7}Be	0.16	**1.79**	3.70
^{12}C → ^{10}Be	1.25	**1.72**	1.99
^{14}N → ^{7}Be	1.00	**1.32**	1.69
^{16}O → ^{10}Be	1.17	**1.29**	1.39
^{12}C → ^{11}B → ^{9}Be	1.21	**1.25**	1.35
^{28}Si → ^{9}Be	1.02	**1.14**	1.31
^{24}Mg → ^{9}Be	0.96	**1.13**	1.46
^{16}O → ^{13}C → ^{7}Be	0.85	**1.02**	1.22
^{16}O → ^{15}N → ^{9}Be	0.84	**1.02**	1.24
^{16}O → ^{15}N → ^{7}Be	0.94	**1.00**	1.06
^{56}Fe → ^{9}Be	0.09	**0.87**	1.52
^{16}O → ^{14}N → ^{7}Be	0.68	**0.83**	0.97
^{12}C → ^{11}B → ^{7}Be	0.52	**0.83**	1.12
^{20}Ne → ^{9}Be	0.68	**0.80**	0.97
^{16}O → ^{11}B → ^{9}Be	0.56	**0.68**	0.78
^{16}O → ^{13}C → ^{9}Be	0.21	**0.59**	0.95
^{16}O → ^{13}C → ^{7}Be	0.47	**0.54**	0.63
^{16}O → ^{12}C → ^{9}Be	0.35	**0.51**	0.70
^{12}C → ^{10}B → ^{9}Be	0.24	**0.46**	0.60
^{16}O → ^{11}B → ^{7}Be	0.29	**0.44**	0.63
^{12}C → ^{11}B → ^{10}Be	0.24	**0.42**	0.58
^{14}N → ^{9}Be	0.19	**0.40**	0.62
^{16}O → ^{10}B → ^{9}Be	0.18	**0.38**	0.51
^{12}C → ^{10}B → ^{7}Be	0.29	**0.36**	0.51
^{32}S → ^{7}Be	0.12	**0.29**	0.53
^{16}O → ^{10}B → ^{7}Be	0.24	**0.29**	0.38
^{25}Mg → ^{7}Be	0.19	**0.26**	0.42
^{27}Al → ^{7}Be	0.15	**0.25**	0.41
^{16}O → ^{14}N → ^{9}Be	0.13	**0.24**	0.34
^{24}Mg → ^{10}Be	0.18	**0.23**	0.32
^{16}O → ^{11}B → ^{10}Be	0.11	**0.23**	0.34
^{26}Mg → ^{7}Be	0.15	**0.23**	0.38
^{28}Si → ^{10}Be	0.16	**0.22**	0.34
^{28}Si → ^{27}Al → ^{7}Be	0.14	**0.19**	0.25
^{12}C → ^{9}Be → ^{7}Be	0.16	**0.19**	0.21
^{24}Mg → ^{23}Na → ^{7}Be	0.12	**0.18**	0.26
^{56}Fe → ^{10}Be	0.01	**0.17**	0.34
^{16}O → ^{15}N → ^{10}Be	0.10	**0.16**	0.21
^{20}Ne → ^{10}Be	0.10	**0.16**	0.26
^{16}O → ^{13}C → ^{10}Be	0.02	**0.14**	0.26
^{16}O → ^{9}Be → ^{7}Be	0.13	**0.14**	0.14
^{26}Mg → ^{9}Be	0.09	**0.13**	0.17
^{24}Mg → ^{16}O → ^{7}Be	0.10	**0.12**	0.14
^{28}Si → ^{24}Mg → ^{7}Be	0.12	**0.12**	0.13
^{25}Mg → ^{9}Be	0.10	**0.12**	0.14
^{32}S → ^{9}Be	0.06	**0.12**	0.19
^{24}Mg → ^{12}C → ^{7}Be	0.10	**0.12**	0.13
^{29}Si → ^{7}Be	0.07	**0.11**	0.17
^{27}Al → ^{9}Be	0.08	**0.11**	0.15
^{20}Ne → ^{16}O → ^{7}Be	0.09	**0.11**	0.13
^{16}O → ^{12}C → ^{10}Be	0.06	**0.11**	0.14
^{24}Mg → ^{22}Ne → ^{7}Be	0.08	**0.11**	0.15
^{20}Ne → ^{12}C → ^{7}Be	0.10	**0.11**	0.11
^{23}Na → ^{7}Be	0.06	**0.10**	0.21
^{14}N → ^{12}C → ^{7}Be	0.07	**0.10**	0.14
^{20}Ne → ^{19}F → ^{7}Be	0.07	**0.10**	0.14

Production cross sections (Genolini, Maurin, Miskalenko,Unger, PRC 2018)



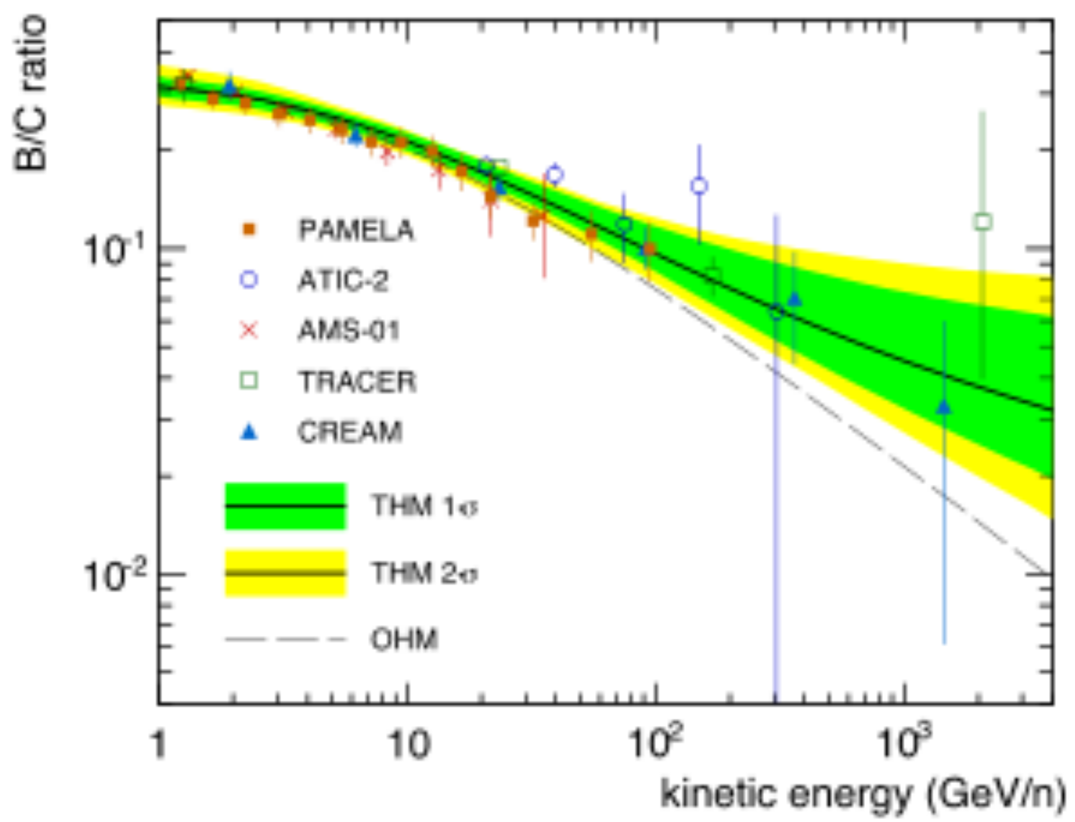




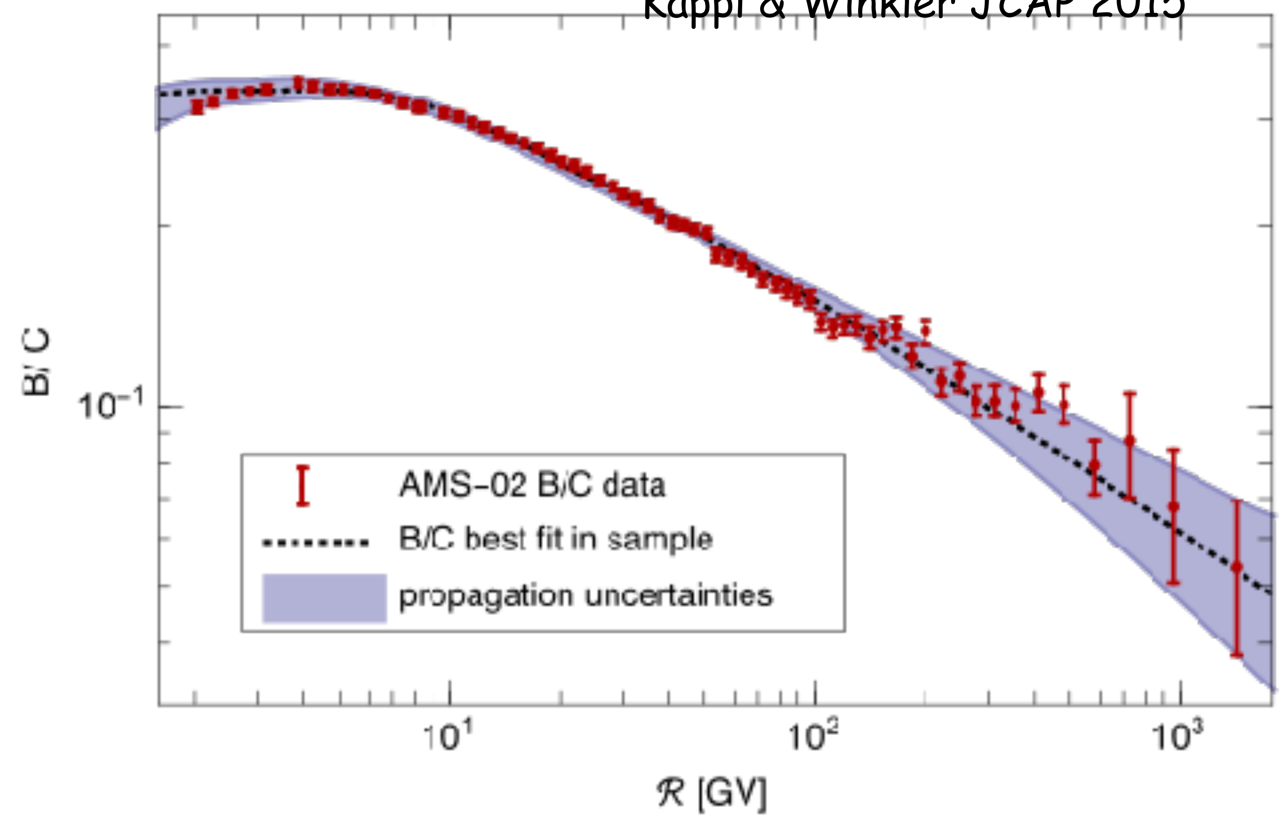
Boron-to-Carbon: a "standard candle" for fixing GALACTIC PROPAGATION

- Li, Be, B are produced by fragmentation of heavier nuclei (mostly C, N, O) on H and He: production cross sections
- B/C is very sensitive to **propagation effects**, kind of standard candle

Feng, Tomassetti, Oliva PRD 2016



Kappl & Winkler JCAP 2015

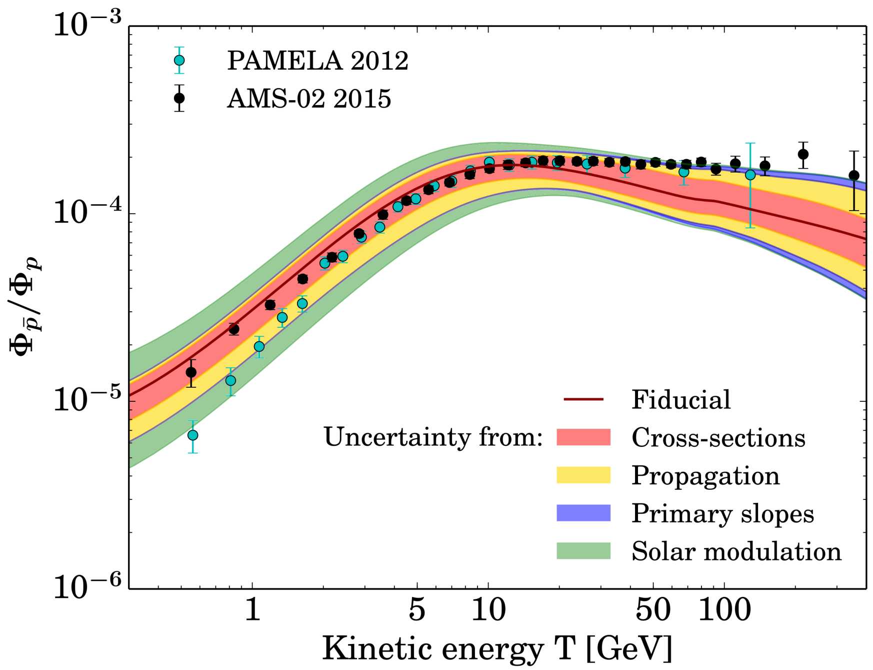


B/C (AMS, PRL 117, 2016) does not show features at high energies

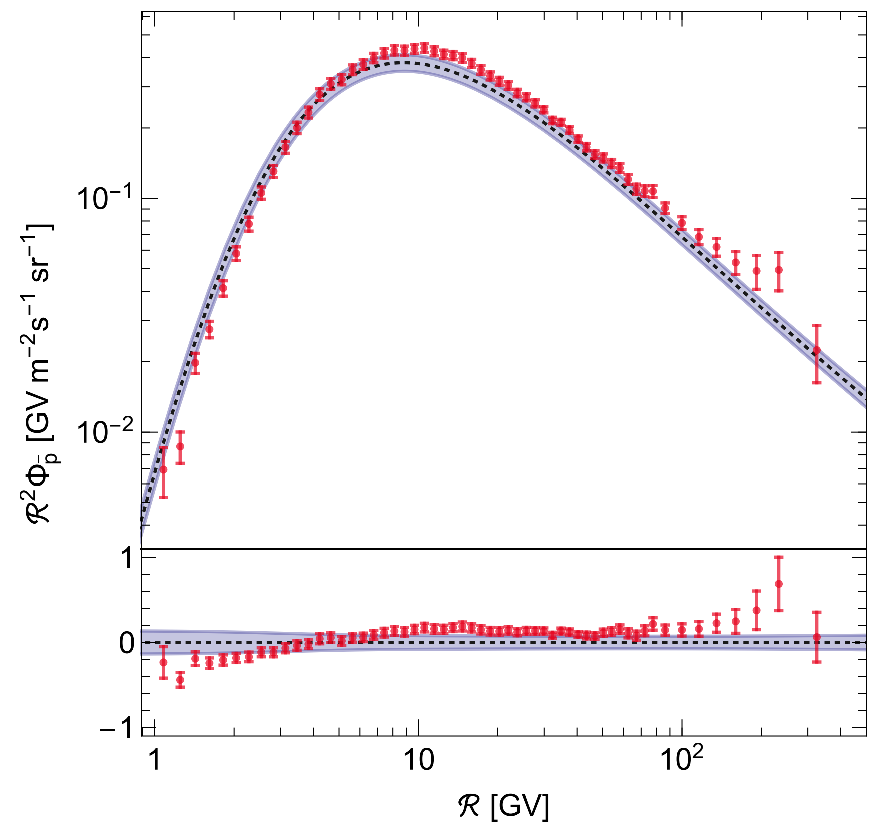
At first order, we understand B/C within Fermi acceleration and isotropic diffusion. This may be no longer sufficient when dealing with data at higher energies, gamma-ray data, other species

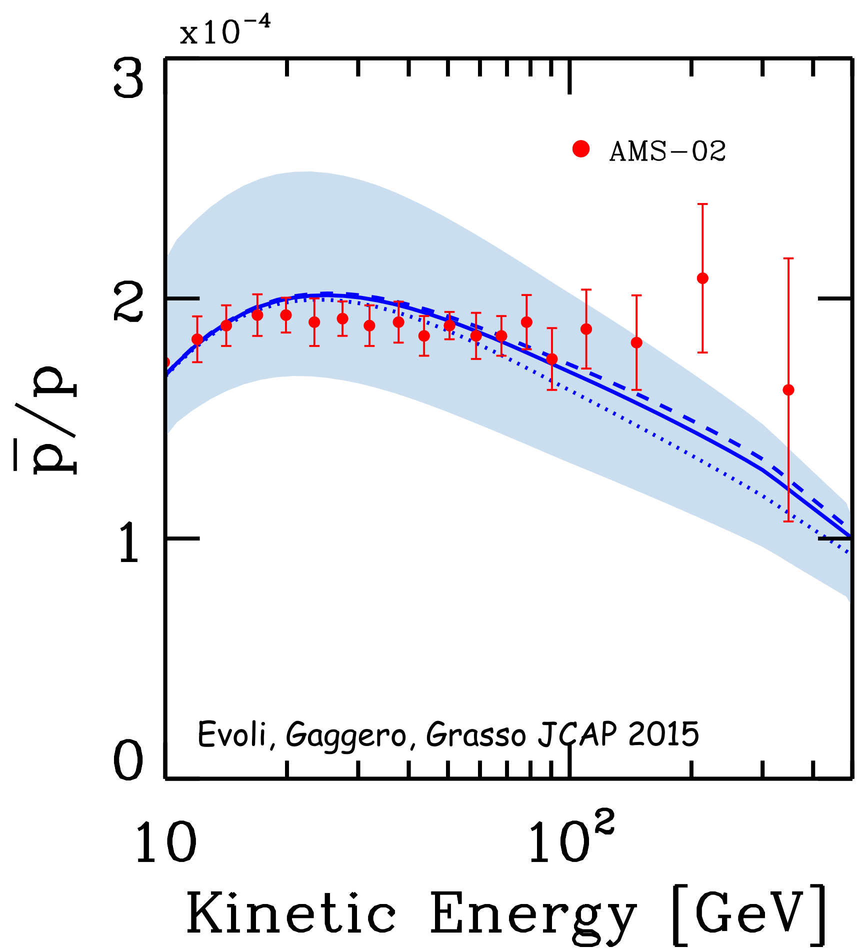
Interpretation of antiproton data

Giesen + JCAP 2015



Reinert & Winkler JCAP 2018



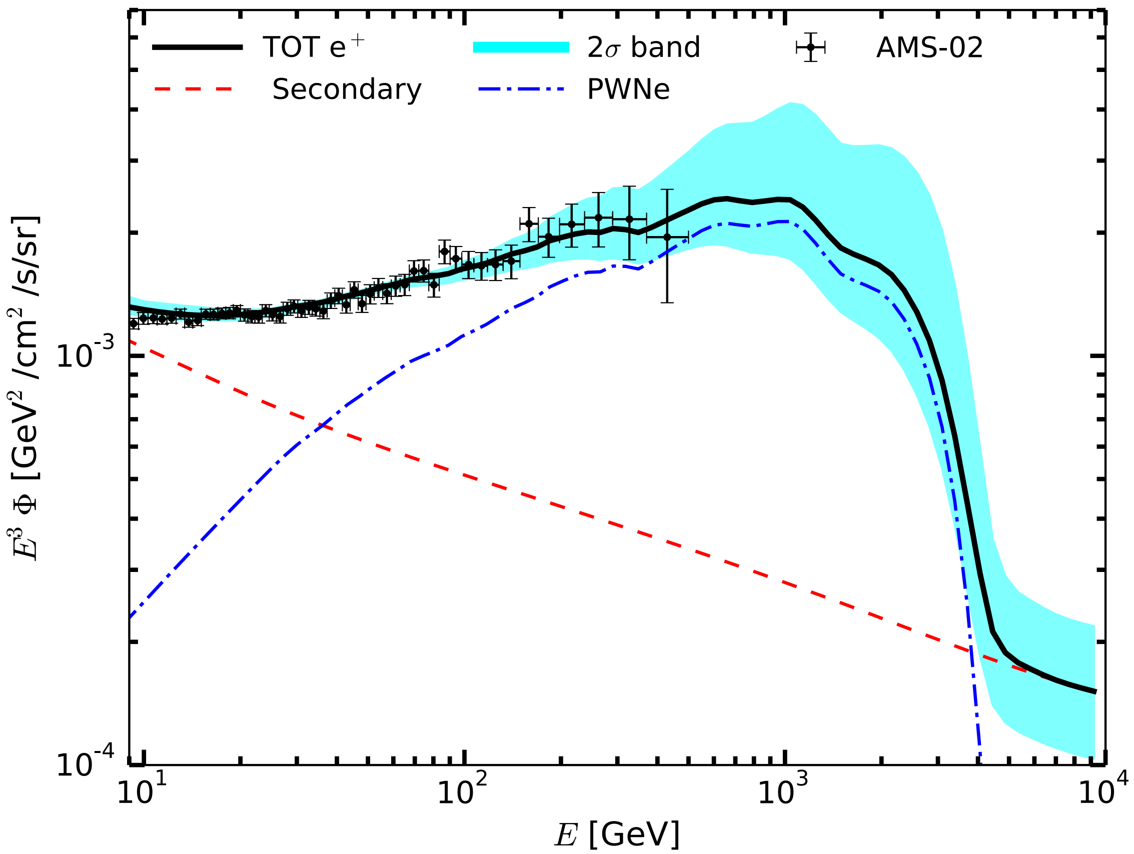


Propagation models fitted on AMS-02 B/C data.
Greatest uncertainty set by nuclear cross sections.

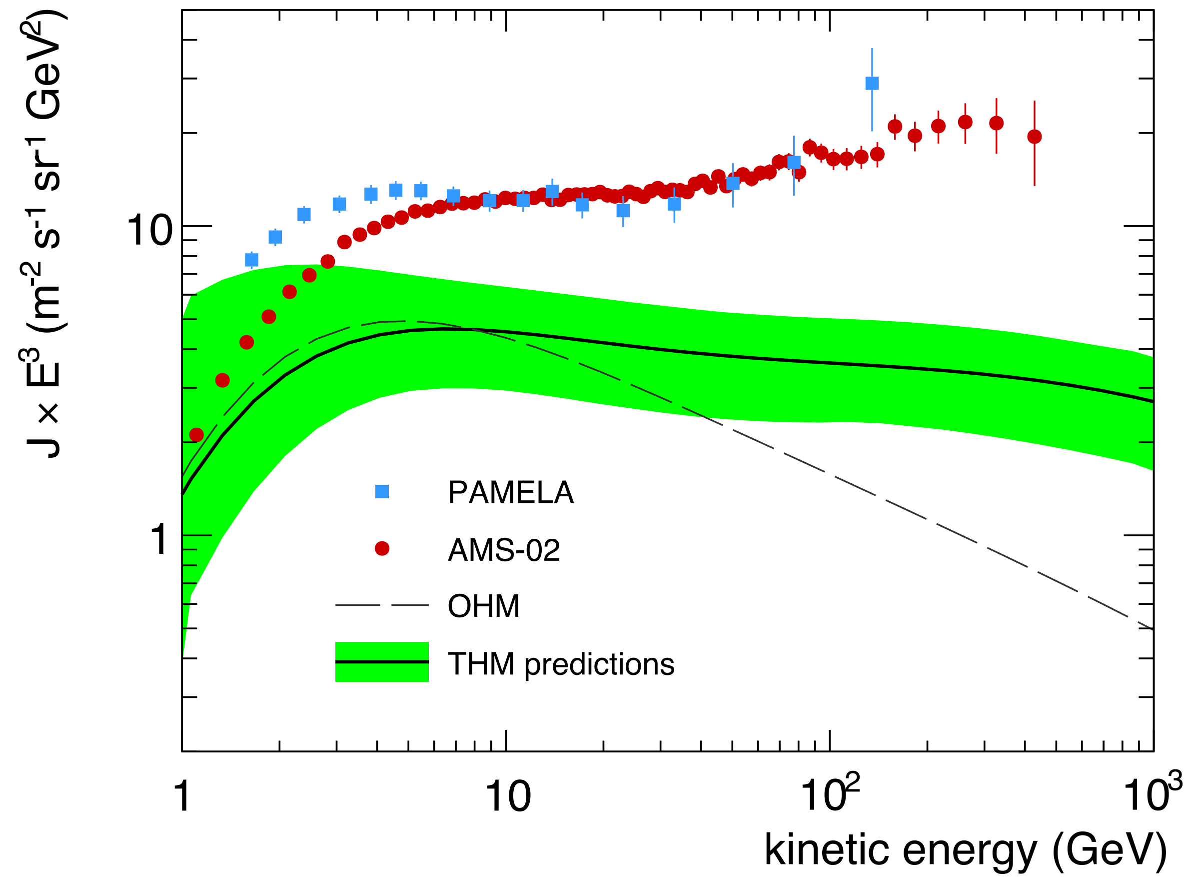
Background antiproton can explain data naturally, mainly because of the small diffusion coefficient slope indicated by B/C.

The cosmic positrons

Manconi, FD, Di Mauro JCAP 2017



Feng, Tomassetti, Oliva PRD 2017



Secondary positrons predicted in realistic transport models cannot explain alone the positron flux.

One or more components are needs, typically in nearby sources given the strong radiative cooling experienced by e+e-.