Constraints and implications from PAMELA and ATIC results

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IHEP, CAS

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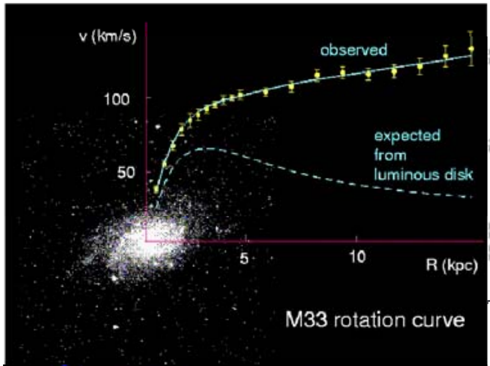
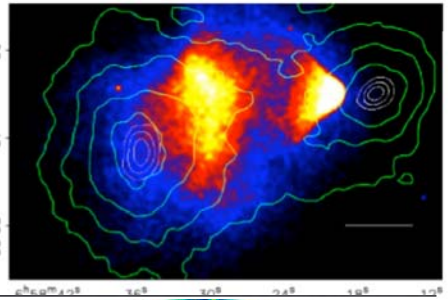
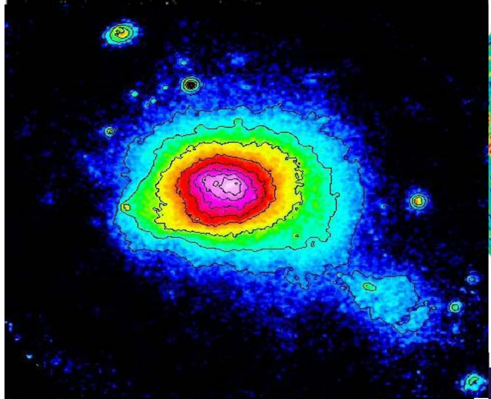
Outline

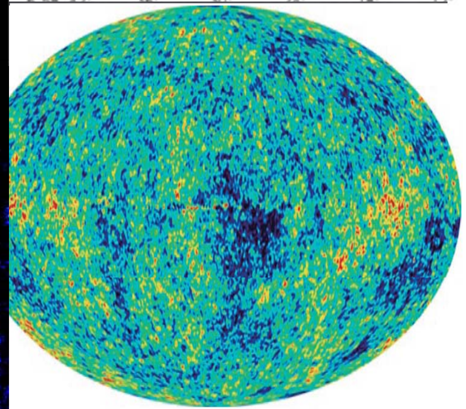
- Brief introduction to PAMELA and ATIC results and explanations
- Constraints on the DM model from data
- Radiations due to the primary electron/positrons
- conclusions

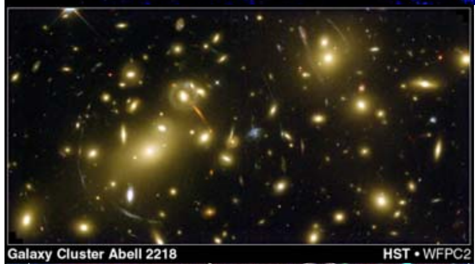
Standard cosmology

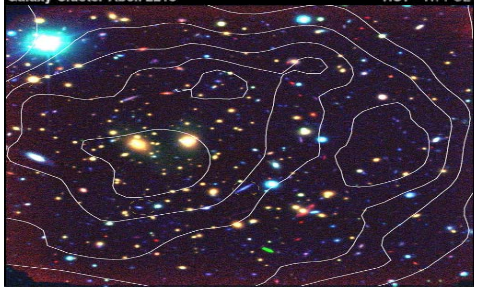


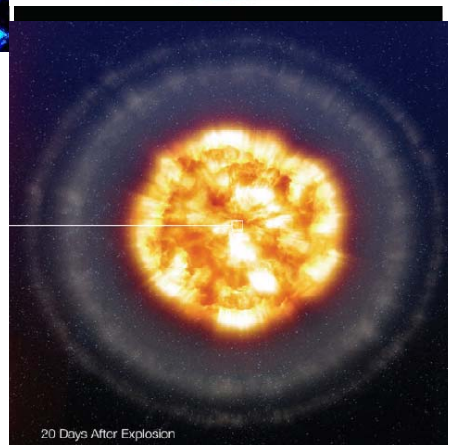


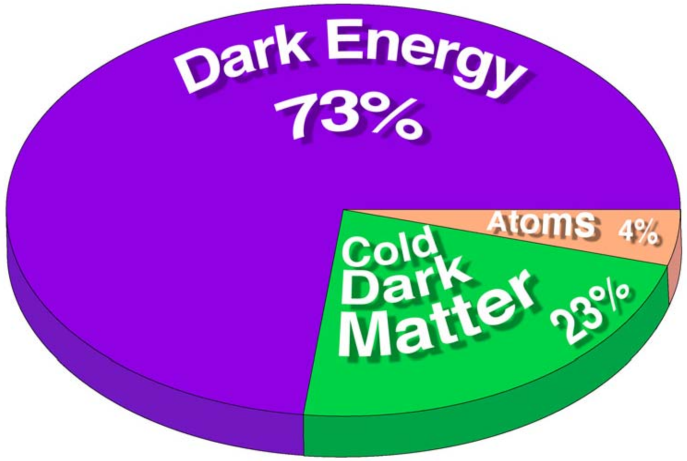








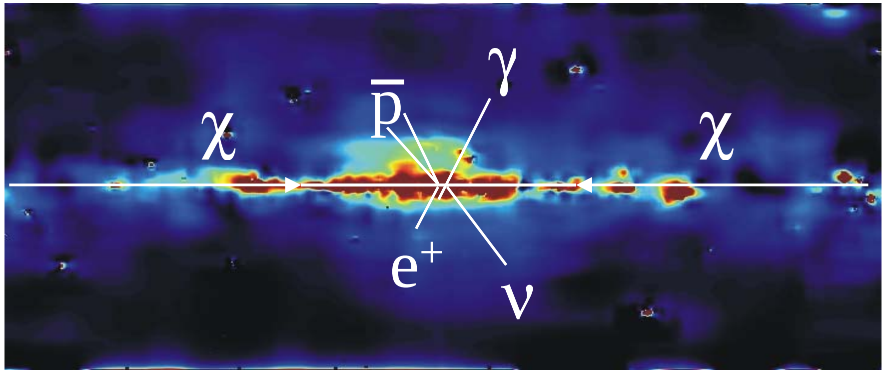




Dark matter (dark energy) exists in the universe. However, we have to figure out its property.

Detection of WIMP

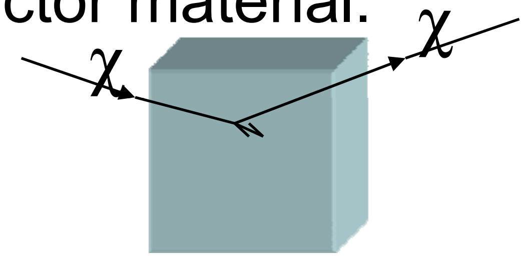
- Indirect detection DM increases in Galaxies, annihilation restarts($\propto \rho^{2}$); ID looks for the annihilation products of WIMPs, such as the neutrinos, gamma rays, positrons at the ground/space-based experiments



indirect detection

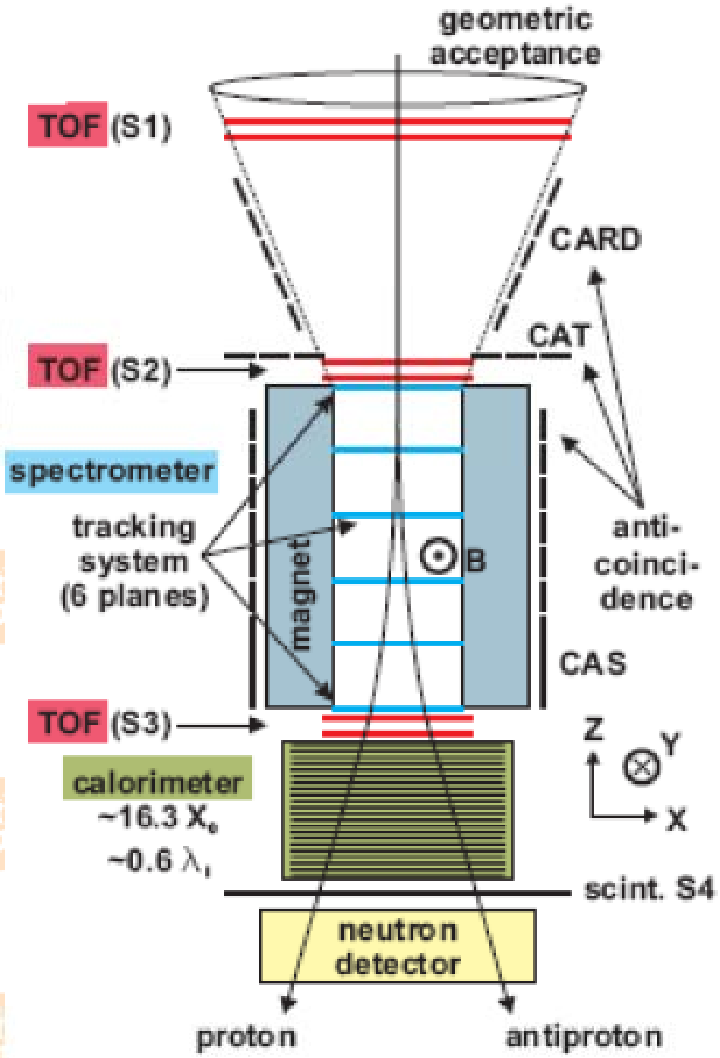
- Direct detection of WIMP at terrestrial detectors via scattering of WIMP of the detector material.

$$\chi\bar{\chi} \rightarrow l\bar{l} \Leftrightarrow \chi l \rightarrow \chi l$$



Direct detection

PAMELA detection ability



$$50MeV < e^{+} < 270GeV$$

$$e^{-} < 400GeV$$

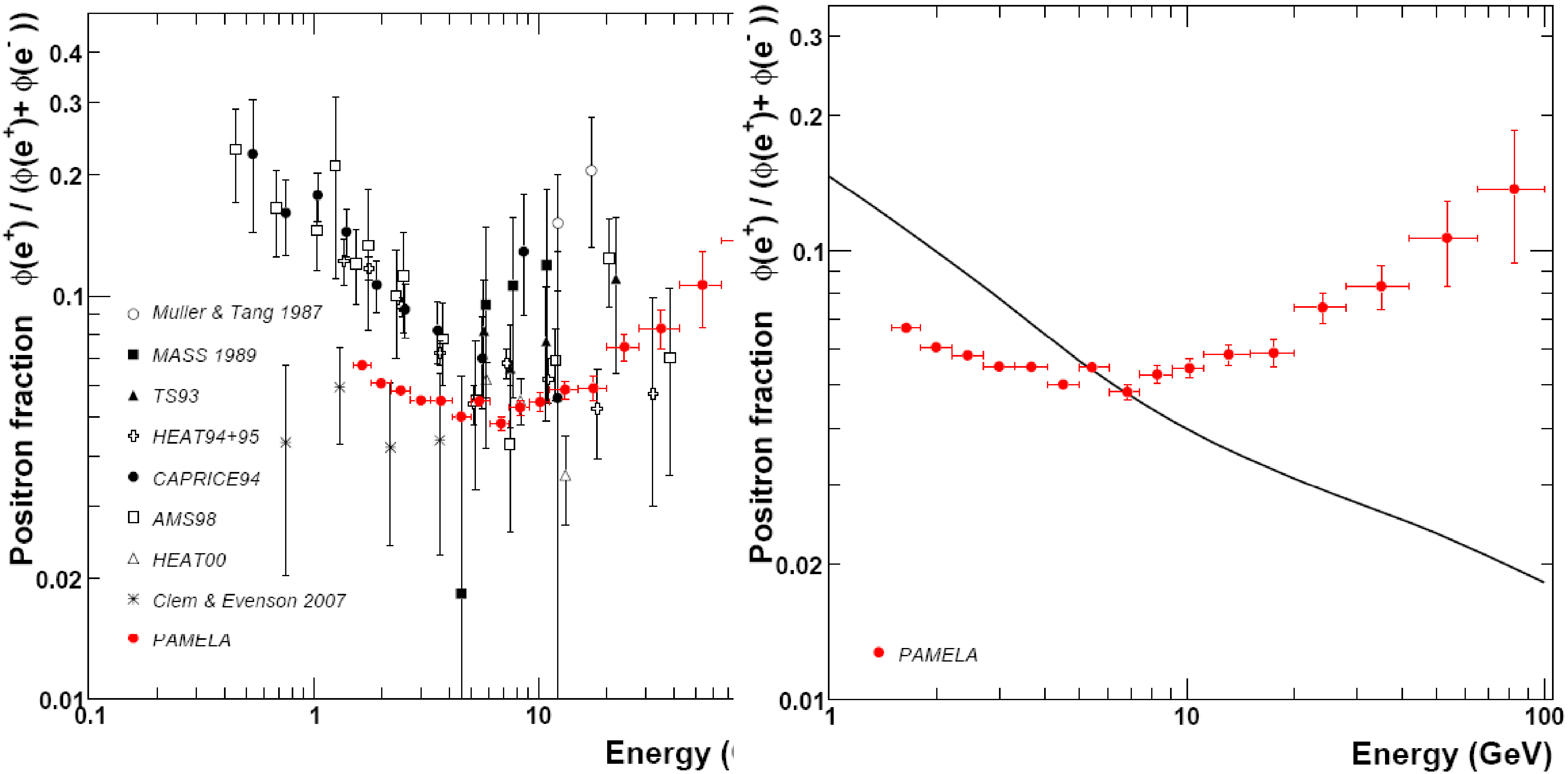
$$80MeV < \overline{p} < 190GeV$$

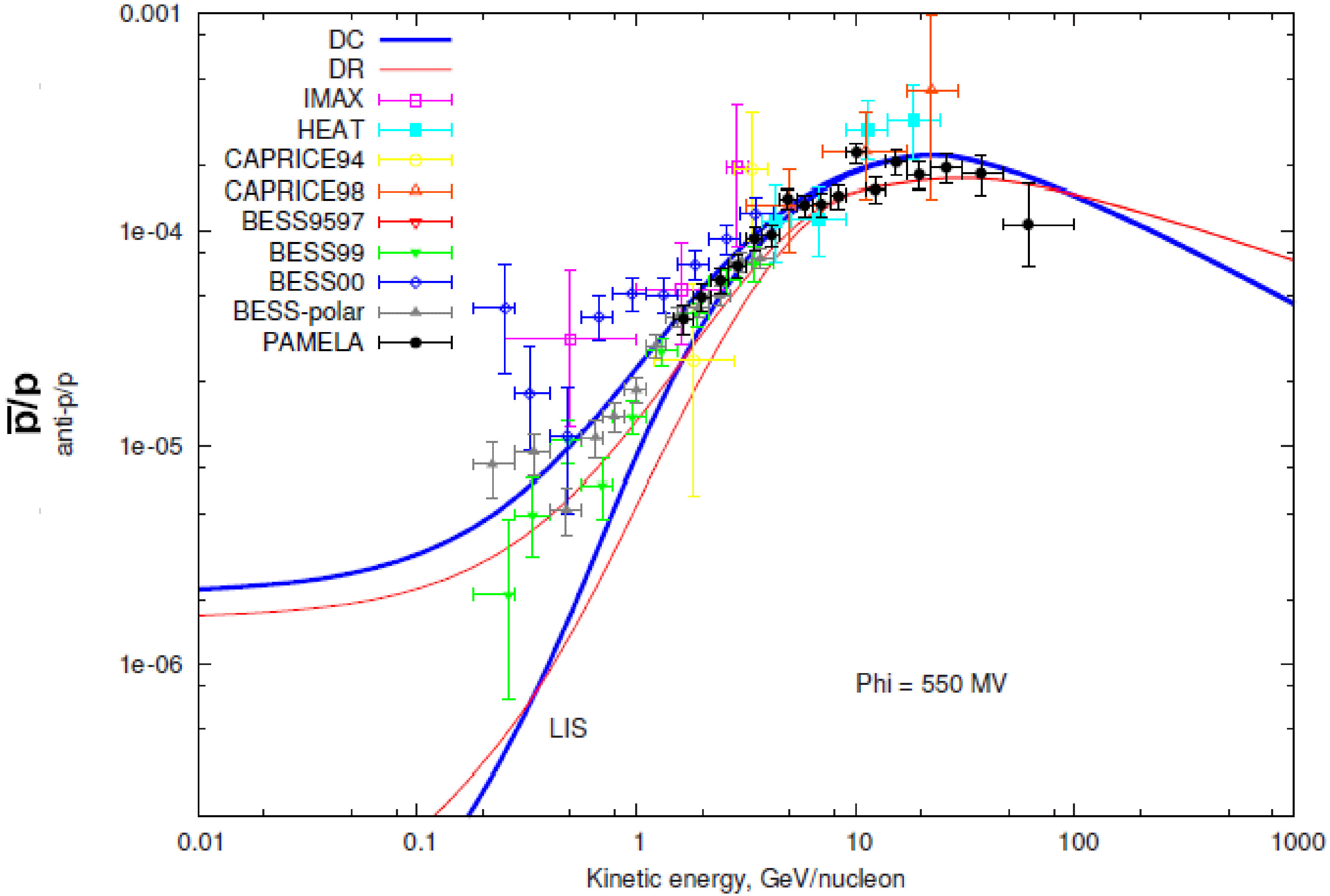
$$p < 700GeV$$

$$e^{\pm} < 2TeV\,(Cal)$$

arXiv:0810.4995 [ps, pdf, other]

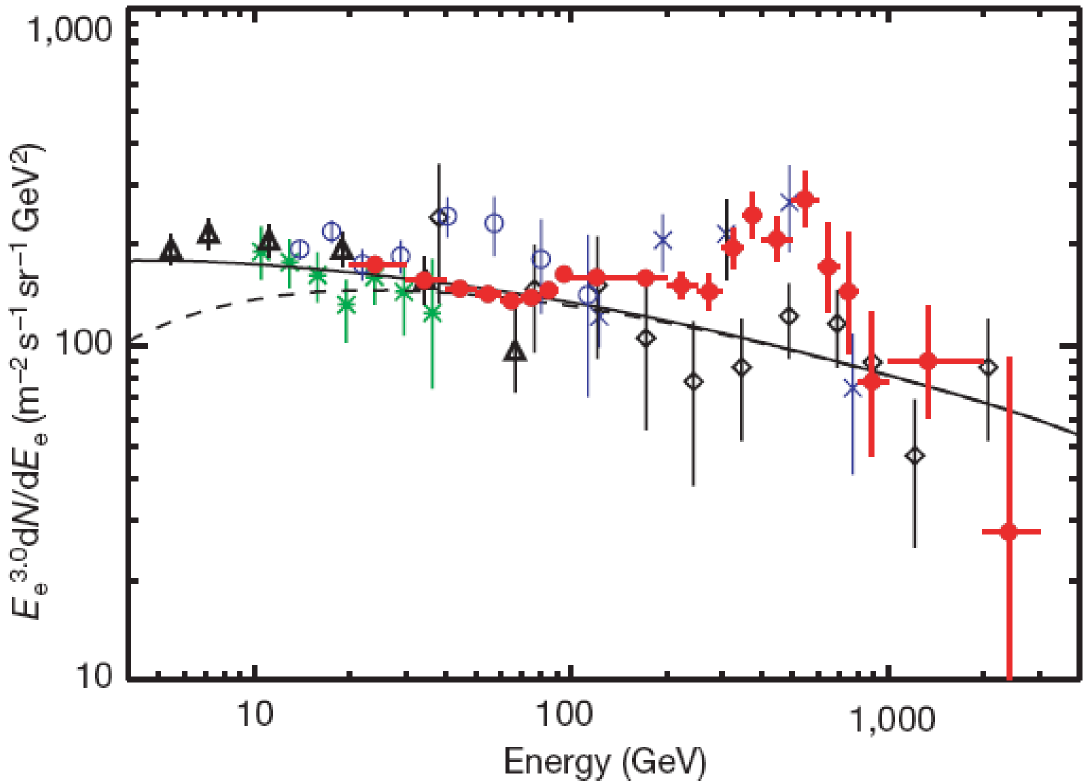
Title: Observation of an anomalous positron abundance in the cosmic radiation





0.001
1e-04
1e-05
1e-06
$\overline{p}/p$
anti-p/p
DC
DR
IMAX
HEAT
CAPRICE94
CAPRICE98
BESS9597
BESS99
BESS00
BESS-polar
PAMELA
Phi = 550 MV
LIS
0.01
0.1
1
10
100
1000
Kinetic energy, GeV/nucleon

Bump at the electron/positron spectrum



Chang et al.
Nature456, 362 2008

Figure 3 | ATIC results showing agreement with previous data at lower energy and with the imaging calorimeter PPB-BETS at higher energy. The electron differential energy spectrum measured by ATIC (scaled by E^3) at the top of the atmosphere (red filled circles) is compared with previous observations from the Alpha Magnetic Spectrometer AMS (green stars)[31], HEAT (open black triangles)[30], BETS (open blue circles)[32], PPB-BETS (blue crosses)[16] and emulsion chambers (black open diamonds)[4,8,9], with one sigma uncertainties. The GALPROP code calculates a power-law spectral

Summary of data

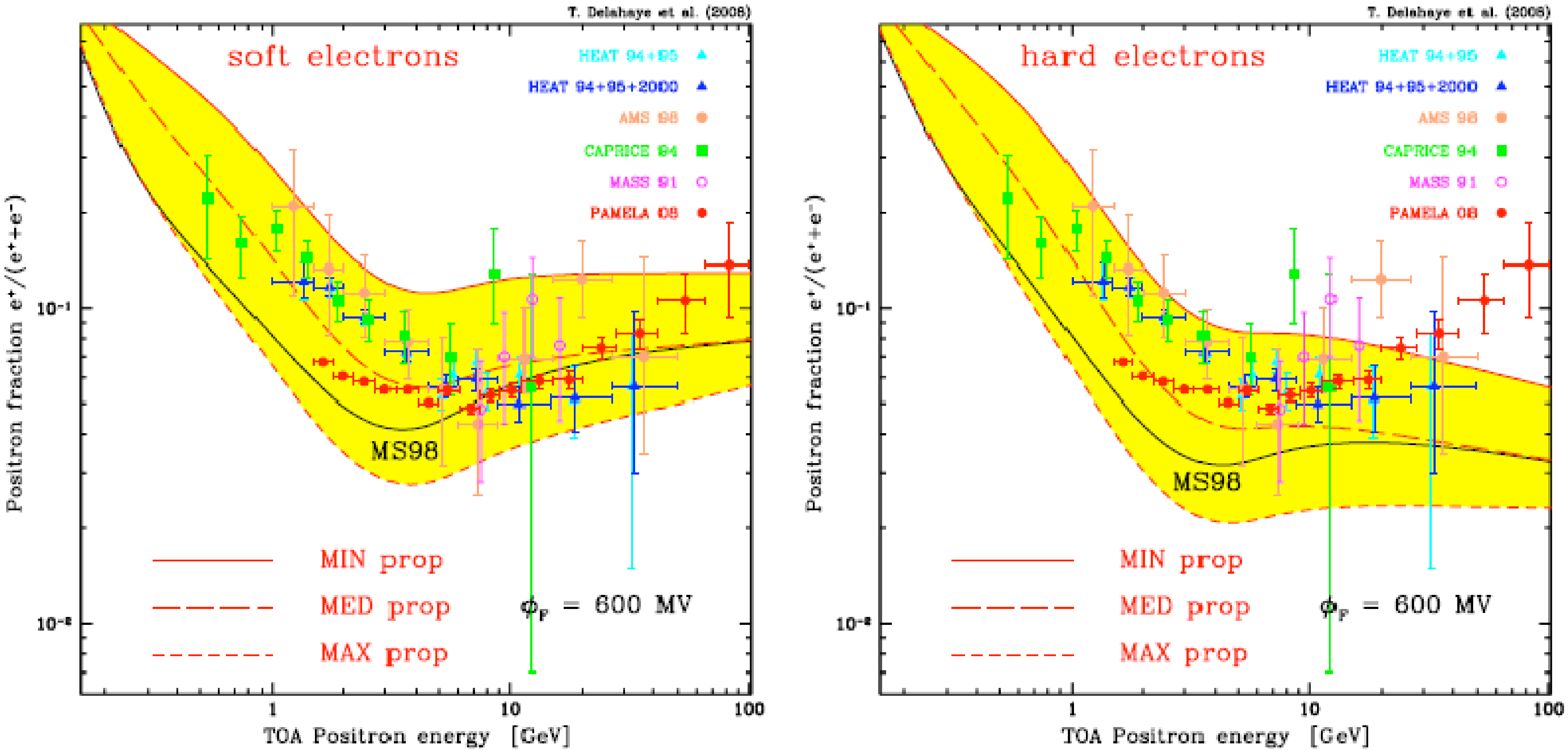
- Substantive positron excess was observed beyond the standard prediction by cosmic ray physics above ~10 GeV (up to ~100 GeV by PAMELA, ~1TeV by ATIC).
- Consistent with previous results from HEAT and AMS01.
- Assuming primary sources producing equal amount of electron/positron, ATIC and PAMELA are consistent with each other that they can be explained by the same source(s) simultaneously.
- ATIC data show very sharp ‘falling’ at the electron spectrum at ~600 GeV. (consistent with the spectrum produced by dark matter; can astrophysical processes produce similar spectrum?)
- No antiproton excess. The sources seem have to be leptonic.

Recalculation of background

- New formulization of spallation cross section pp -> e+
- Uncertainty from e- spectrum
- Uncertainty from propagation

PAMELA result might not be really an excess
but due to the uncertainty of background estimate

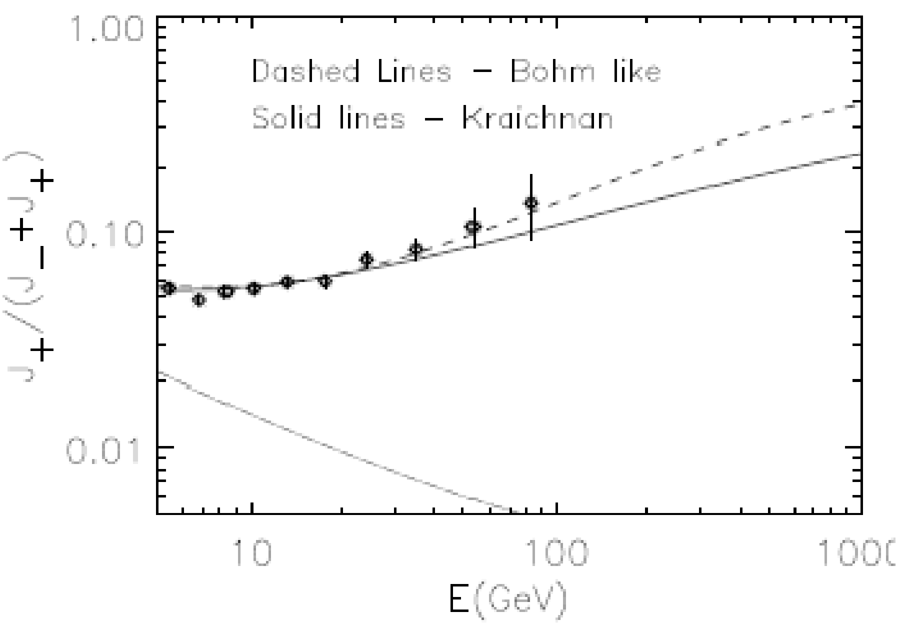
Delahaye et al., 0809.5268

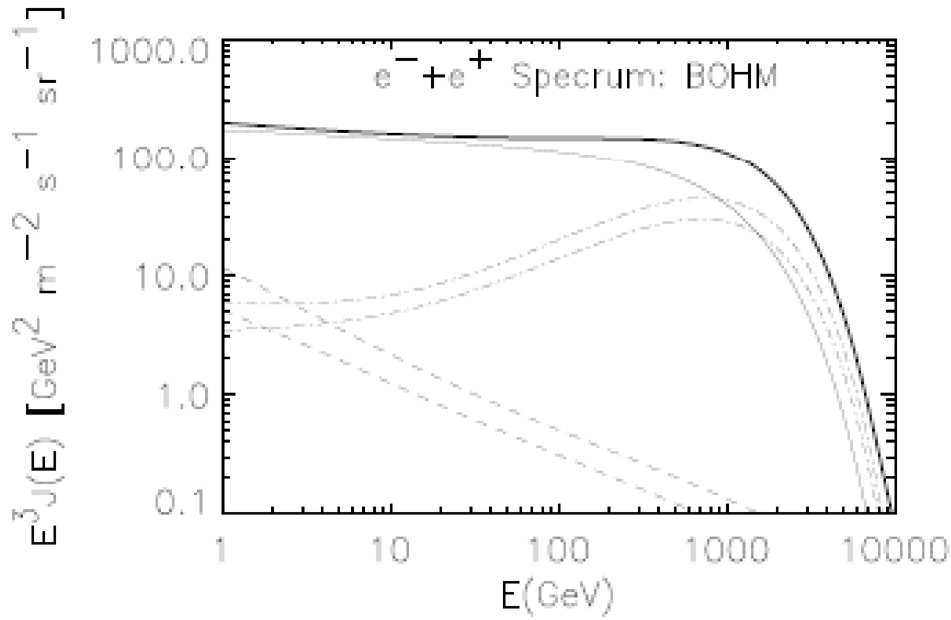


But cannot explain ATIC result

Possible origins of e^+e^-: pp interaction (Blasi, 0903.2794)

Occur at the cosmic ray acceleration source: hard spectrum

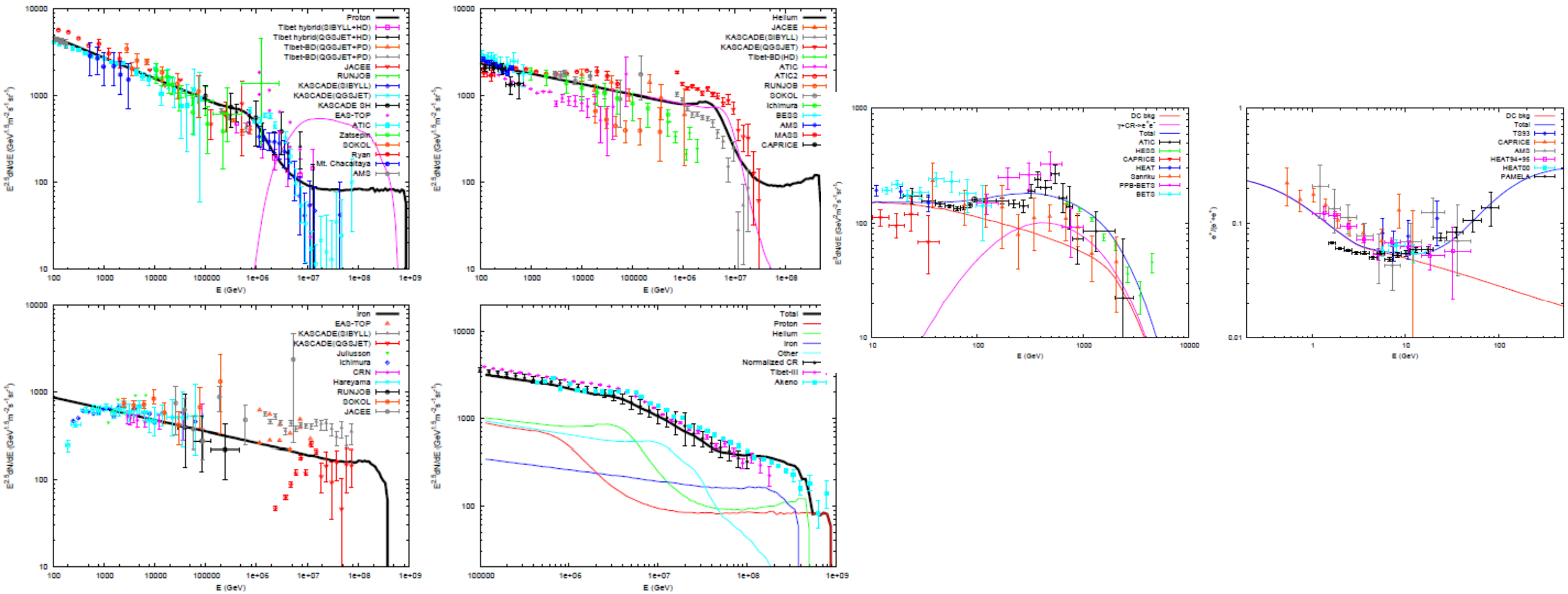




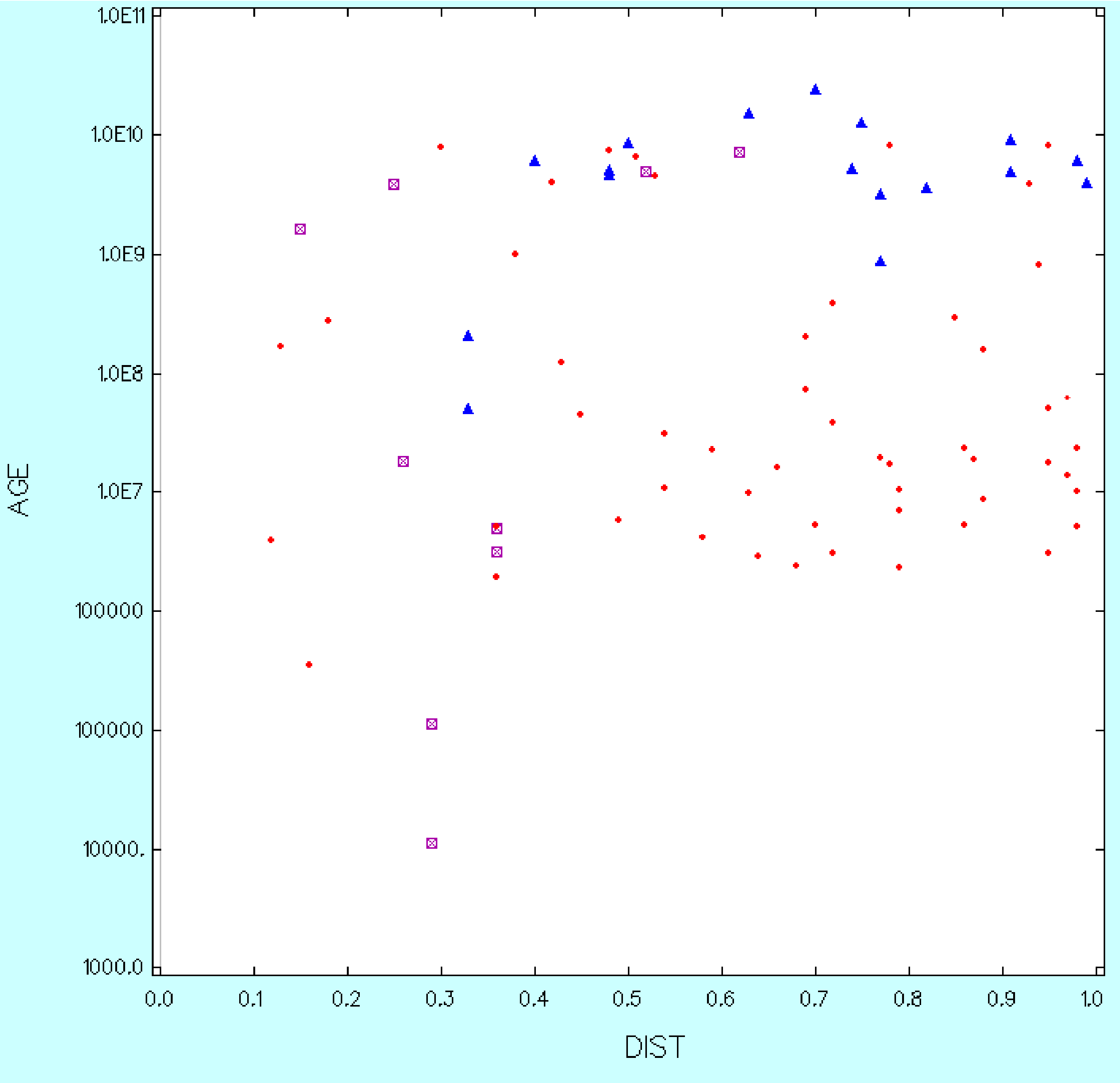
Comment: antiprotons may set constraints on this picture

From CRs interaction (Hu, Bi et al., 0901.1520)

- There is knee in CR spectrum at ~10^15 eV
- It is proposed the knee is generated by $p\gamma \to pe^+e^-$ interaction, with Eγ=1eV, the threshold energy is at ~10^15 eV
- 3% converted e^+e^- can explain the ATIC excess



Nearby pulsars



Astrophysical sources

- Nearby pulsars:

D. Hooper et al.

S. Profumo

……

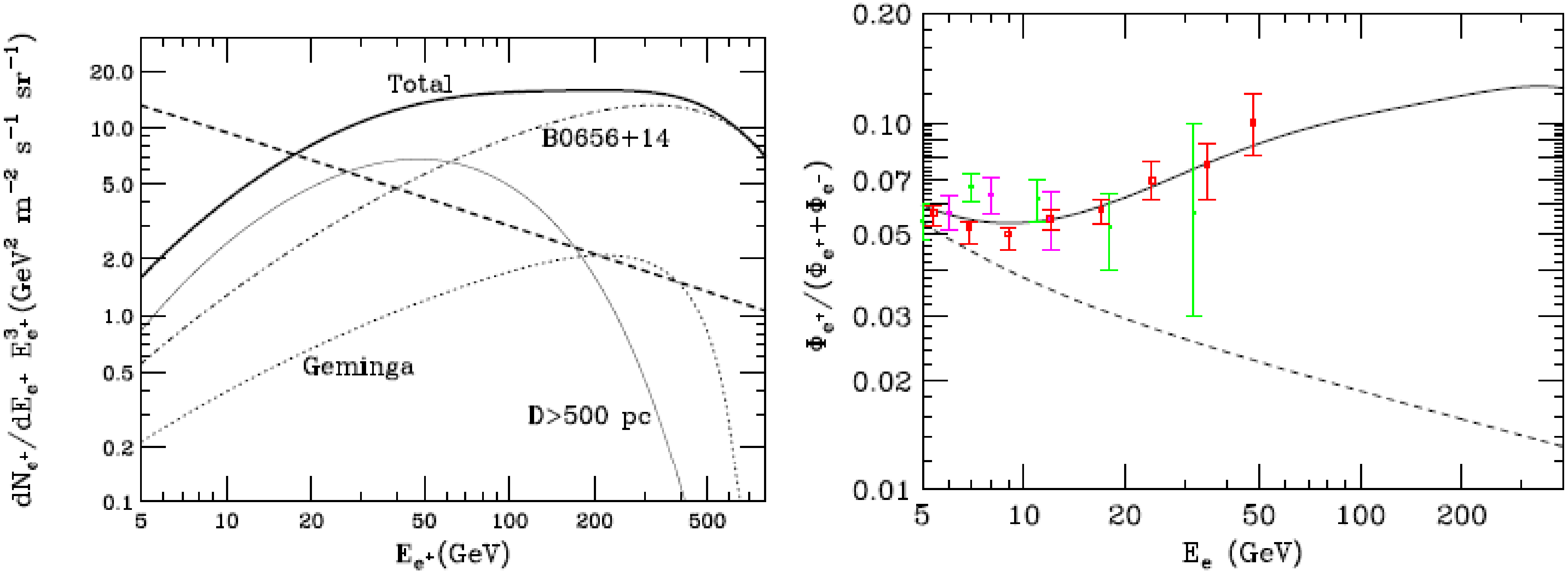


FIG. 4: The positron spectrum and positron fraction from the sum of contributions from B0656+14, Geminga, and all pulsars farther than 500 parsecs from the Solar System.

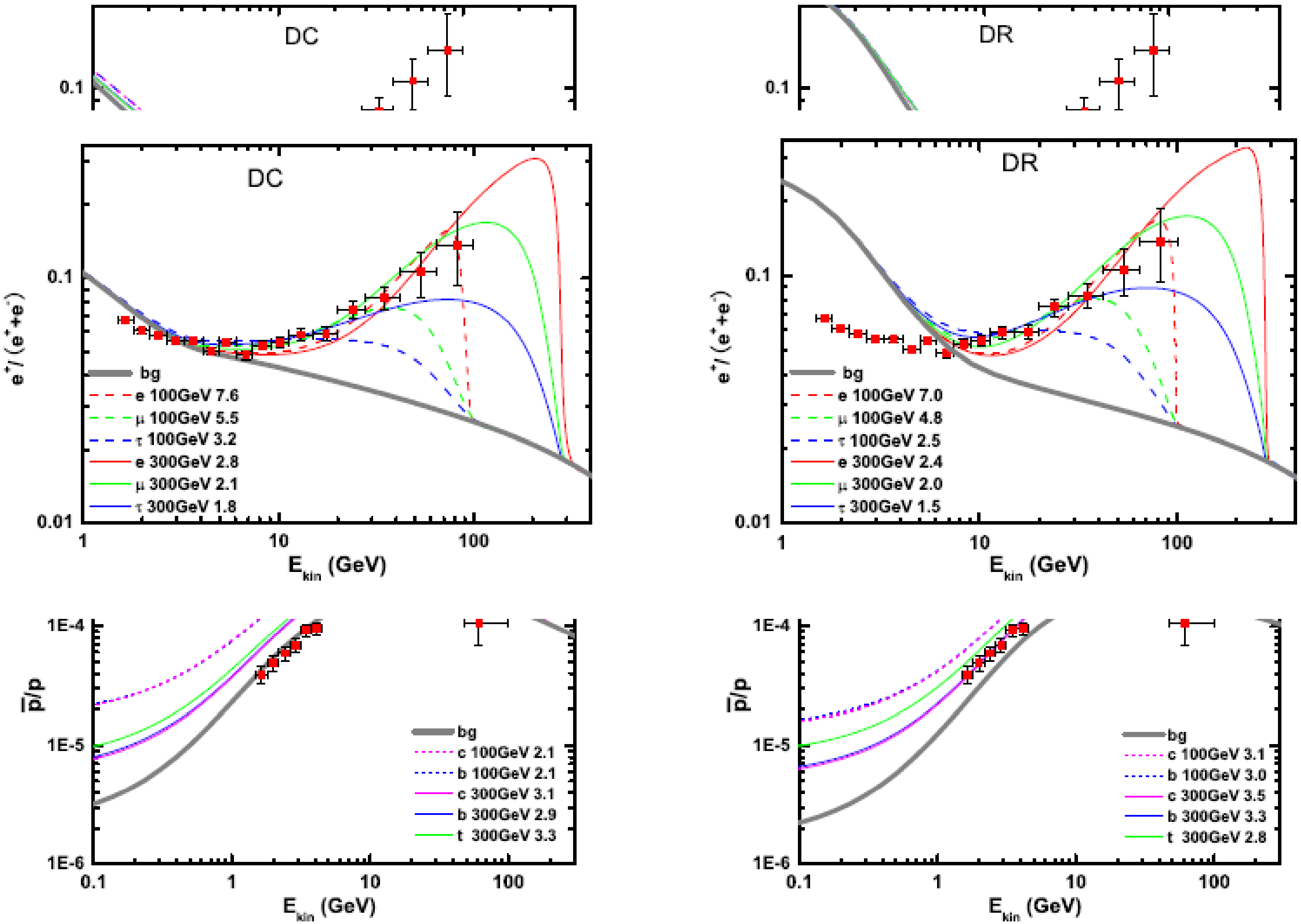
Primary positron/electrons from dark matter – implication from new data

- DM annihilation/decay produce leptons dominantly in order not to produce too much antiprotons.
- Very hard electron spectrum -> dark matter annihilates/decay into leptons.

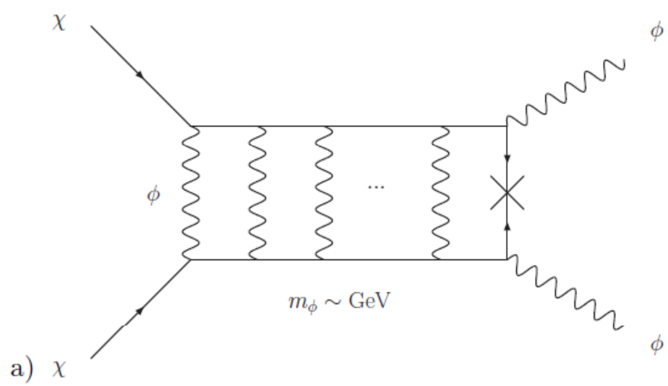
- Very large annihilation cross section, much larger than the requirement by relic density. (1) nonthermal production, 2) Sommerfeld enhancement, 3) Breit-Wigner enhancement, 4) dark matter decay.)

why should annihilate into leptons?

Yin, Yuan, Bi et al.
arXiv:0811.0176



Dark matter models to produce leptons



- Kinematically suppression

Mass of φis about 1GeV, is

Kinematically suppressed to anti

At the same time attractive interaction can enhance the annihilaition rate, Sommerfeld enhancement. (Arkani-Hamed et al. 0810.0713)

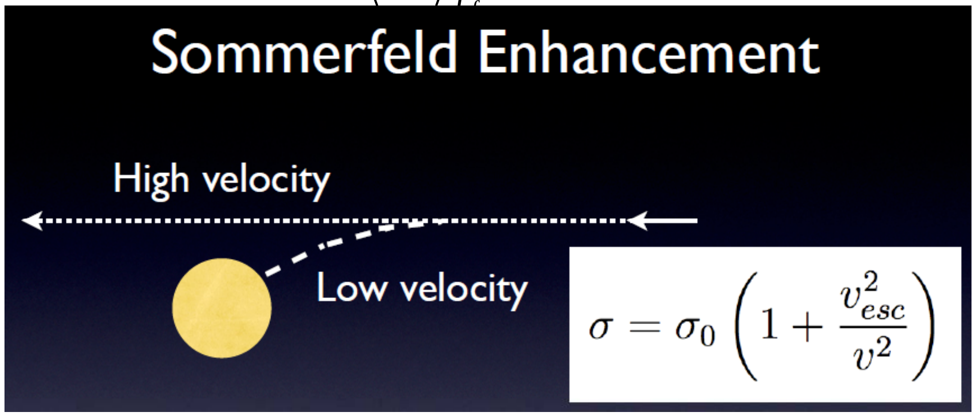
- Dynamically suppression, φ carries $U(1)'_{e-\mu(\tau)}$ (Baek; Fox; Bi)
- DM models related with neutrino mass (Bi et al 0901.0176; Cao et al. 0901.1334)
- These models lead to hard positron spectrum and suppress antiproton flux naturally.

Large flux

- Nonthermal production

$$\Omega_\chi h^2 \approx \frac{3\cdot 10^{-27}\, cm^3 s^{-1}}{\langle \sigma v \rangle_{T_c}}$$

- (from N. Weiner)



- Sommerfeld enhancement
- For attractive CoulombPotential

$$S_k \sim \left|\frac{\epsilon_v^{1/2} \alpha M}{M v}\right|^2 = \frac{\alpha}{v}$$

- To enhance the dark matter annihilation we have long range attractive force

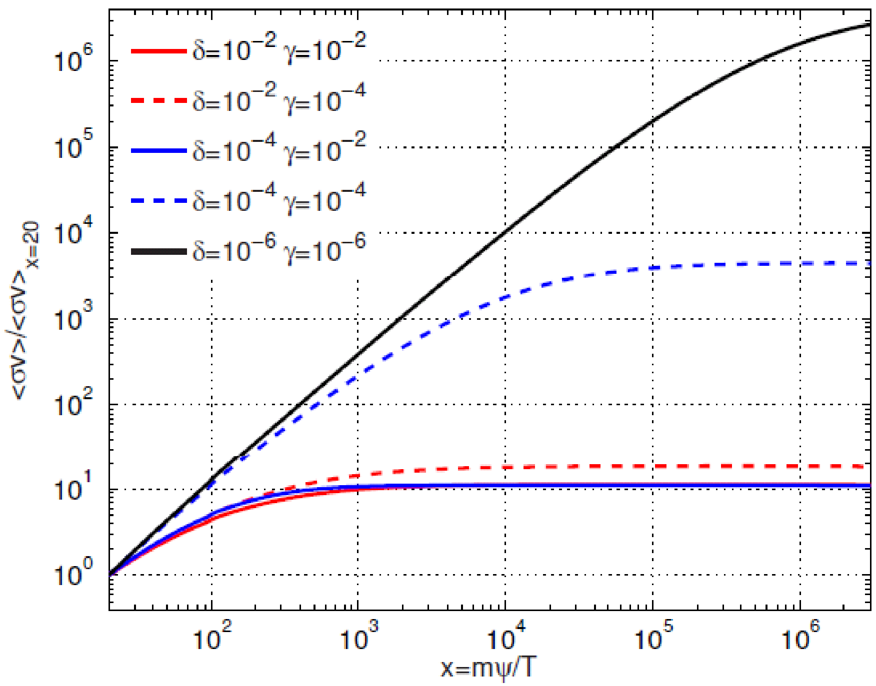
$$m_\phi^{-1} \gtrsim (\alpha M_{DM})^{-1}$$

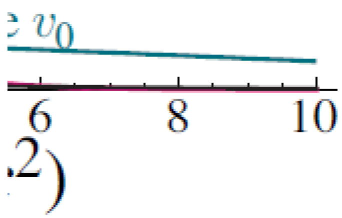
Ibe, Murayama, Yanagida

Guo, Wu

Large flux

Breit-Wigner enhancement, $$\sigma = \frac{16\pi}{E_{cm}^2 \bar{\beta}_i \beta_i} \frac{M^2\Gamma^2}{(E_{cm}^2 - M^2)^2 + M^2\Gamma^2} B_i B_f,$$





The Breit-Wigner enhanced relative cross section $\langle \sigma v\rangle / \langle \sigma v\rangle_{x=20}$ as a function of time x.

Bi, He, Yuan 0903.0122

Decay dark matter with life time 10^{26}s

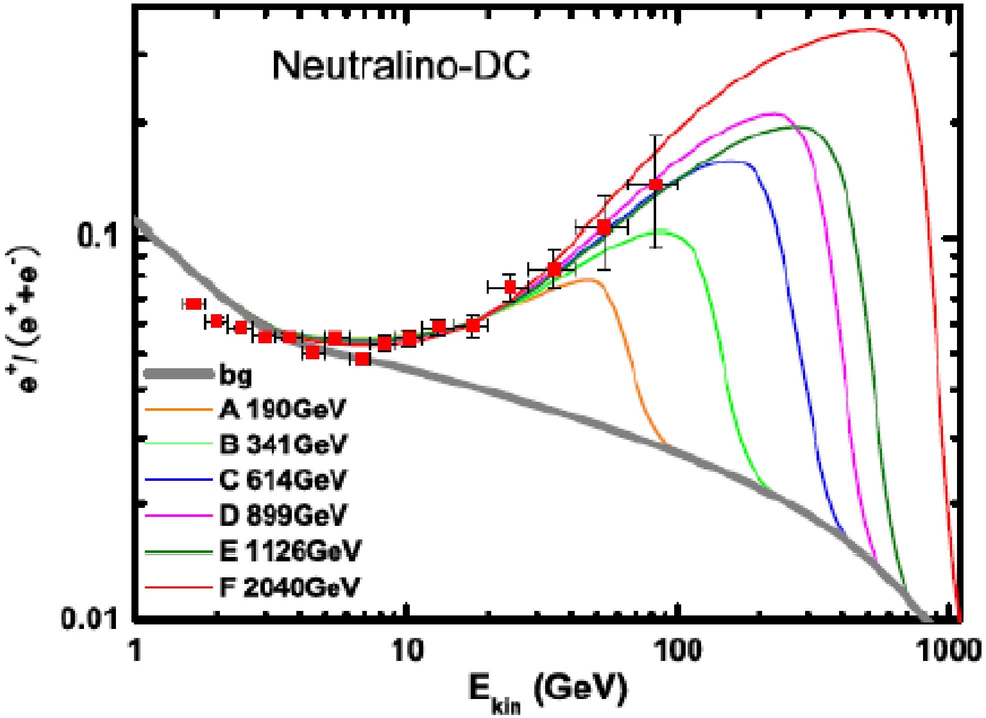
Yin, Yuan, Bi et al.

Ibarra, Tran

Hamguchi, Shirai, Yanagida

	SUSY	MC	Mass(GeV)	$m_0(GeV)$
A	SPS6	bino	190	150
	SUSY	MC	Mass(GeV)	$m_0(GeV)$
B	mSUGRA	bino	341	900
C	mSUGRA	bino	614	1750
D	mSUGRA	bino	899	5000
E	mSUGRA	higgsino	1126	9100
	SUSY	MC	Mass(GeV)	$m_0(GeV)$
F	AMSB	wino	2040	18000

DC	$\tau(10^{26}s)$	$\lambda'(10^{-25})$	DR	$\tau(10^{26}s)$	$\lambda'(10^{-25})$
A	9.1	2.2	A	7.3	2.5
B	5.3	10.3	B	4.3	11.3
C	3.4	11.5	C	2.8	12.4
D	2.5	41.5	D	2.0	46.4
E	2.0	180.1	E	1.7	195.1
F	1.2	113.7	F	1.0	122.8



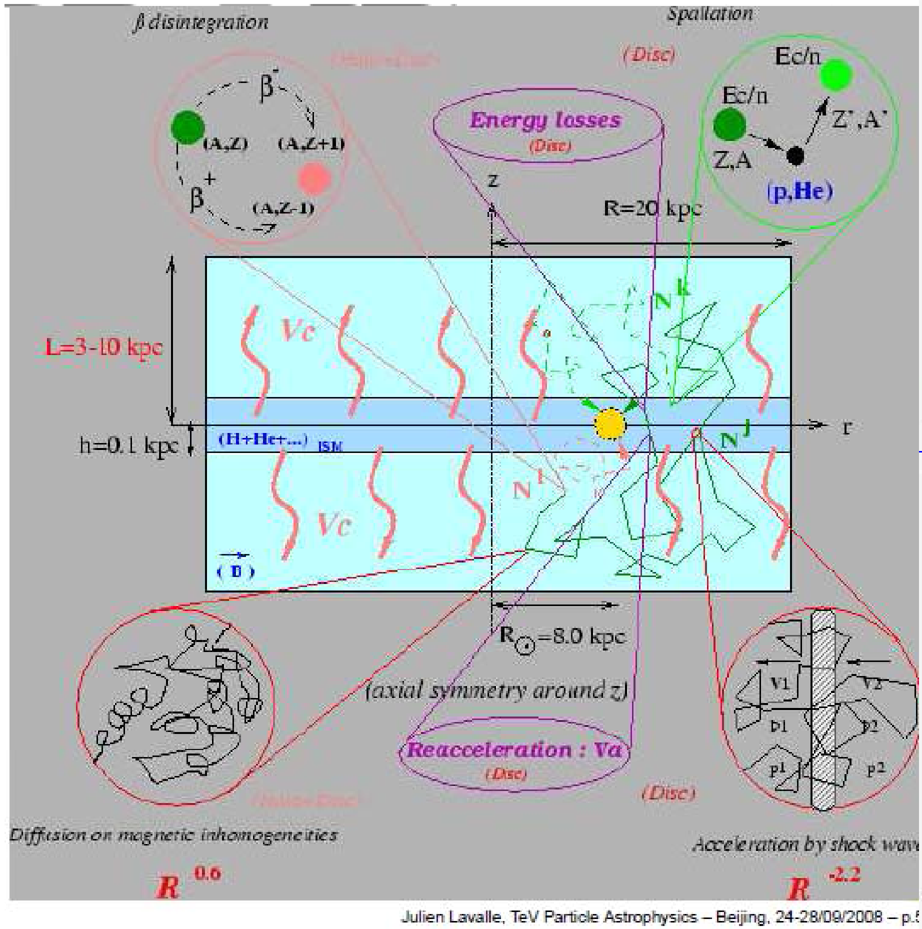
How DM models are constrained by the PAMELA and ATIC data

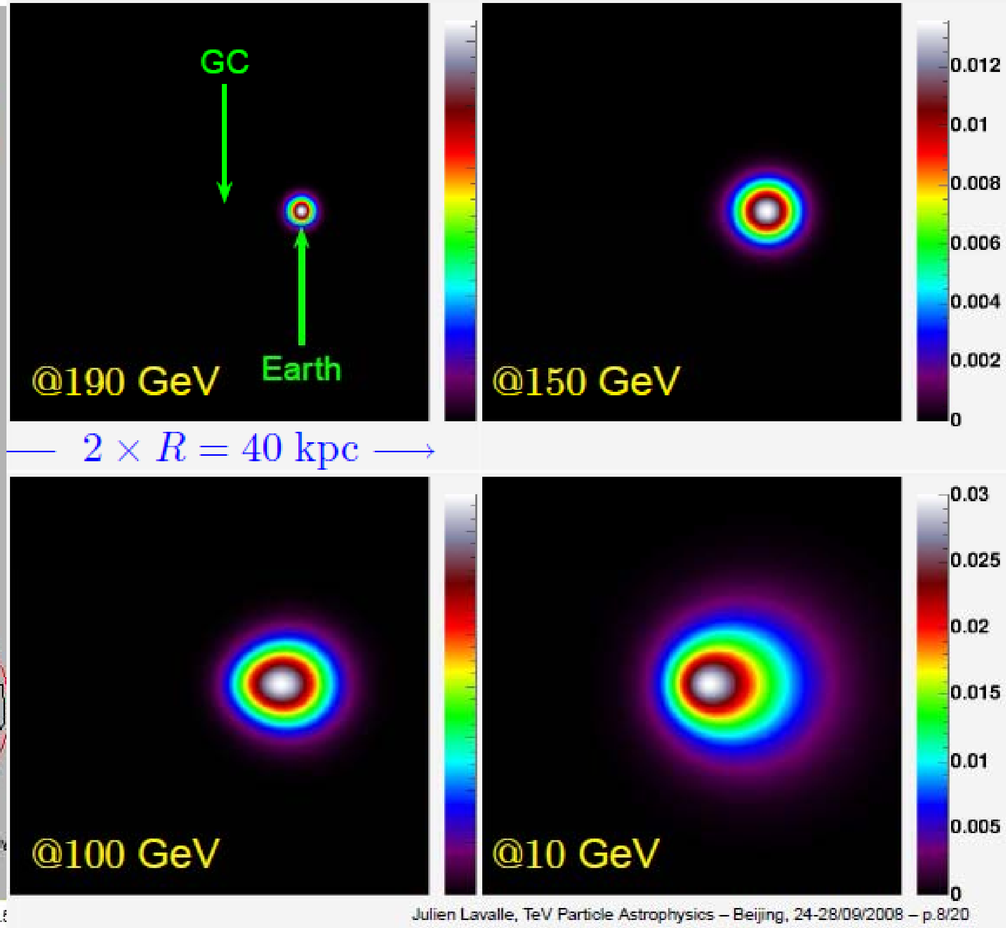
--- branching ratios to gauge bosons and quarks are constrained

Propagation of CRs

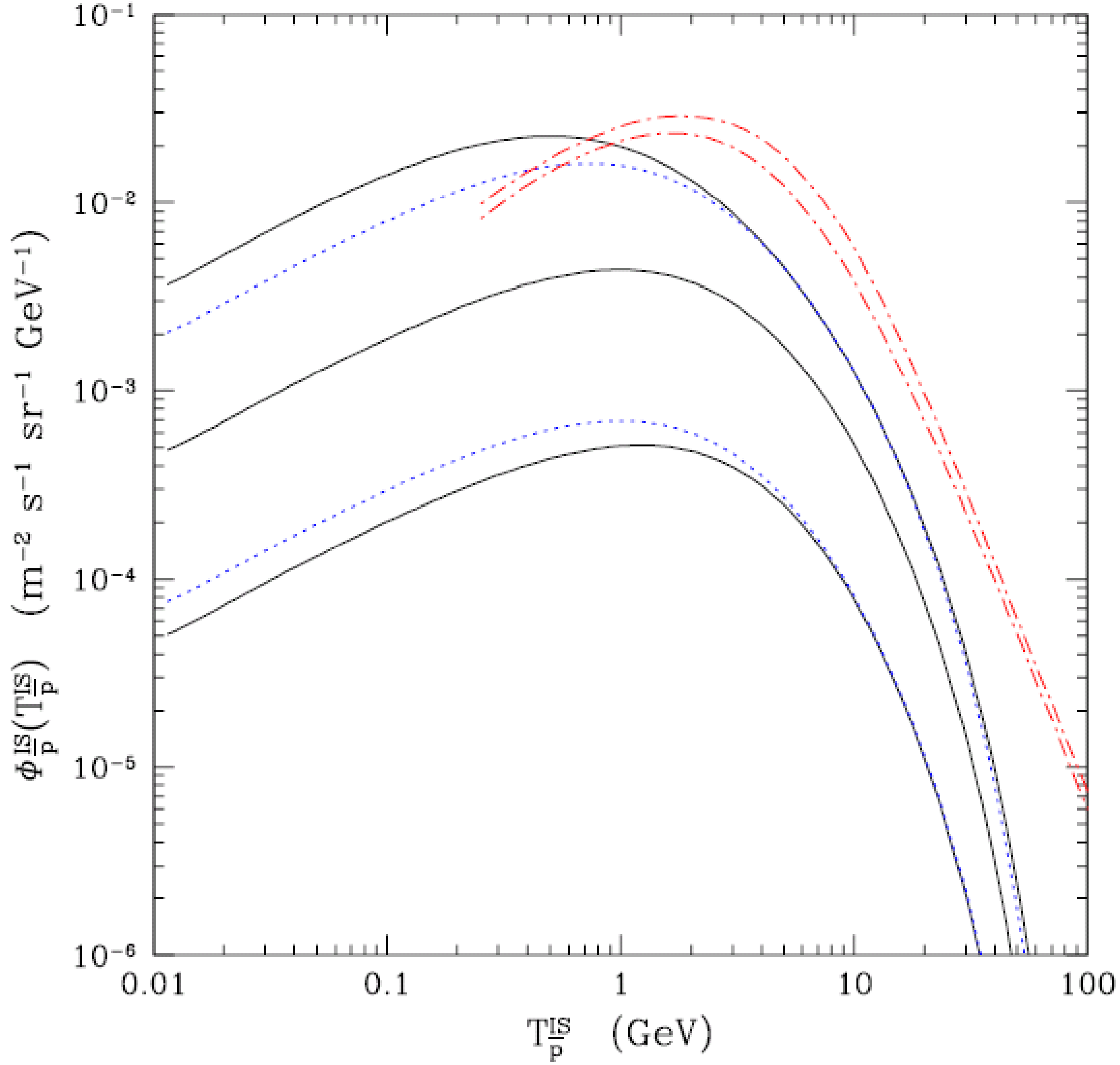
- Due to rapid energy loss of electron/positron the flux measured on Earth comes from nearby regions; antiproton can come from far regions
- Height of diffusion region is a crucial factor; astrophysical sources from the Galactic plane is less affected; however, DM signals will be affected significantly.

From Lavalla





Primary antiproton flux depends on the diffusion region heavily



F. Donato et al. 2003

For L=1, 4, 15kpc

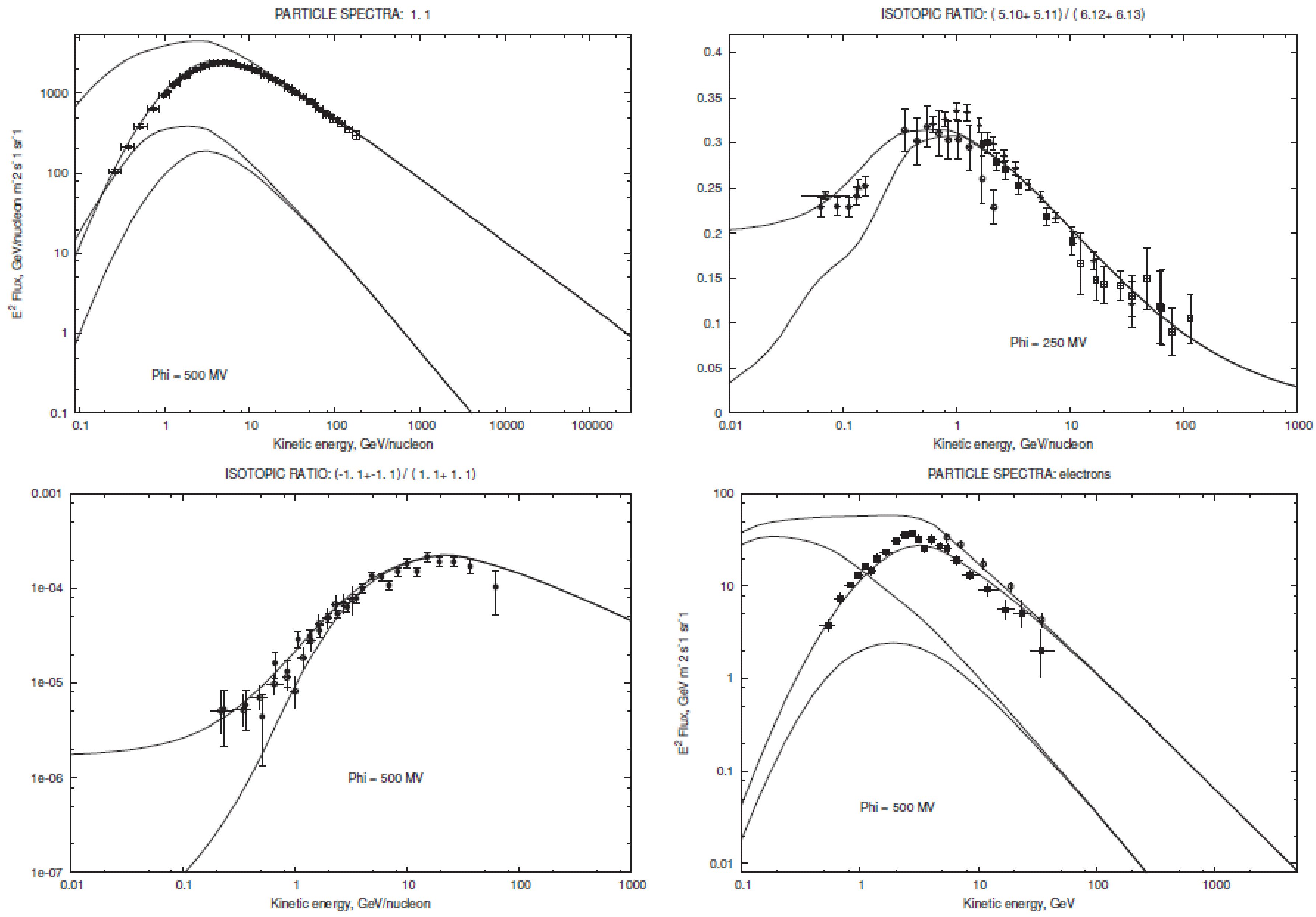
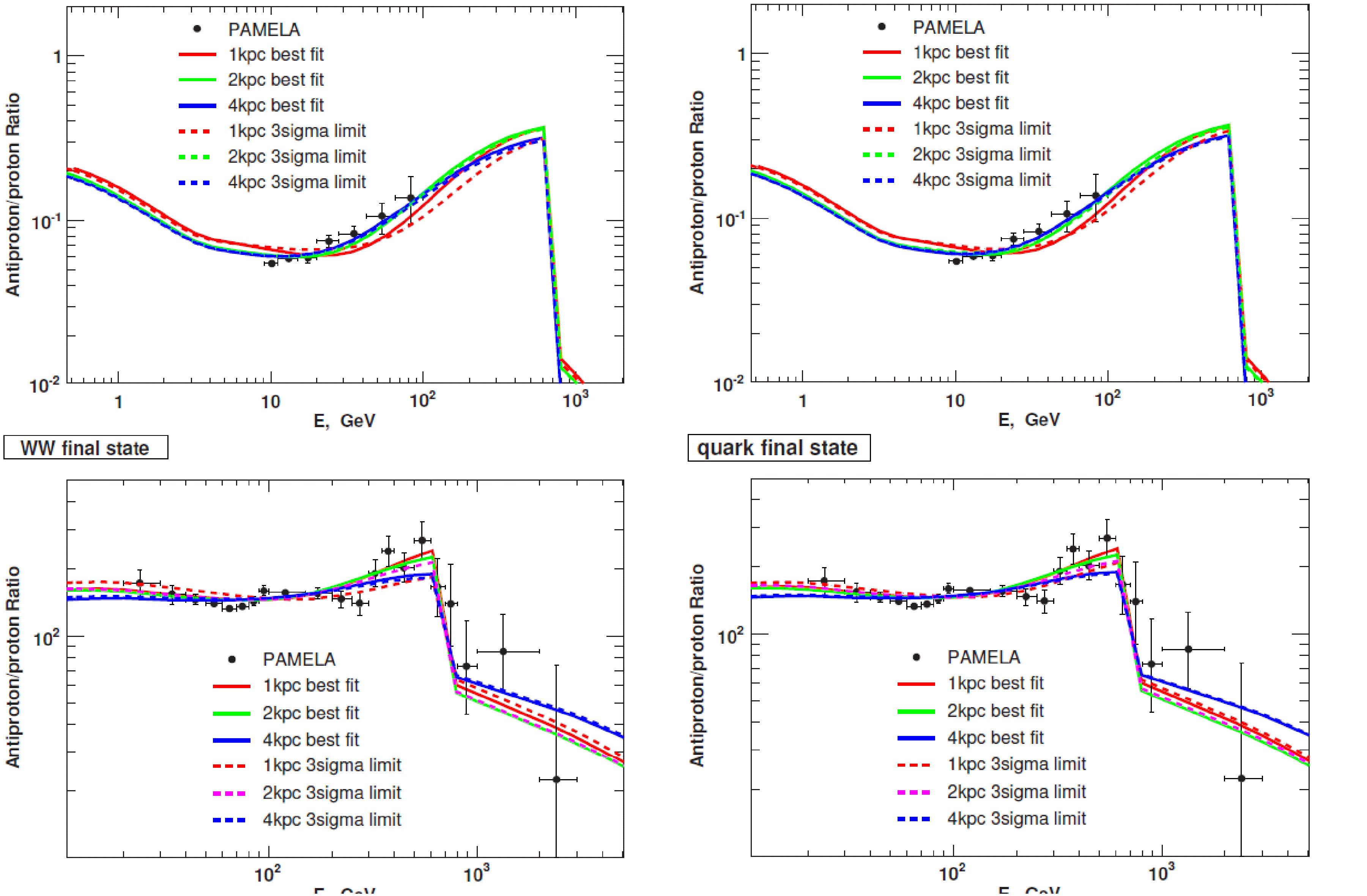


Figure 3: The background predictions of 4 kpc model.

Give good fits to PAMELA and ATIC results with WW quark branchs



Upper bounds on the WW and quark branching ratios for M_{DM}=1TeV

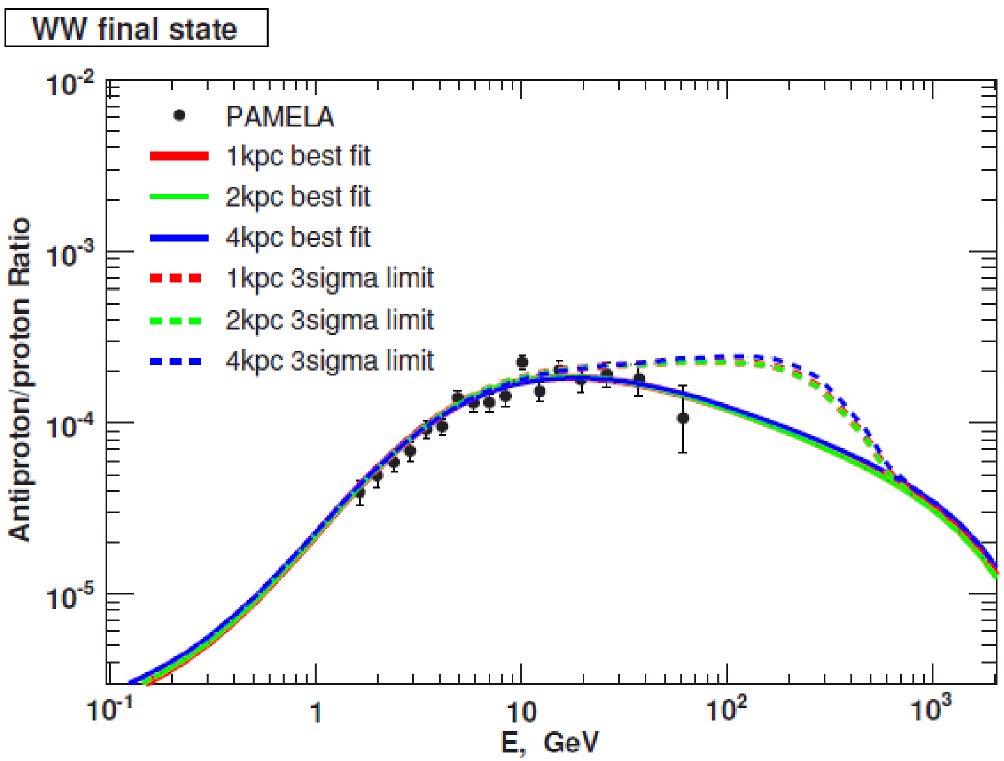
Table 3: Results for ww and lepton final state

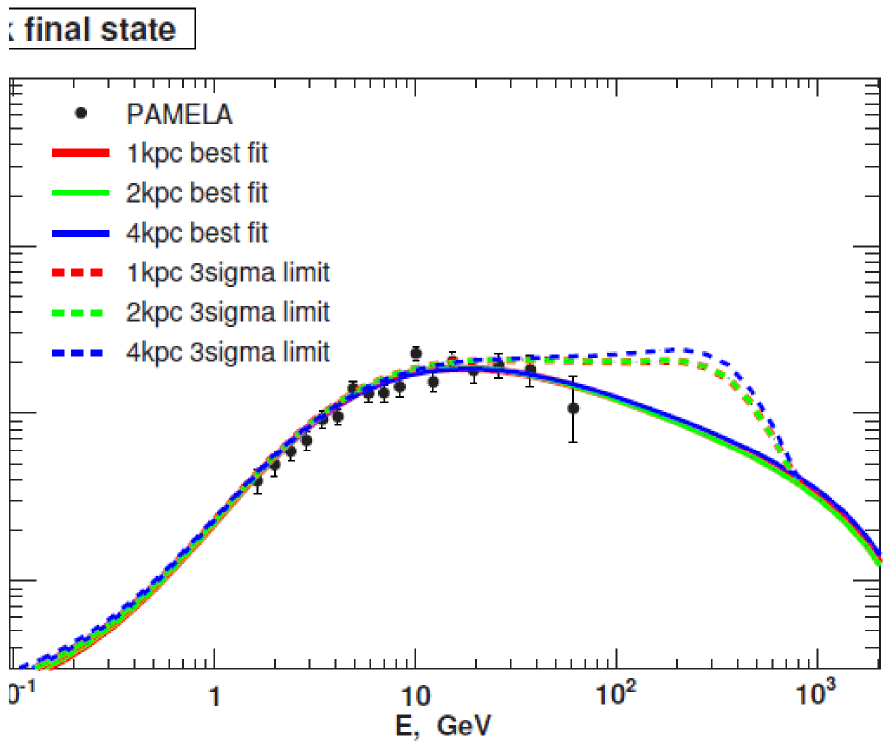
ww	1kpc	2kpc	4kpc
$\bar{p}/p\ \chi^2_{min}/(N-1)$	19.63/16	19.63/16	18.65/16
Br_{ww}, best fit	0.00%	0.00%	0.00%
Br_{ww}, C.L. 68.3%	15.51%	7.09%	3.81%
Br_{ww}, C.L. 95.5%	34.20%	15.83%	8.05%
Br_{ww}, C.L. 99.7%	51.27%	23.46%	12.29%

Table 5: Results for quark-pair and lepton final state

quark	1kpc	2kpc	4kpc
$\bar{p}/p\ \chi^2_{min}/N$	19.63/16	19.63/16	18.65/16
Br_{quark}, best fit	0.00%	0.00%	0.00%
Br_{quark}, C.L. 68.3%	7.33%	3.60%	2.01%
Br_{quark}, C.L. 95.5%	19.91%	10.04%	5.07%
Br_{quark}, C.L. 99.7%	32.01%	16.64%	8.17%

For antiprotons with M_{DM}=1TeV





Constraints on some DM models (~1TeV)

- Neutralino, mainly into gauge bosons; excluded
- In UED KK mode of $U(1)_Y$ gauge boson, ~30% into quarks; marginally allowed
- Leptophilic models $U(1)'_{e\text{-}mu(tau)}$, best fit data
- $U(1)'_{B\text{-}L}$, ~40% into quarks, slightly disfavored

For DM=300GeV

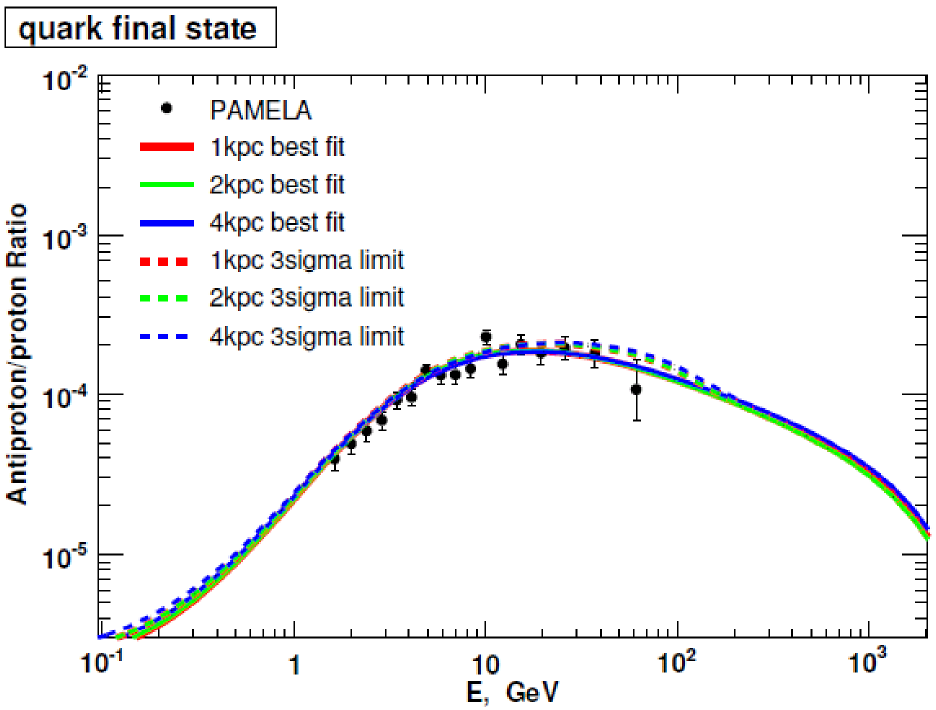
Table 3: Results for ww and lepton final state with DM=300 GeV

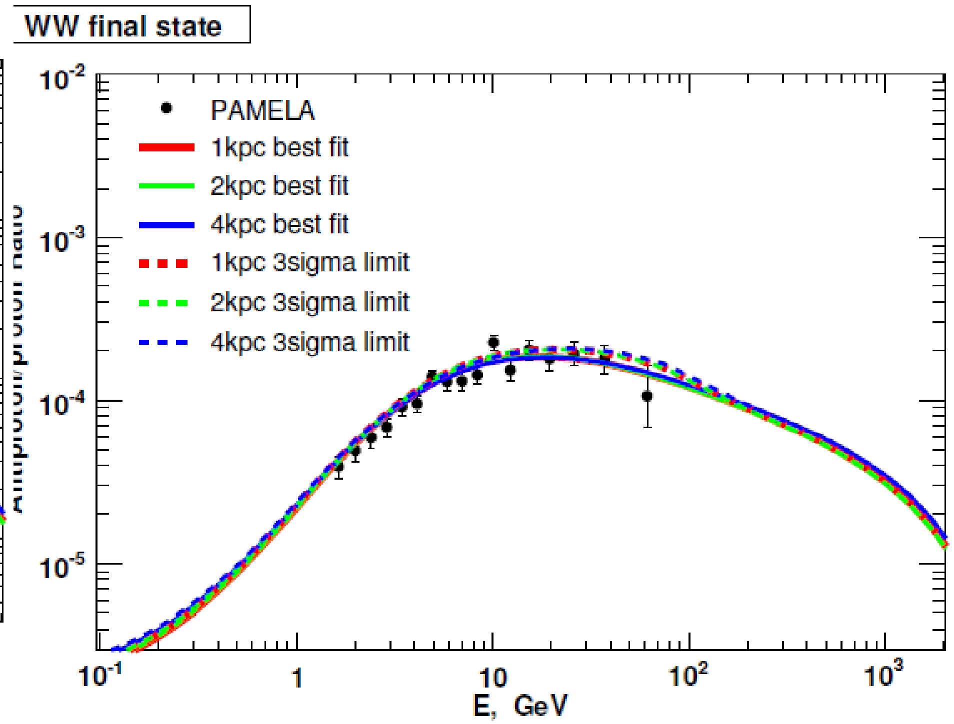
ww	1kpc	2kpc	4kpc
$\bar{p}/p\ \chi^2_{min}/(N-1)$	19.63/16	19.63/16	18.65/16
Br_{ww}, best fit	0.00%	0.00%	0.00%
Br_{ww}, C.L. 68.3%	3.24%	2.40%	1.47%
Br_{ww}, C.L. 95.5%	9.32%	7.08%	3.96%
Br_{ww}, C.L. 99.7%	15.46%	12.07%	6.46%

Results for quark-pair and lepton final state with DM=300GeV

quark	1kpc	2kpc	4kpc
$\bar{p}/p\ \chi^2_{min}/N$	19.63/16	19.63/16	18.65/16
Br_{quark}, best fit	0.00%	0.00%	0.00%
Br_{quark}, C.L. 68.3%	2.84%	2.14%	1.27%
Br_{quark}, C.L. 95.5%	8.17%	6.23%	3.43%
Br_{quark}, C.L. 99.7%	13.53%	10.49%	5.62%

For DM=300GeV





- SUSY, UED DM models are excluded nearly only leptonic dark matter models are permitted.

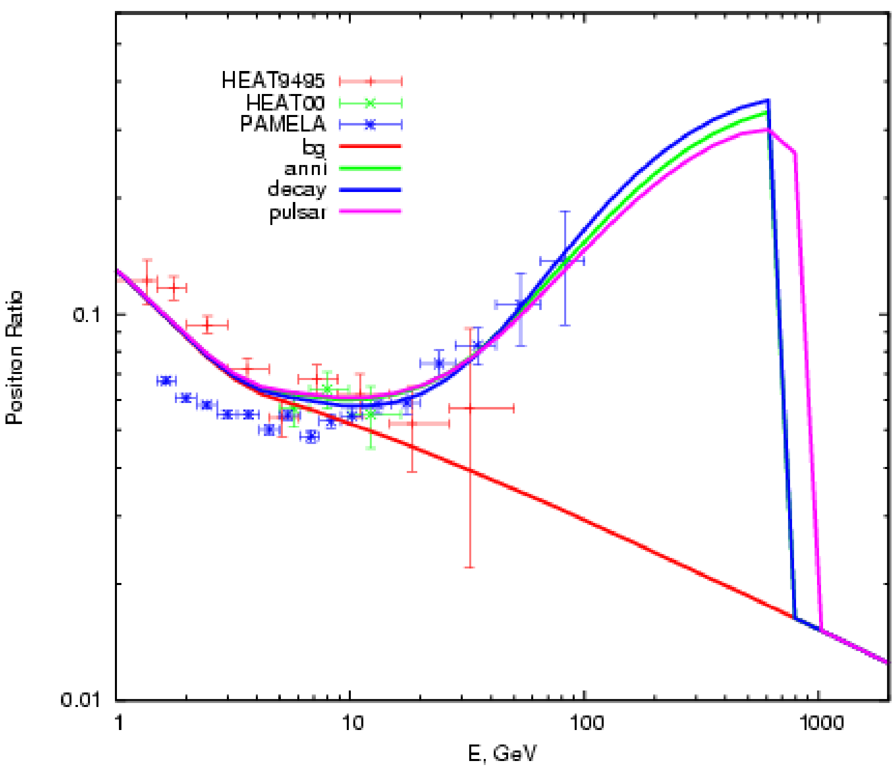
Radiations from these primary electrons/positrons to account for PAMELA and ATIC data

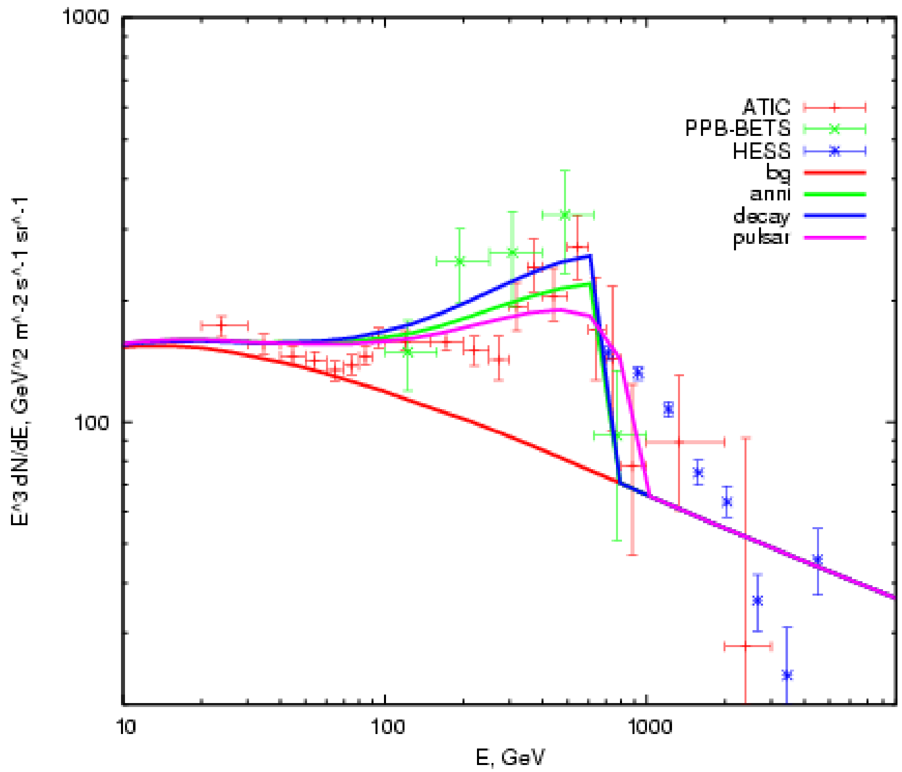
--- how to discriminate different scenarios?

Different models can work well

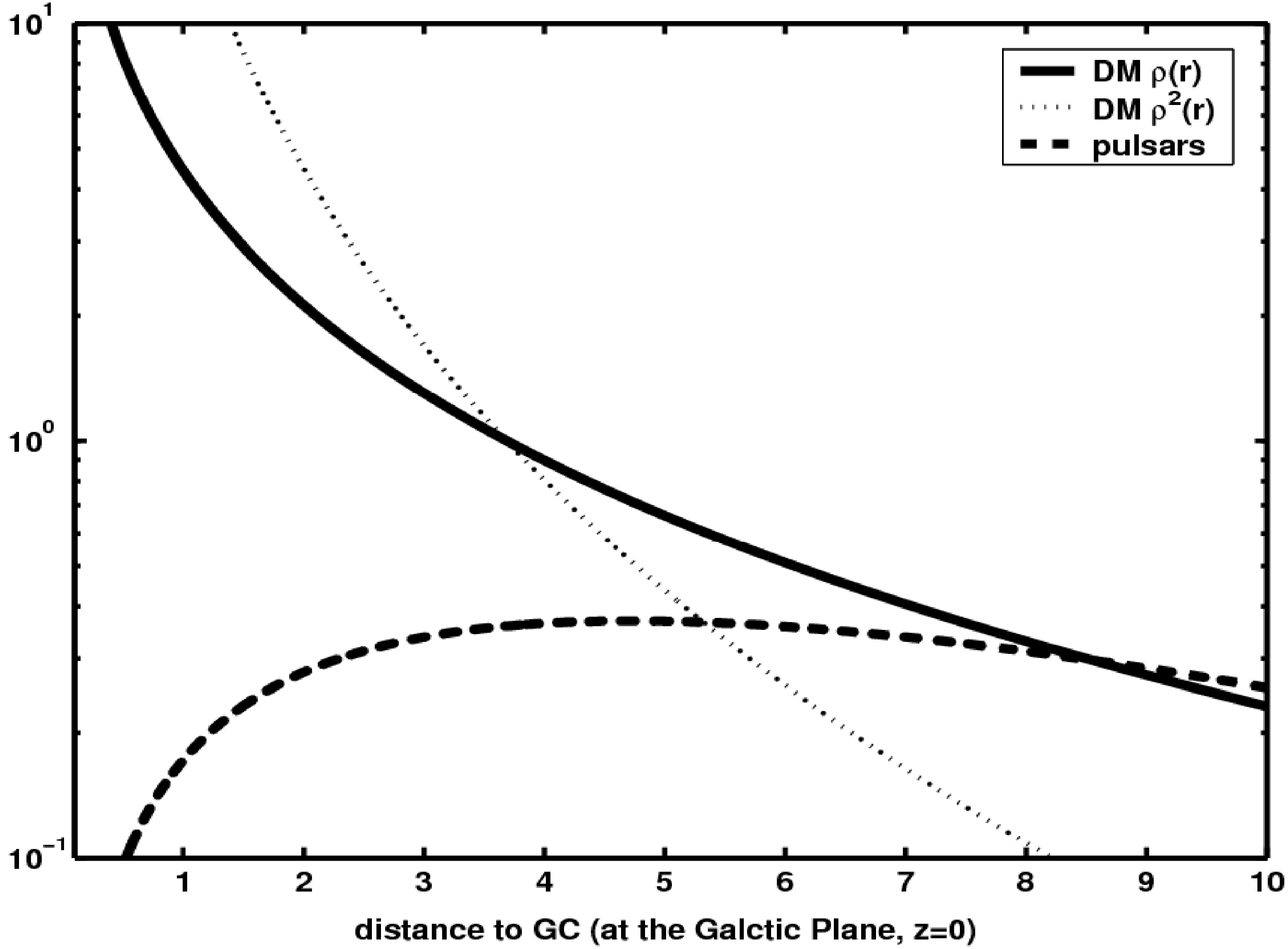
- Adjusting parameters, DM decay/annihilation, pulsars can all explain PAMELA and ATIC

Zhang, Bi, et al. 0812.0522





Source distribution

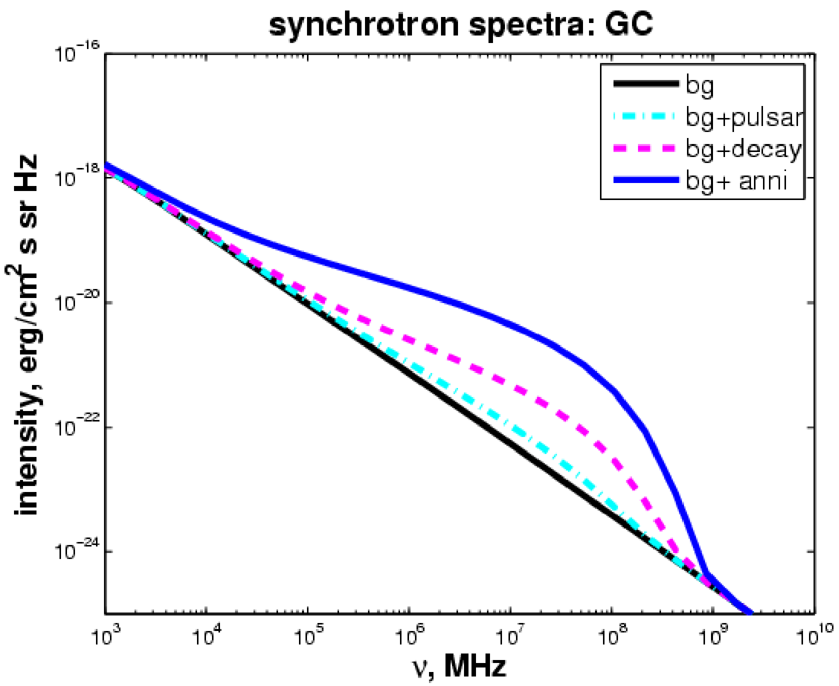


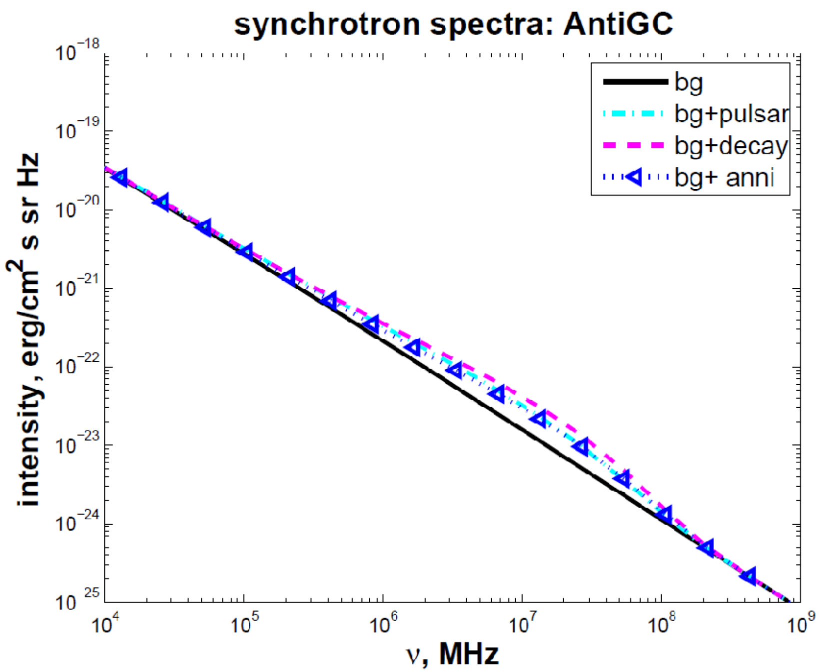
Galactic Pulsar source

- $$Q_P(R, z, E) = K \cdot f(R, z) \cdot \left.\frac{dN}{dE}\right|_P$$
- $$f(R, z) \propto \left(\frac{R}{R_\odot}\right)^a e^{-\frac{b(R-R_\odot)}{R_\odot}} e^{-\frac{|z|}{z_s}}$$, a=1.0,b=1.8
- $$\frac{\mathrm{d}N}{\mathrm{d}E} \sim E^{-\alpha}$$, α ~1.2, Ec~1TeV,

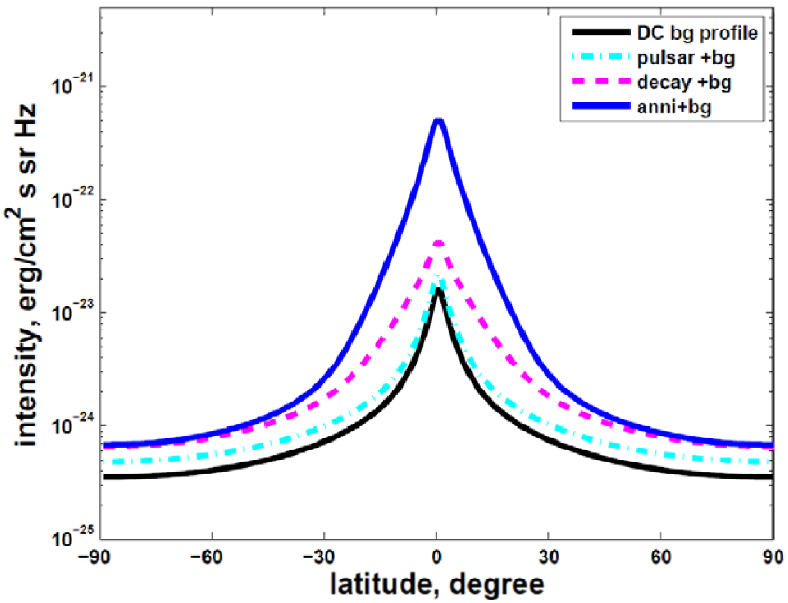
Can we test these scenarios?

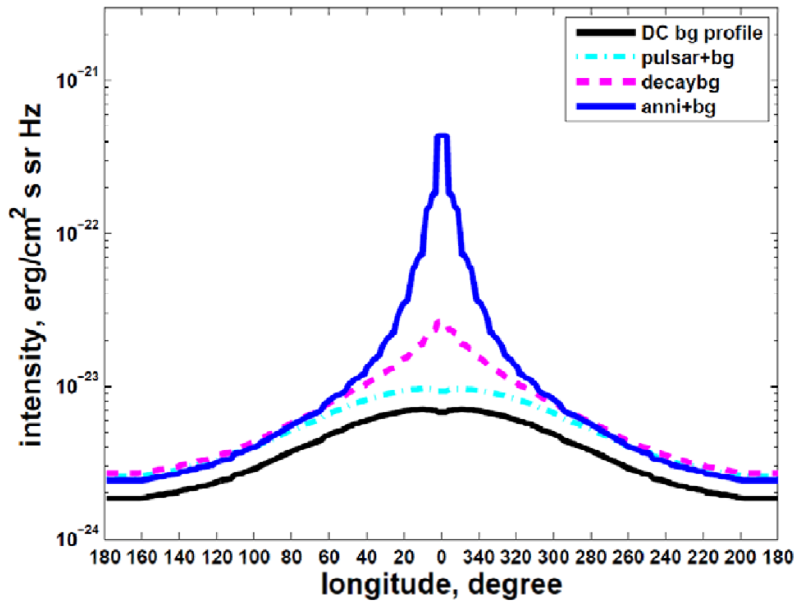
- Detect the synchrotron and IC gamma ray signals from the GC.

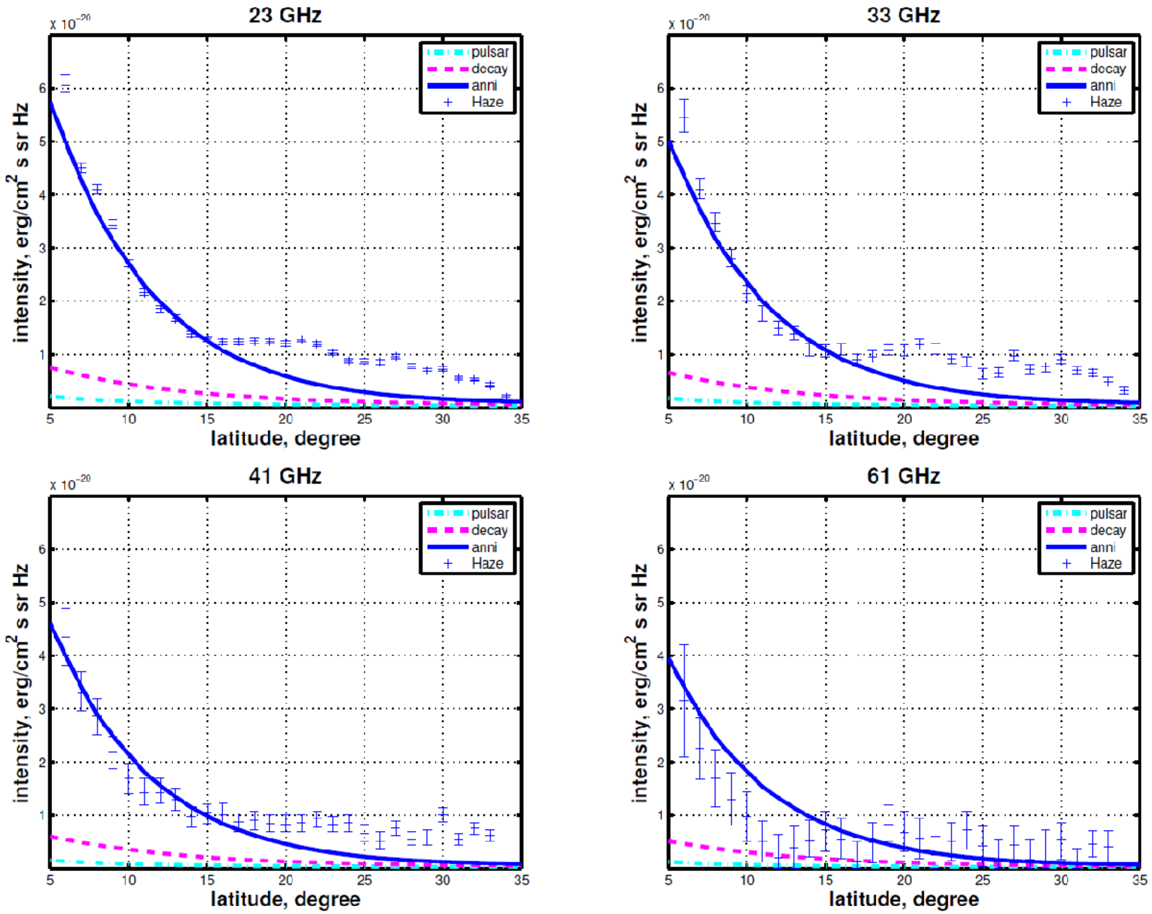




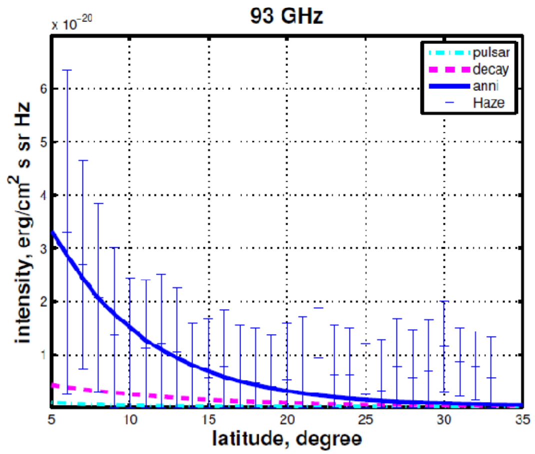
Synchrotron Profiles:



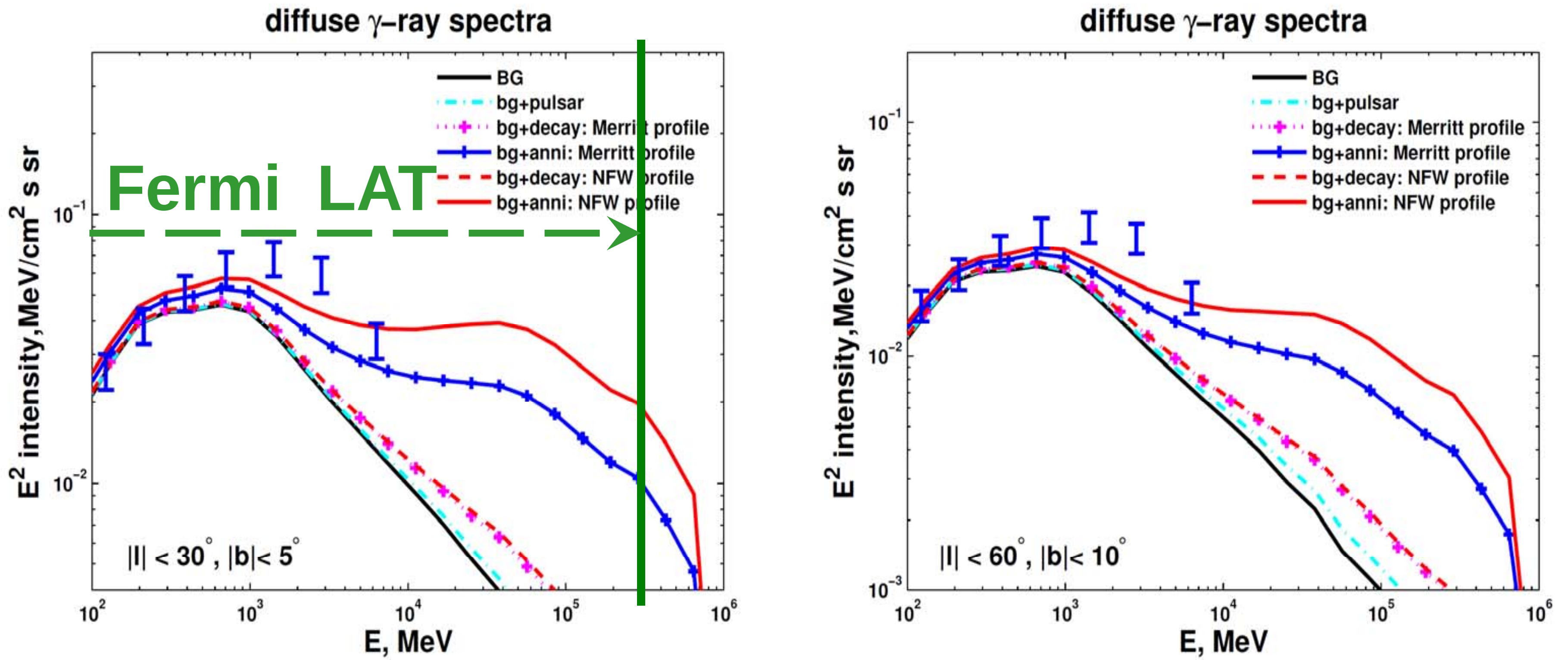




Compared with Haze data:

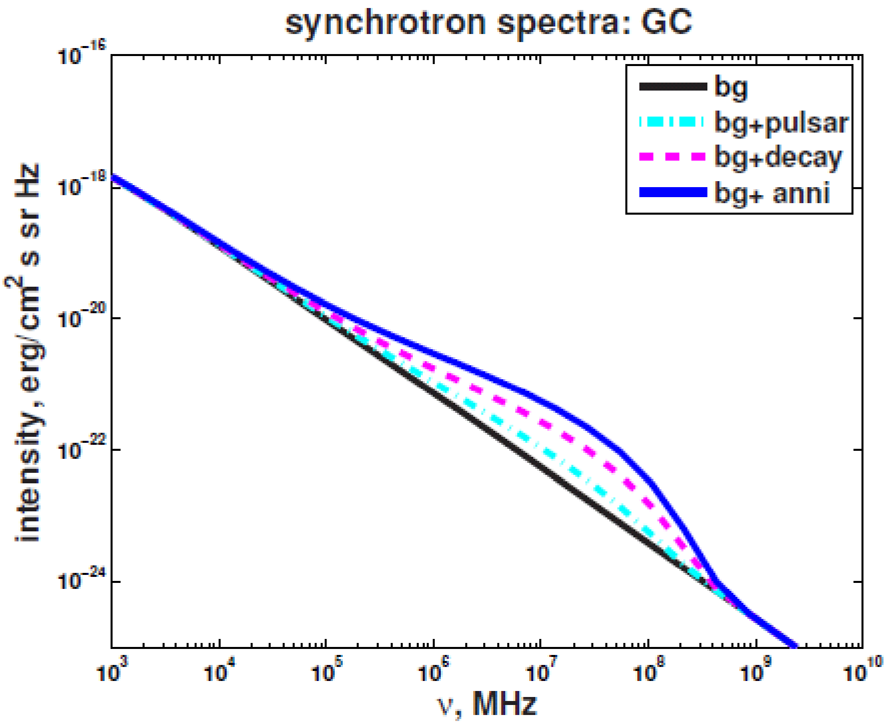


Diffuse gamma spectra:



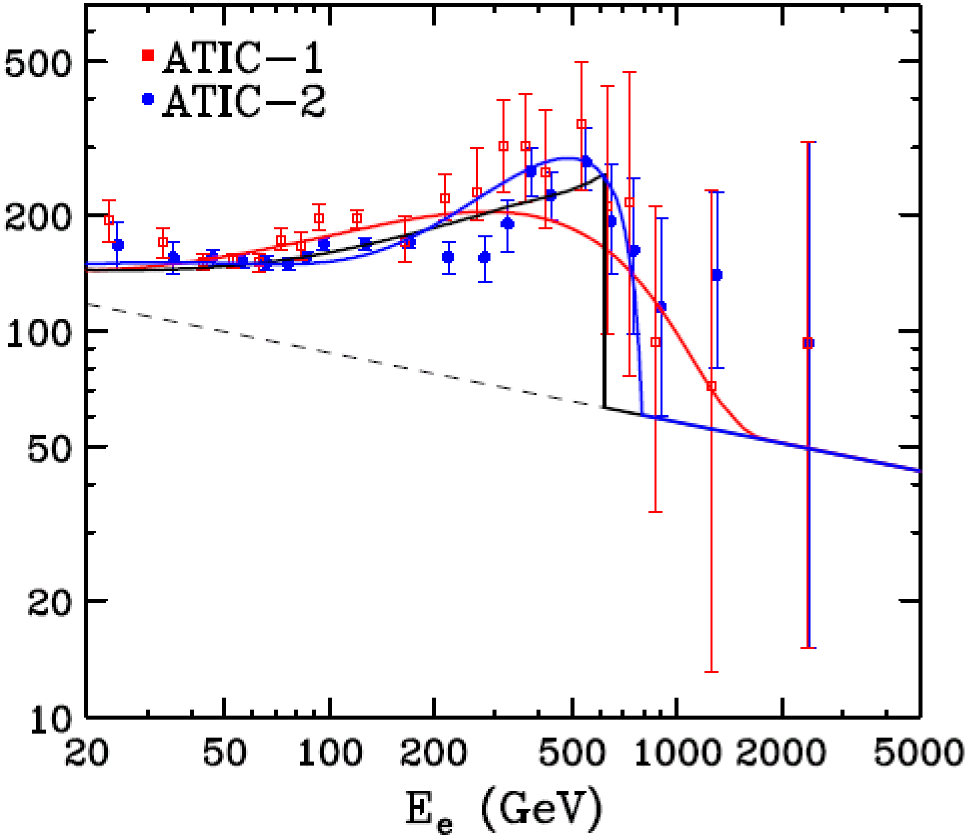
Uncertainties of the prediction

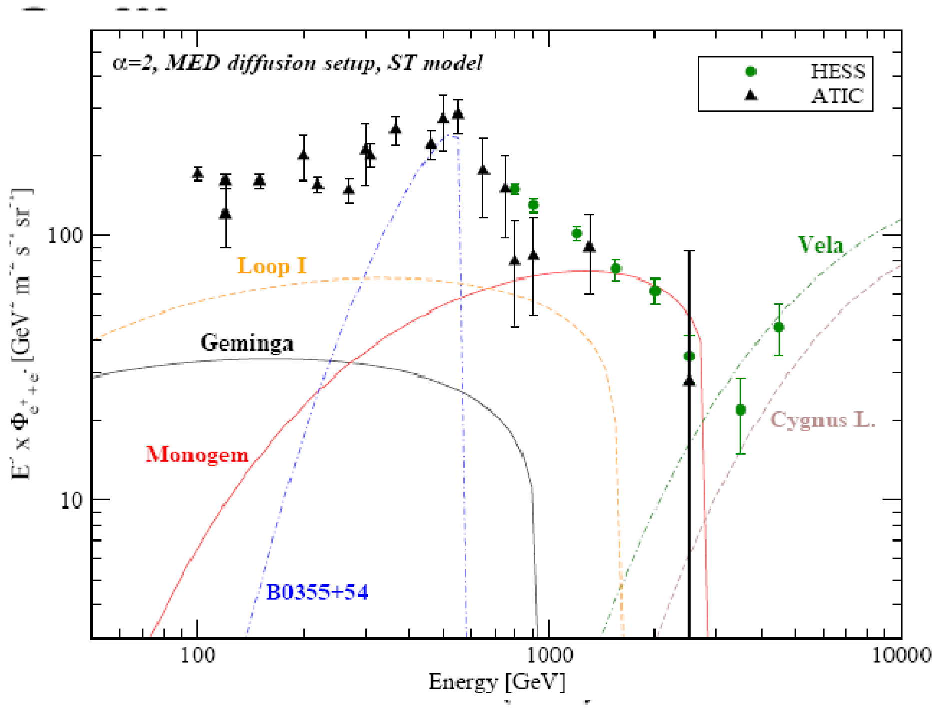
- Particle physics models
- Propagation models
- Dark matter profiles
- Sources of boost fac



Discrimination I. precise spectrum measurement of e^+e^-

Dark matter vs. pulsar: sharp drop or not? (Hall & Hooper, 0811.3362)

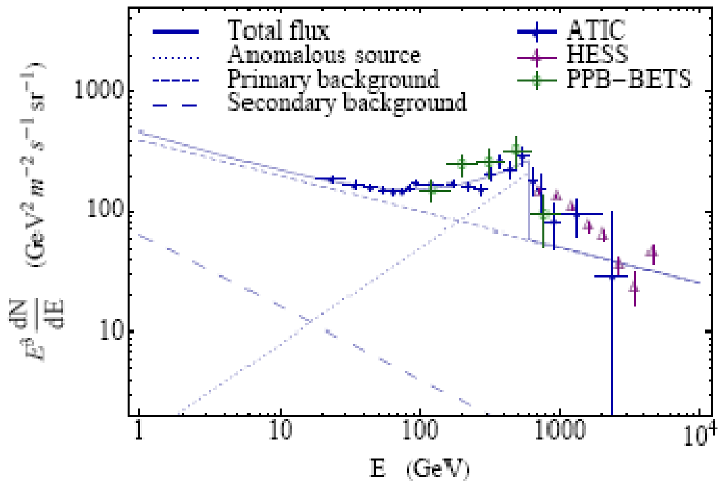


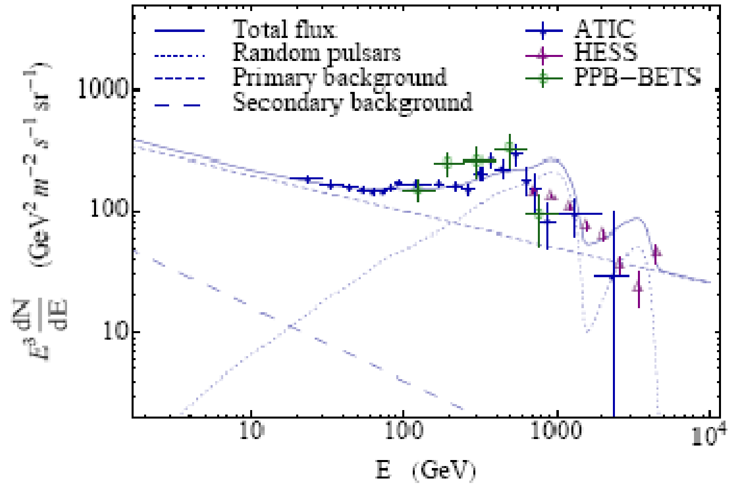


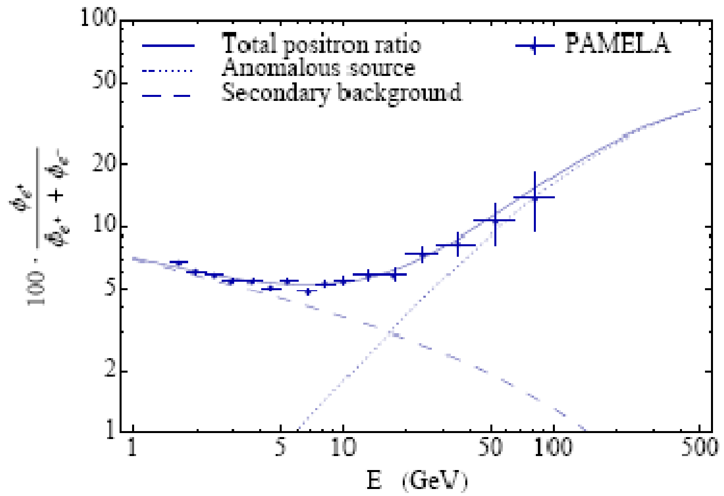
ɔwever, pulsars can also result in sharp cut in some cases (Profumo, 0812.4457)

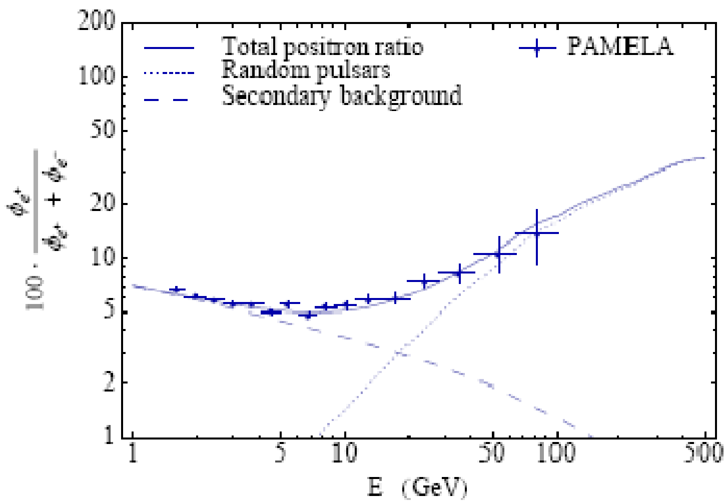
Discrimination I. precise electron spectrum (continued)

Dark matter vs. pulsar: fluctuations on the spectrum? (Malyshev et al., 0903.1310)



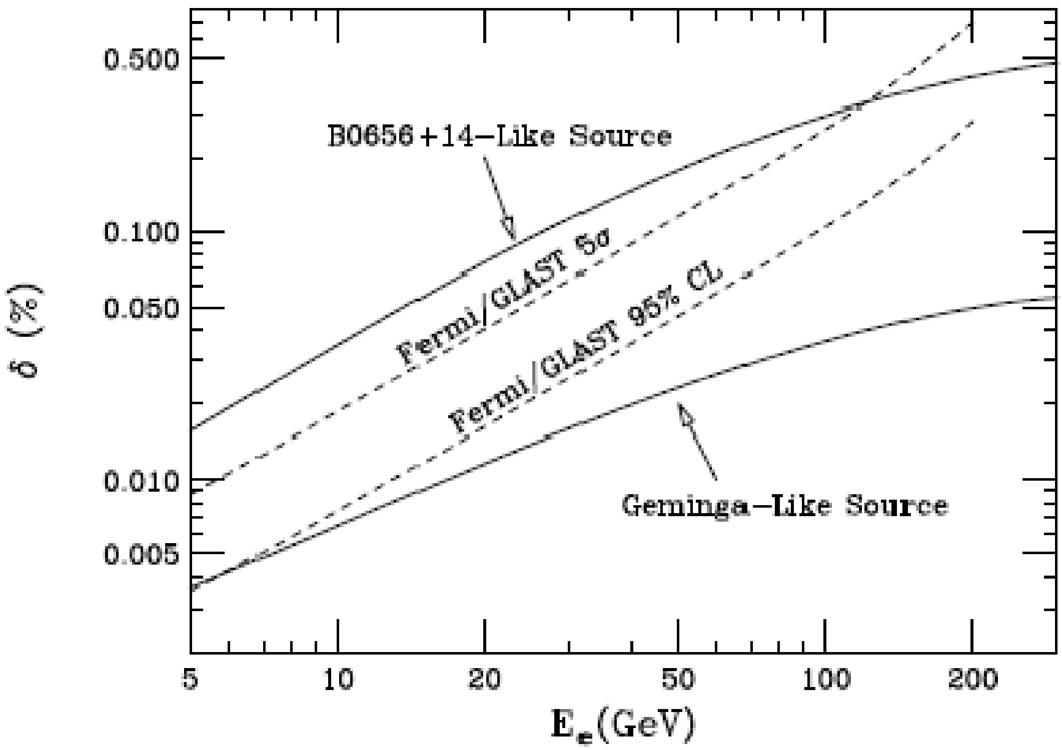






Discrimination II. anisotropy of electron flux

Diffuse vs. point (Hooper et al., 2009, JCAP, 01, 025)



A local dark matter clump may also behave like this.

Summary

- ATIC and PAMELA data stimulated a lot of interests; many models are proposed.
- From the data, strict bounds on the DM annihilation products can be set, if the ATIC PAMELA anomalies are from DM.
- Ways to discriminate different scenarios to account for the data are proposed. Study the radiation from the GC may be a viable way.