Cosmic $e^{+/-}$ excess and its possible origins and implications

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Tainan, Taiwan

- *O. Adriani et al., PAMELA Collaboration, arXiv:0810.4995 [221]*

  An anomalous positron abundance in cosmic rays with energies 1.5-100 GeV

- *O. Adriani et al., PAMELA Collaboration, arXiv:0810.4994 [118]*

  A new measurement of the antiproton-to-proton flux ratio up to 100 GeV in the cosmic radiation

- *J. Chang et al., ATIC Collaboration, Nature 456, 362 (2008) [147]*

  An Excess of Cosmic Ray Electrons at Energies Of 300-800 GeV

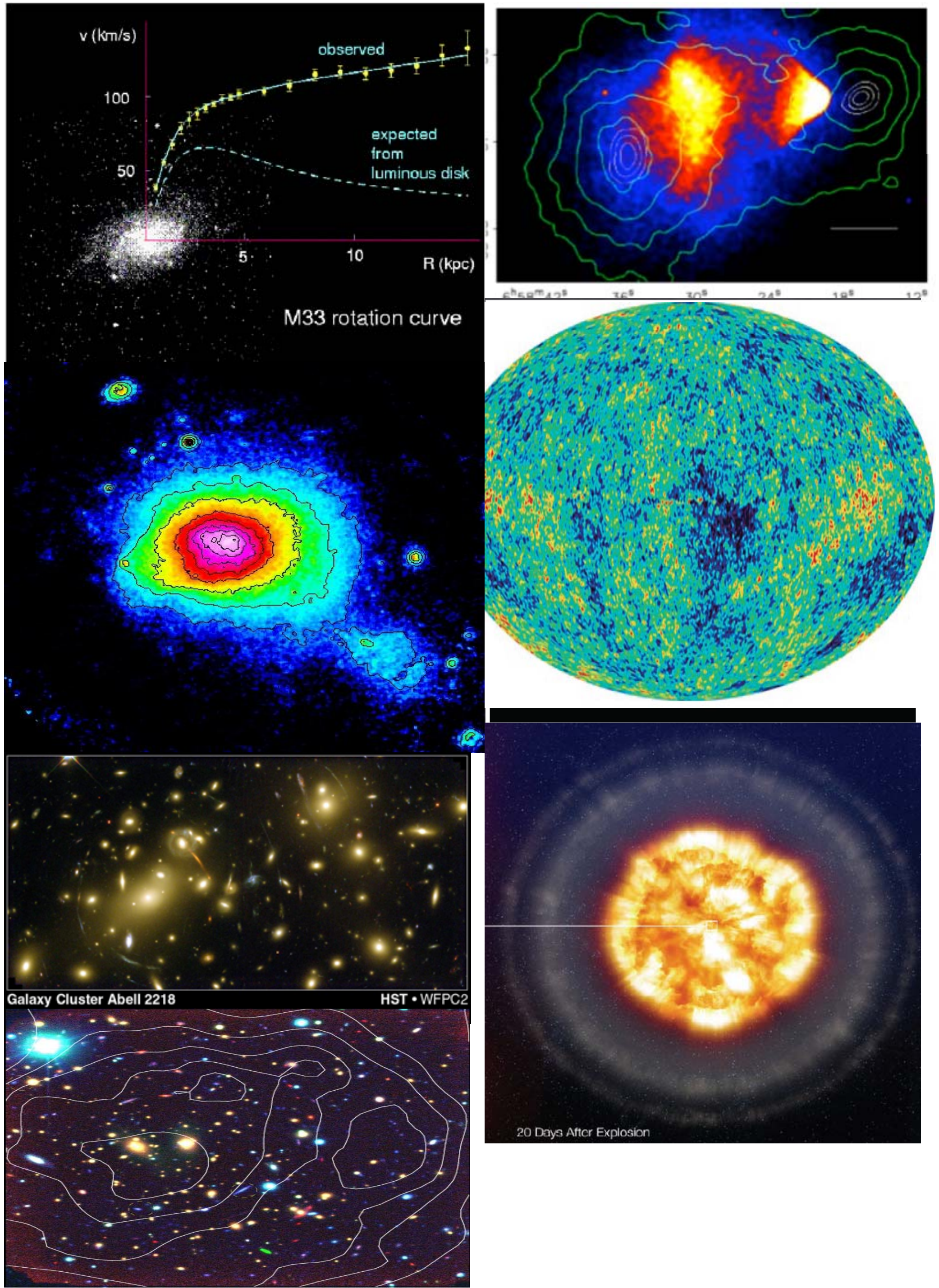
- *HESS Collaboration, arXiv:0811.3894 [59]; arXiv:0905.0105 [12]*

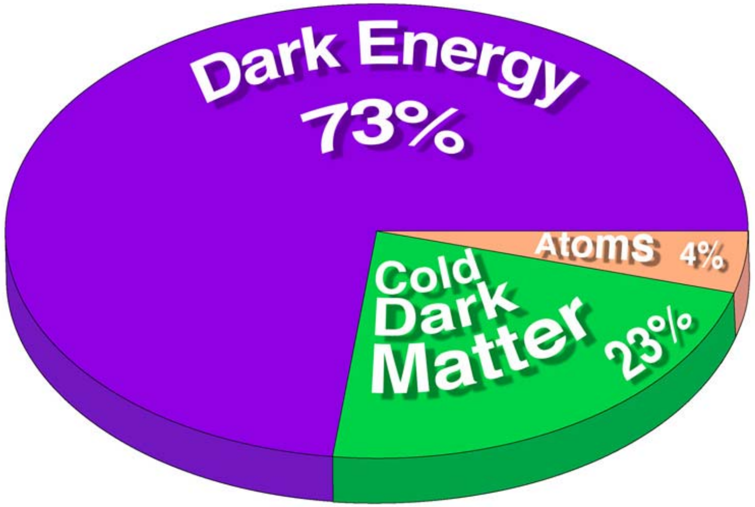
  Probing the ATIC peak in the cosmic-ray electron spectrum with H.E.S.S

- *Fermi Collaboration, arXiv:0905.0025 [18]*

  Measurement of the Cosmic Ray e+ plus e- spectrum from 20 GeV to 1 TeV with the Fermi Large Area Telescope

Standard cosmology

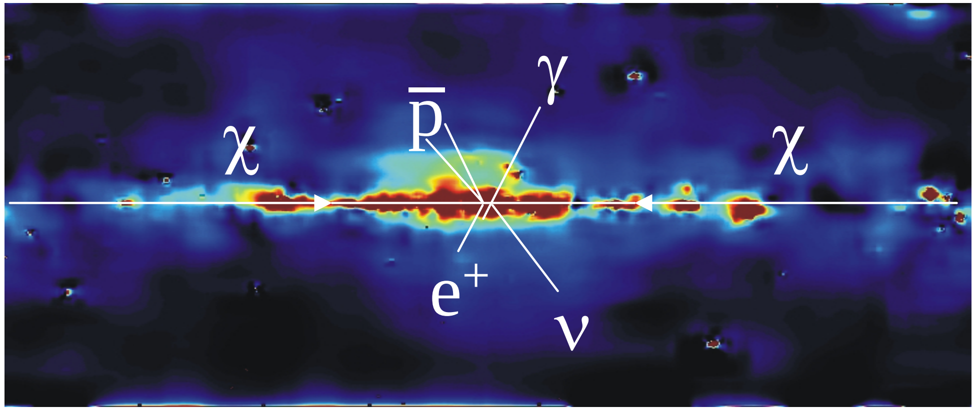




Dark matter (dark energy) exists in the universe. However, we have to figure out its property.

Detection of WIMP

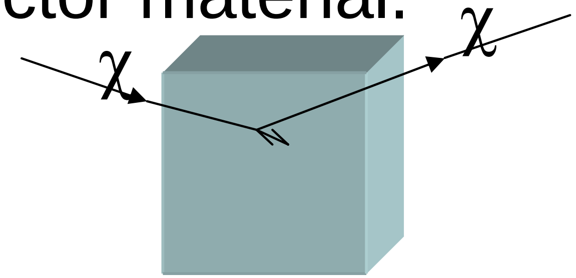
- Indirect detection DM increases in Galaxies, annihilation restarts($\propto \rho^2$); ID looks for the annihilation products of WIMPs, such as the neutrinos, gamma rays, positrons at the ground/space-based experiments



indirect detection

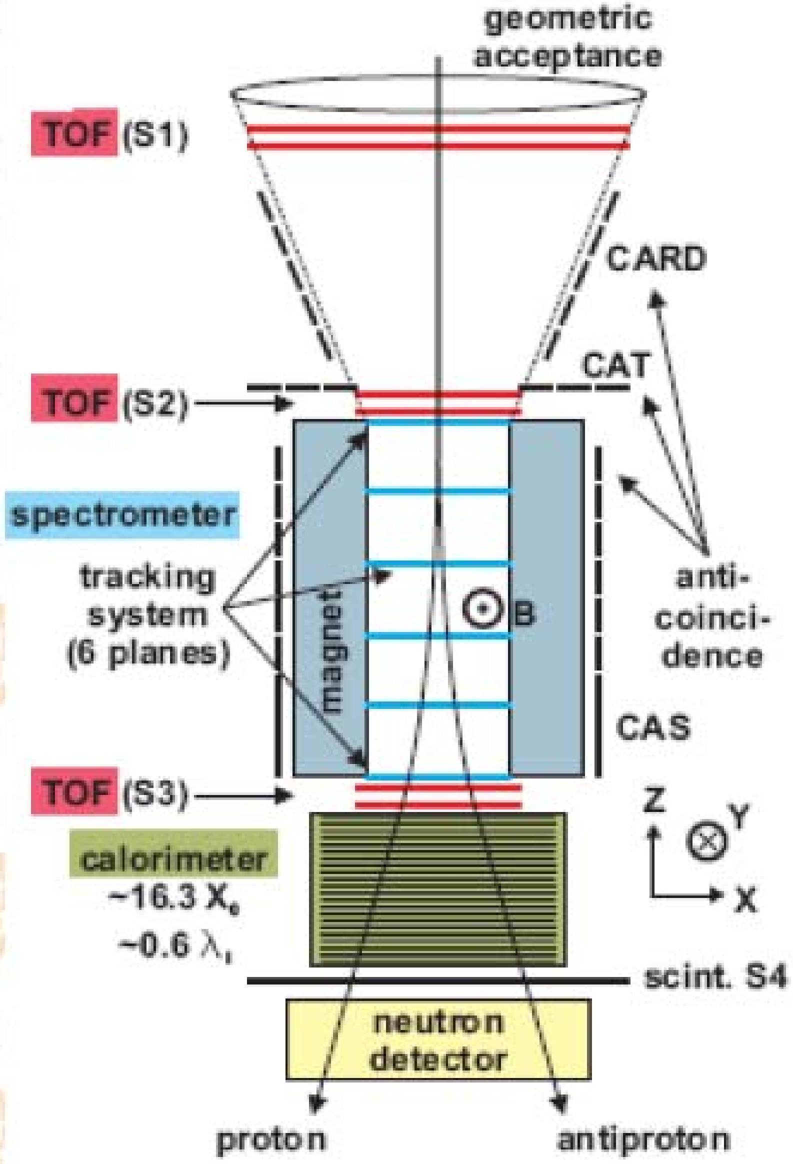
- Direct detection of WIMP at terrestrial detectors via scattering of WIMP of the detector material.

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



Direct detection

PAMELA detection ability



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

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

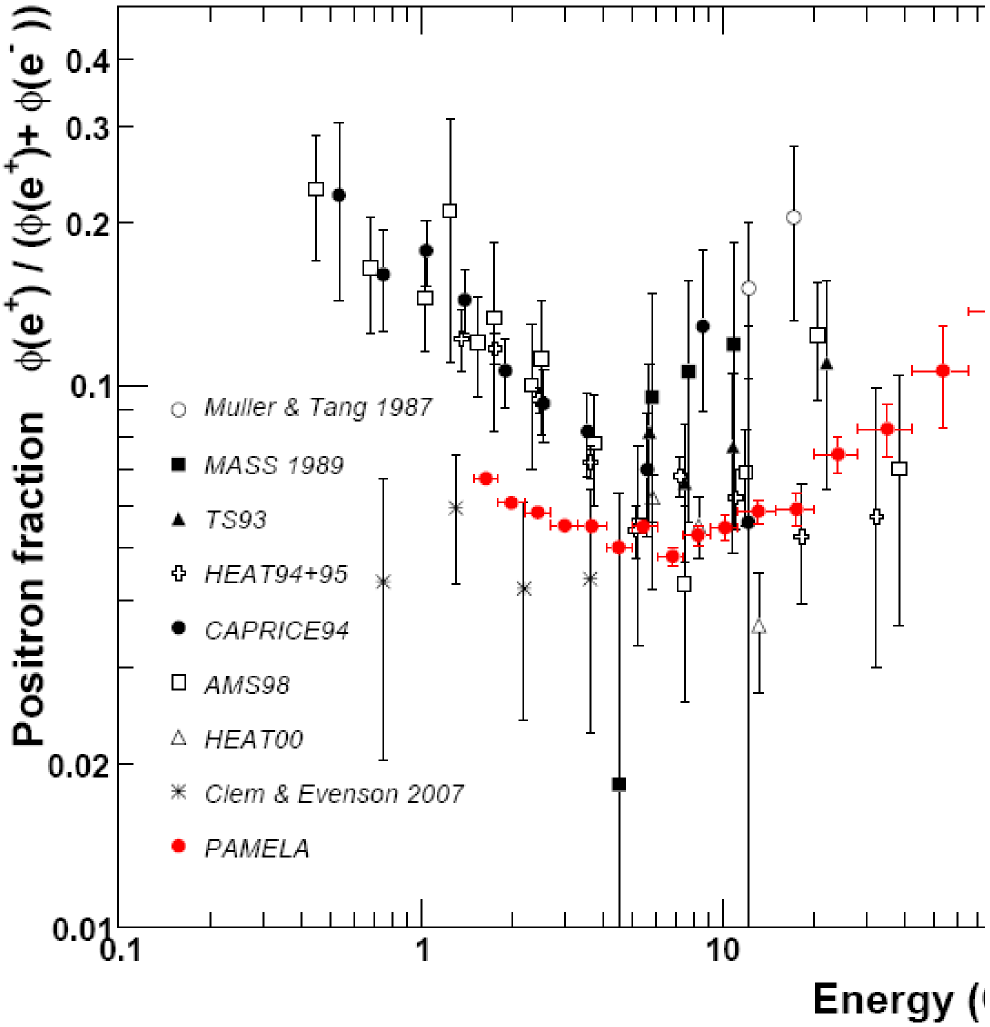
$$80MeV < \overline{p} < 190GeV$$

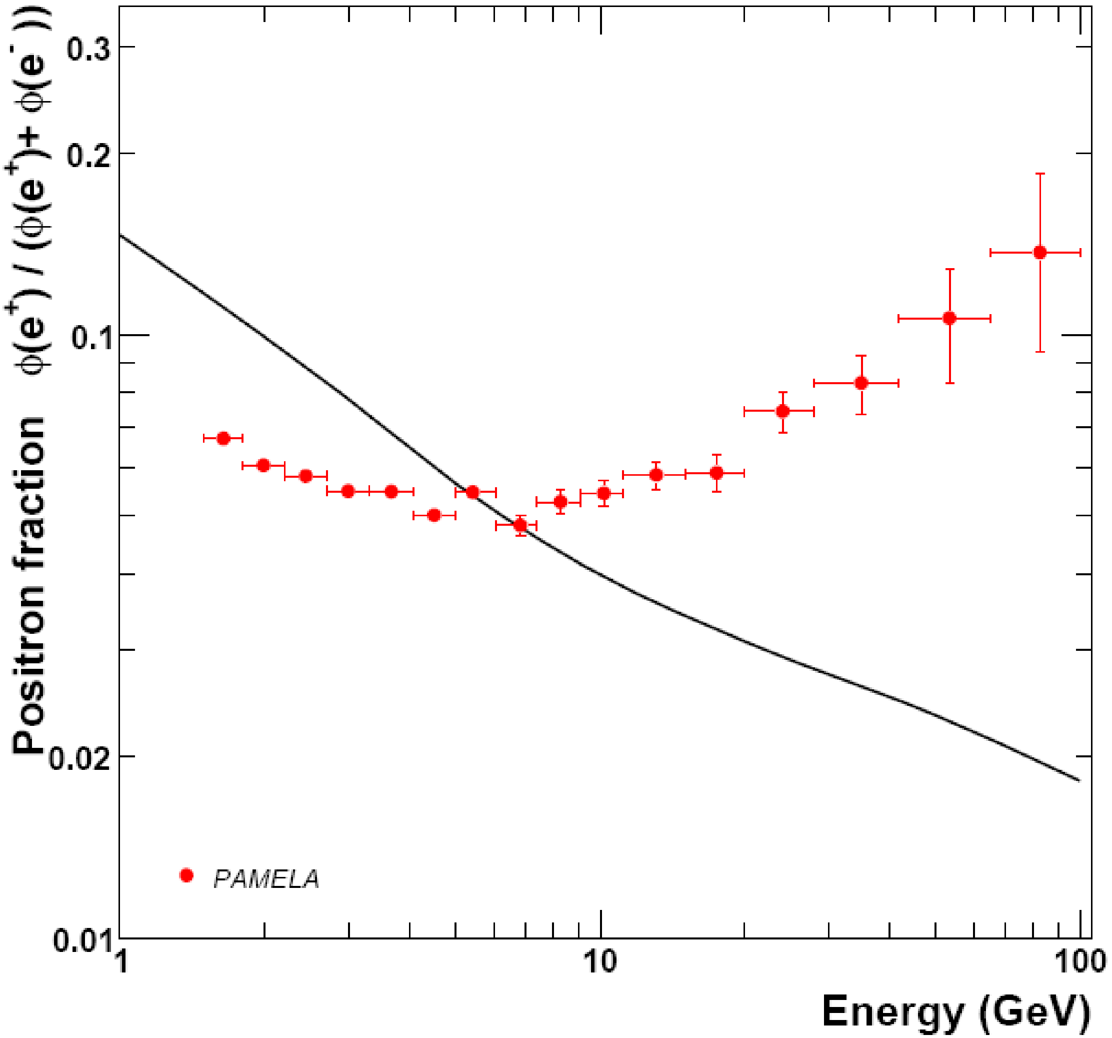
$$p < 700GeV$$

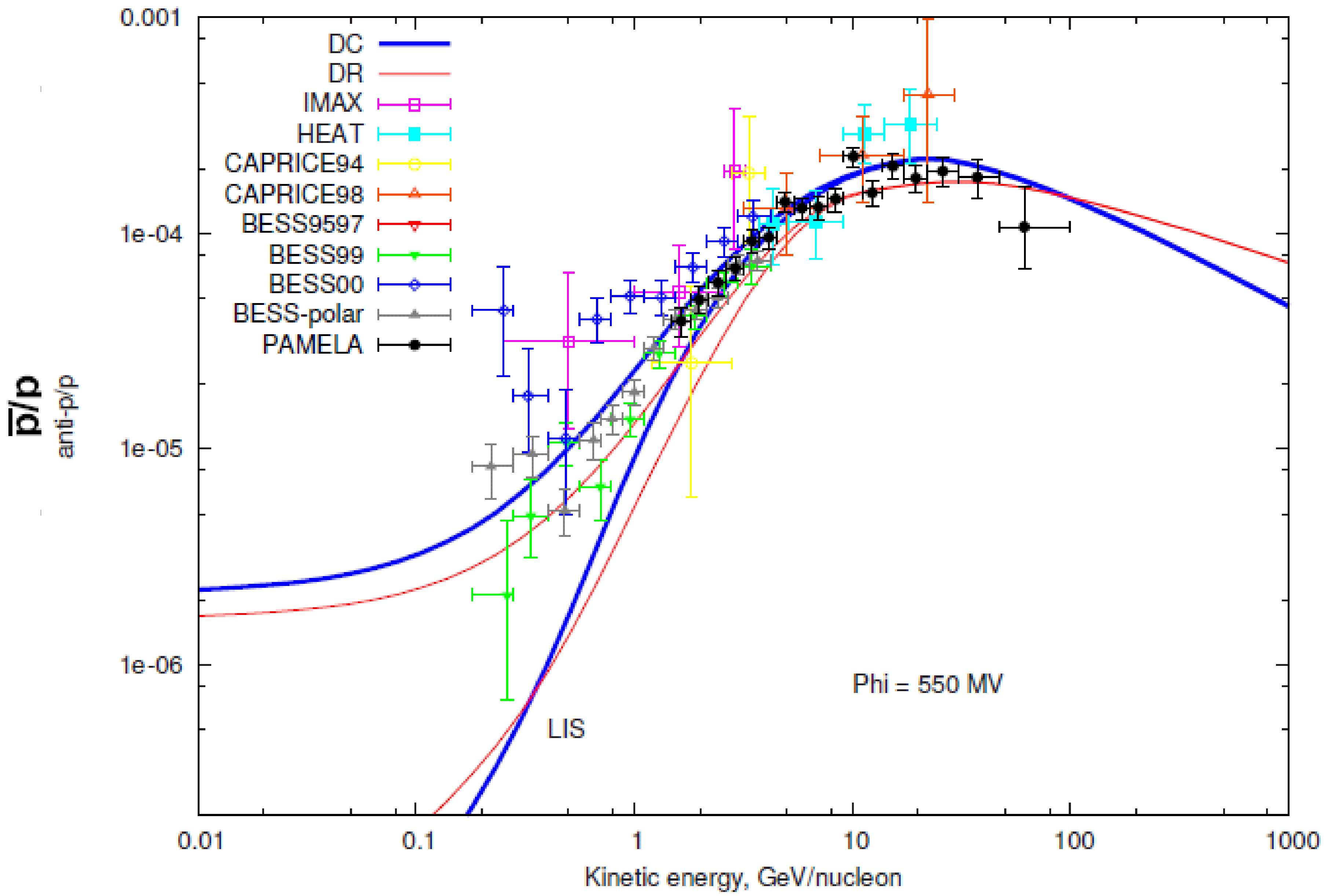
$$e^{\pm} < 2TeV\,(Cal)$$

arXiv:0810.4995 [ps, pdf, other]

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

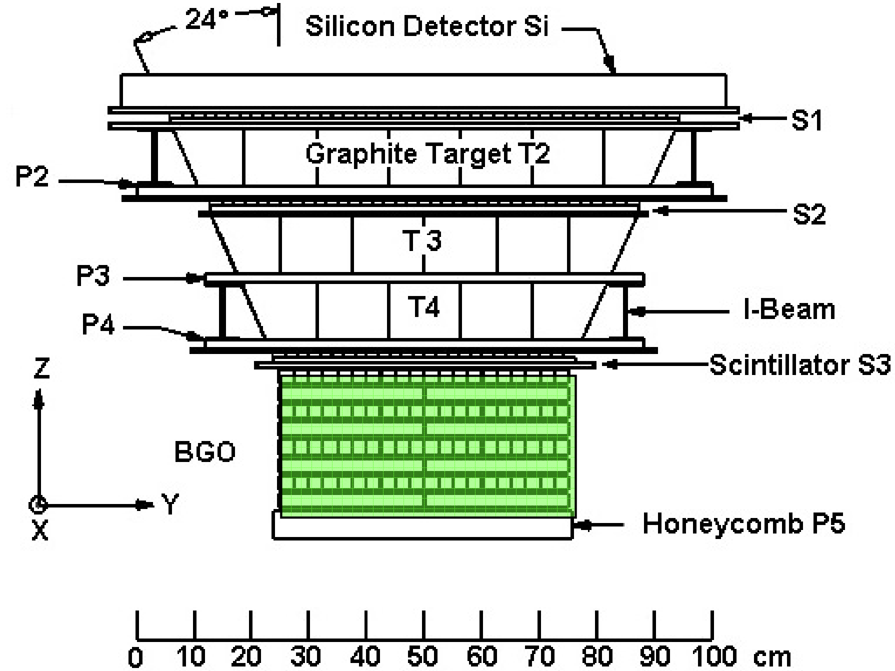


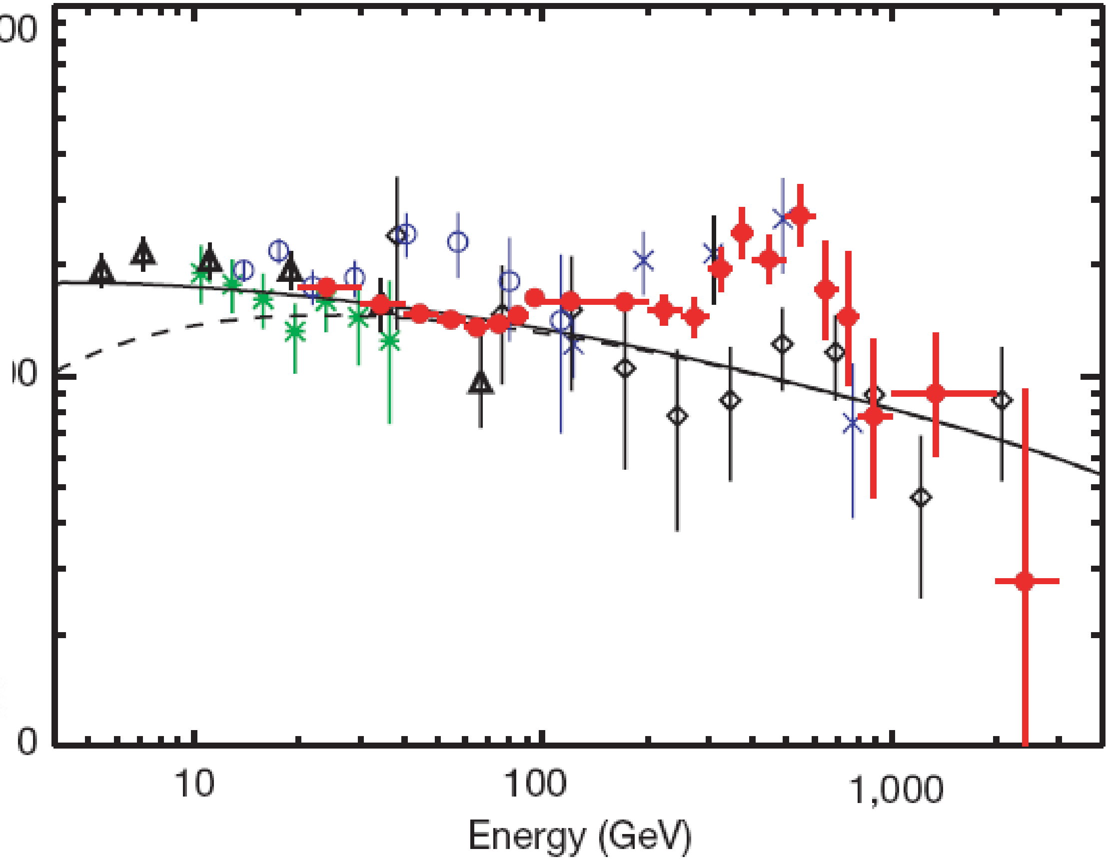



DC
DR
IMAX
HEAT
CAPRICE94
CAPRICE98
BESS9597
BESS99
BESS00
BESS-polar
PAMELA
$\overline{p}/p$
anti-p/p
0.001
1e-04
1e-05
1e-06
0.01
0.1
1
10
100
1000
Kinetic energy, GeV/nucleon
Phi = 550 MV
LIS

Bump at the electron/positron spectrum

Chang et al.
Nature456, 362 2008





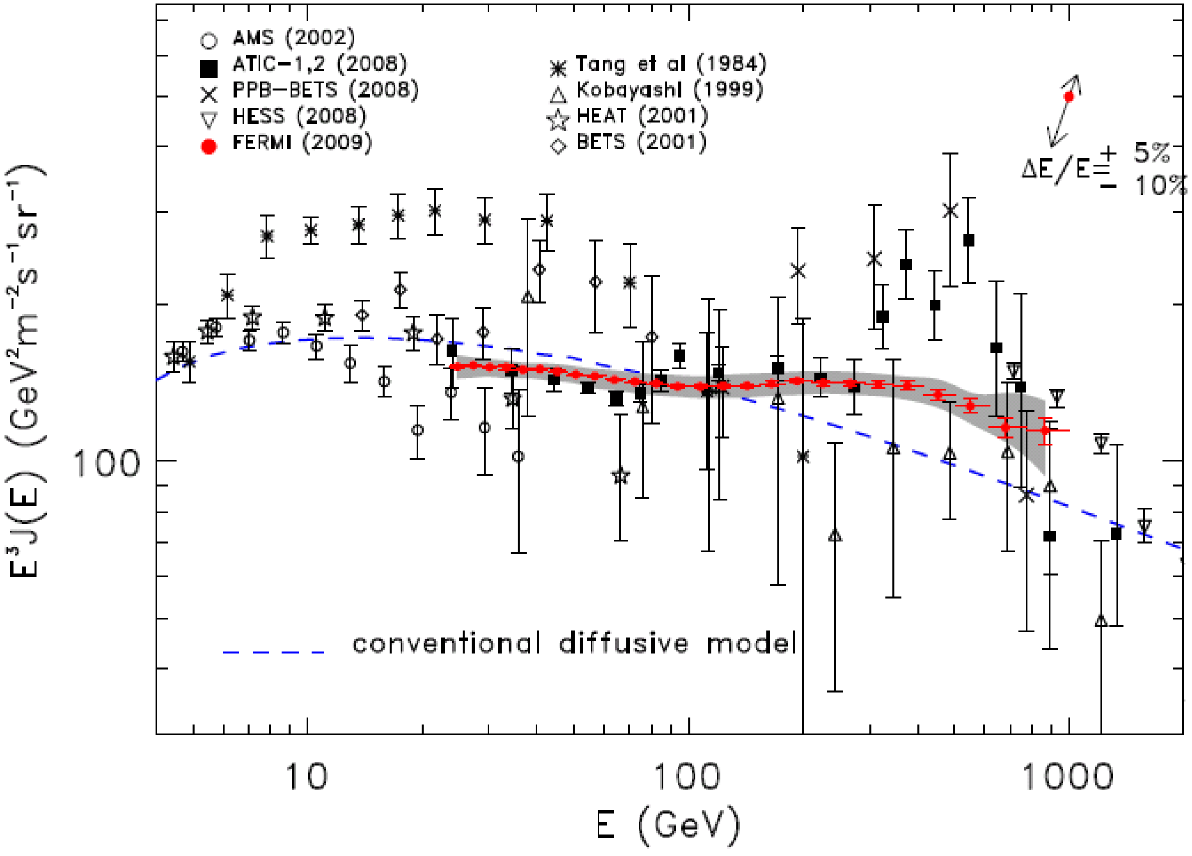
TIC results showing agreement with previous data at lower with the imaging calorimeter PPB-BETS at higher energy. The electron differential energy spectrum measured by ATIC (scaled by E^3) at the top of the atmosphere (red filled circles) is compared with previous observations from the Alpha Magnetic 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.

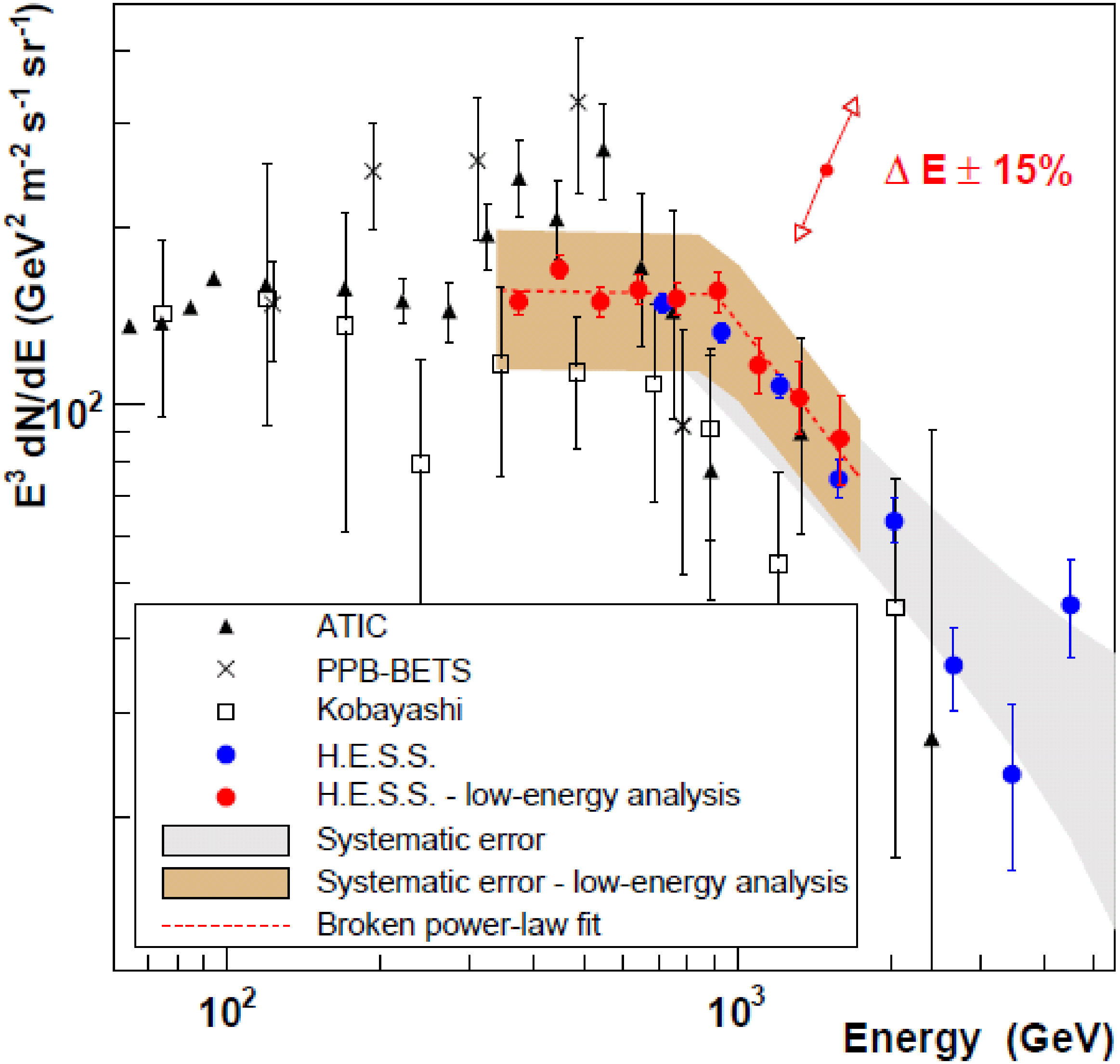
Fermi results

- Fermi gives softer spectrum of (e+e-) than ATIC. Excess exists above the conventional model



HESS result

- HESS measures the Cherenkov light of the showers developed by high energy cosmic rays in the atmosphere.
- It can discriminate hardronic and EM showers. However, can not discriminate electrons and gammas.
- Electron flux is larger than gamma beyond the galactic plane.
- Energy resolution is at best 15%.



Comments

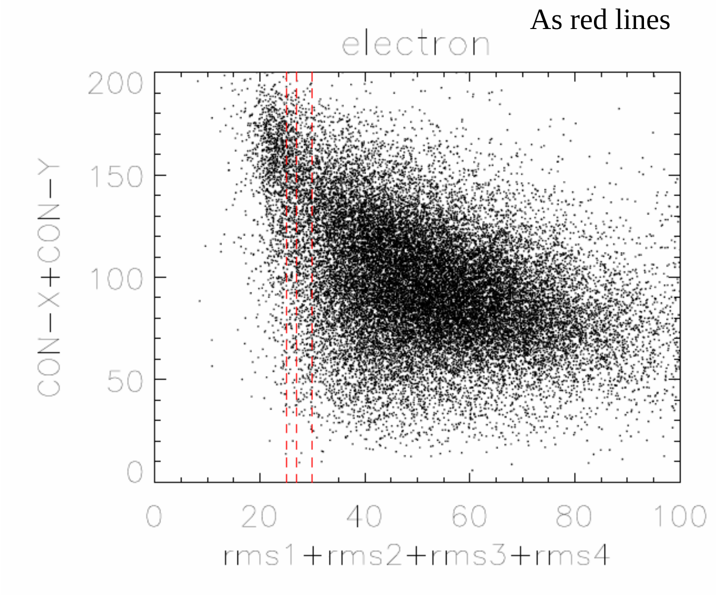
- Debates on the inconsistent results of Fermi and ATIC.
- Fermi is a satellite experiment with large statistic of events. Therefore the error bar is very small.
- However, Fermi is a ‘thin’ detection which leads to bad energy resolution, low efficiency of background rejection.
- Possibly there is misidentification of protons.

- Each set of data is consistent with PAMELA separately.
- For DM annihilation explanation, actually we need similar DM mass and annihilation rates.
- Fermi does not lead to very different DM pictures from ATIC.

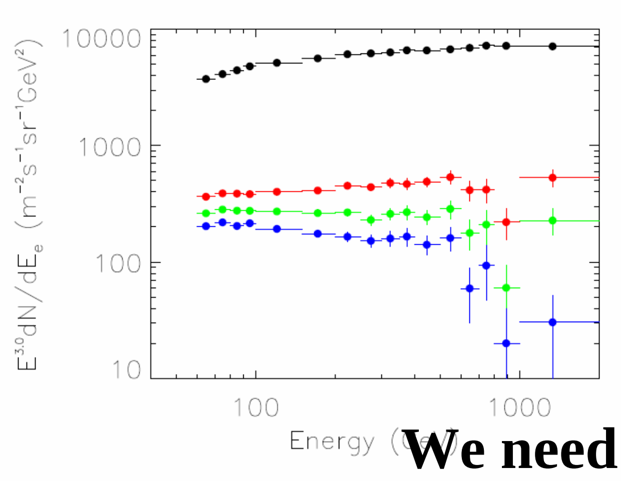
cosmic electron observation

- It is difficult to observe electron in the space because of high cosmic ray backgrounds
- If we want to observe electron using ‘Thin’ detector (as FERMI), the detection efficiency is not a ‘Constant’, it will change with energy.
- Here is the expect result from a ‘Thin ATIC’ Detector (thickness is like FERMI)

Electron is top left island, we use 3 cut
As red lines



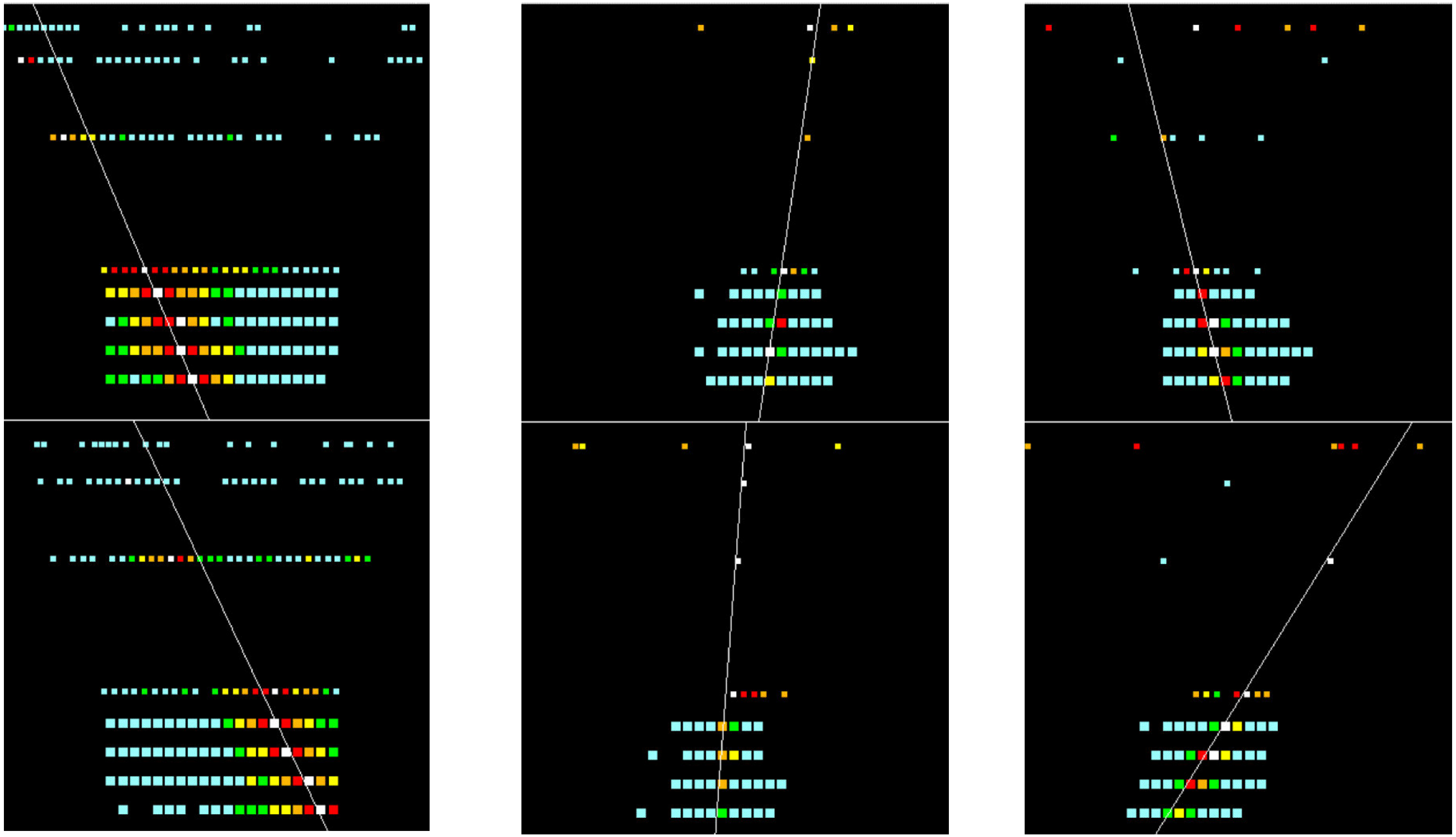
The bump disappear, but
spectrum with a cut off from 500 GeV



**We need deep
Detector for future!**

Typical (p,e,γ) shower image from ATIC flight data

- 3 events, energy deposit in BGO is about 250 GeV
- Electron and gamma-ray showers are narrower than the proton shower
- Gamma-ray shower: No hits in the top detectors around the shower axis



proton electron gamma

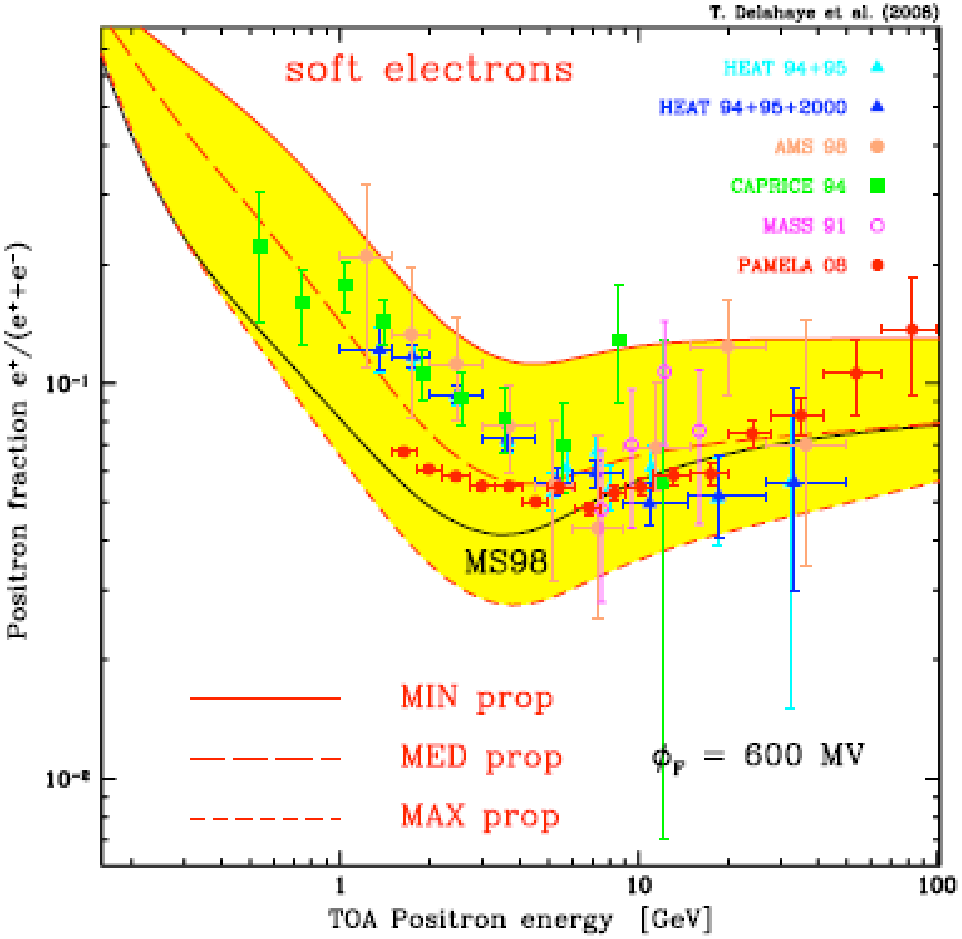
- Theoretical works to explain the excesses

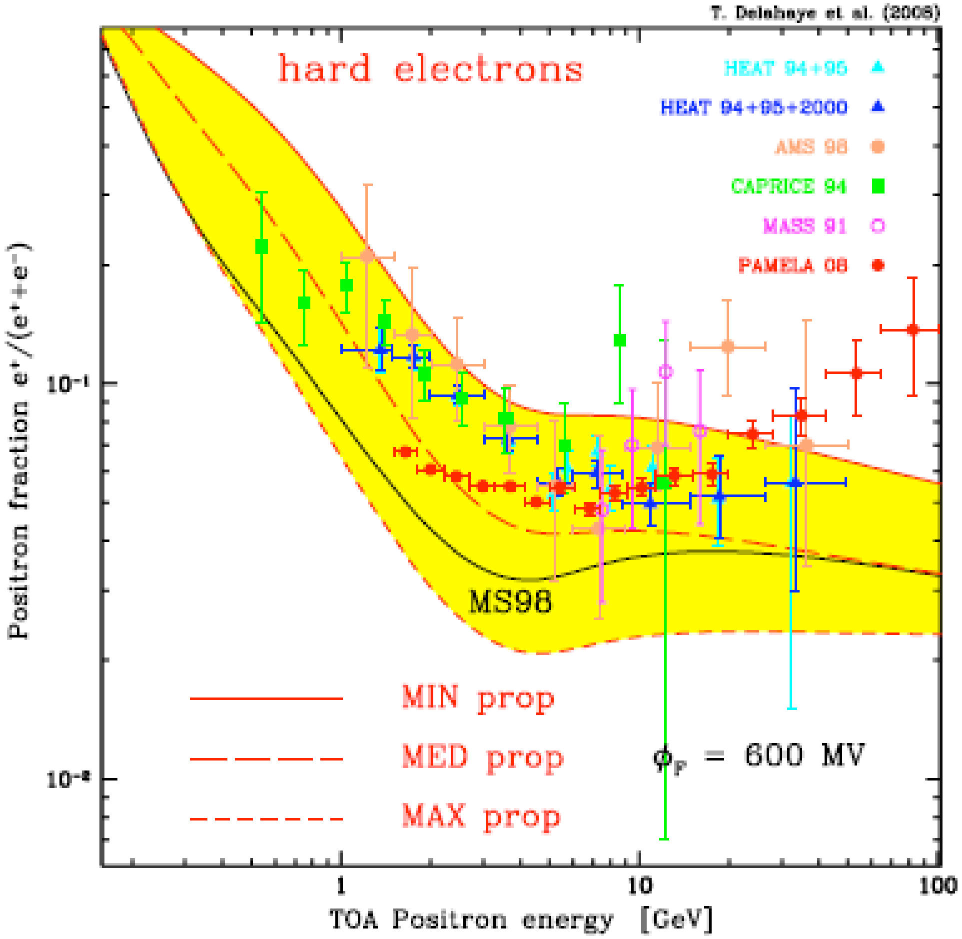
Recalculation of background

- 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

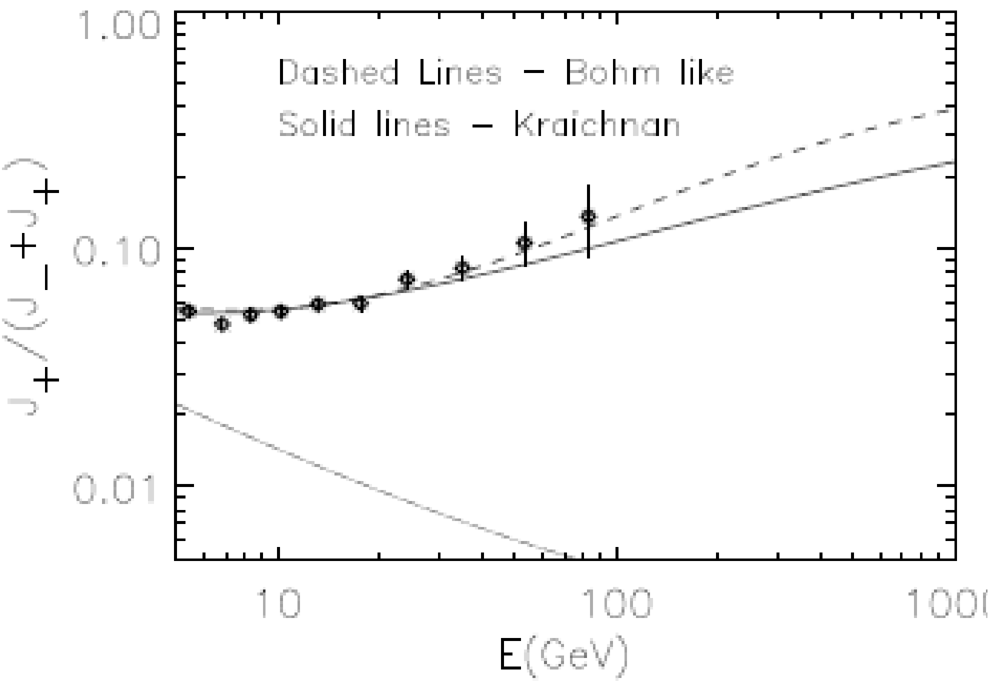


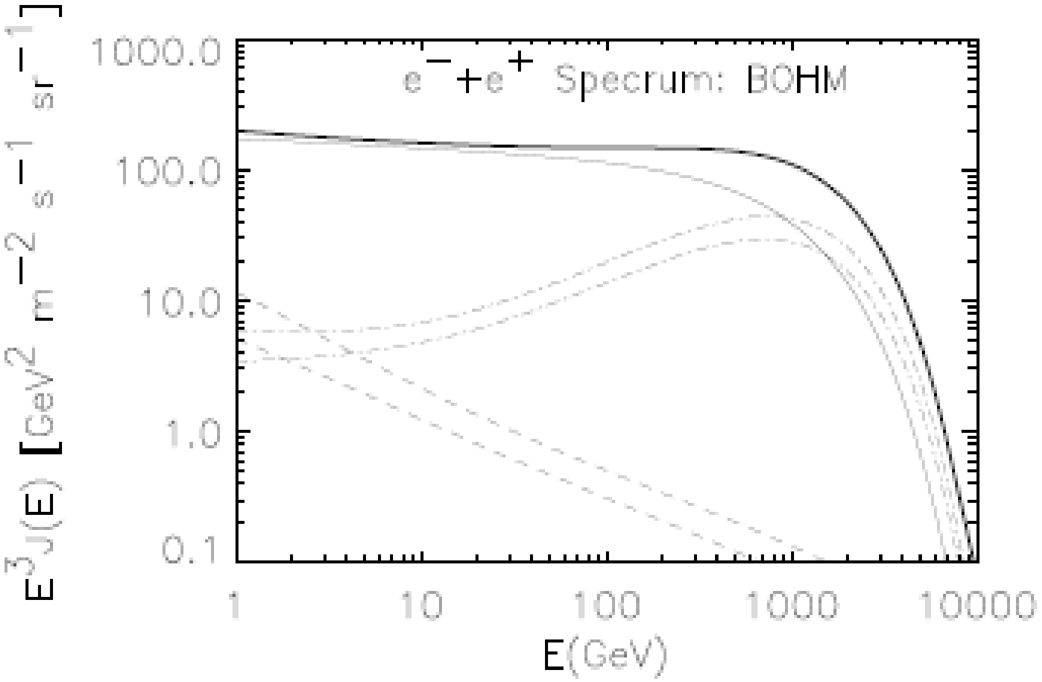


But cannot explain ATIC result

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

Occur at the cosmic ray acceleration source: hard spectrum

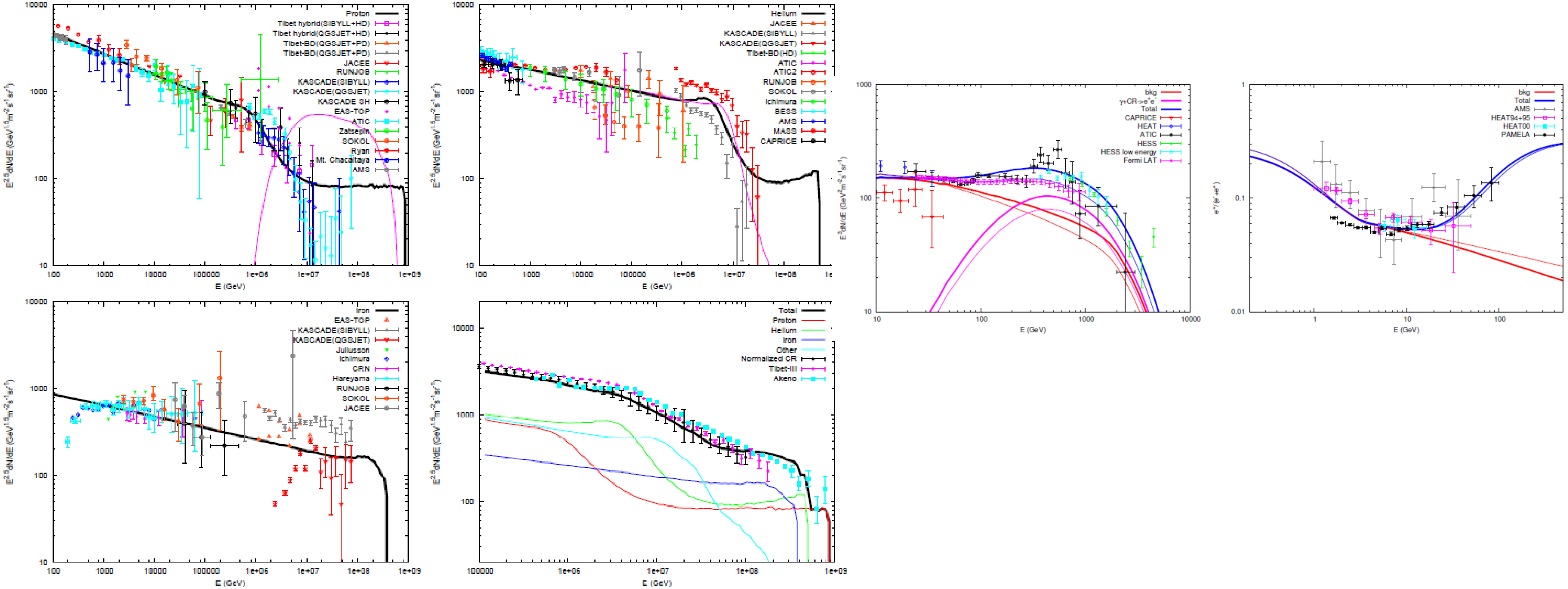




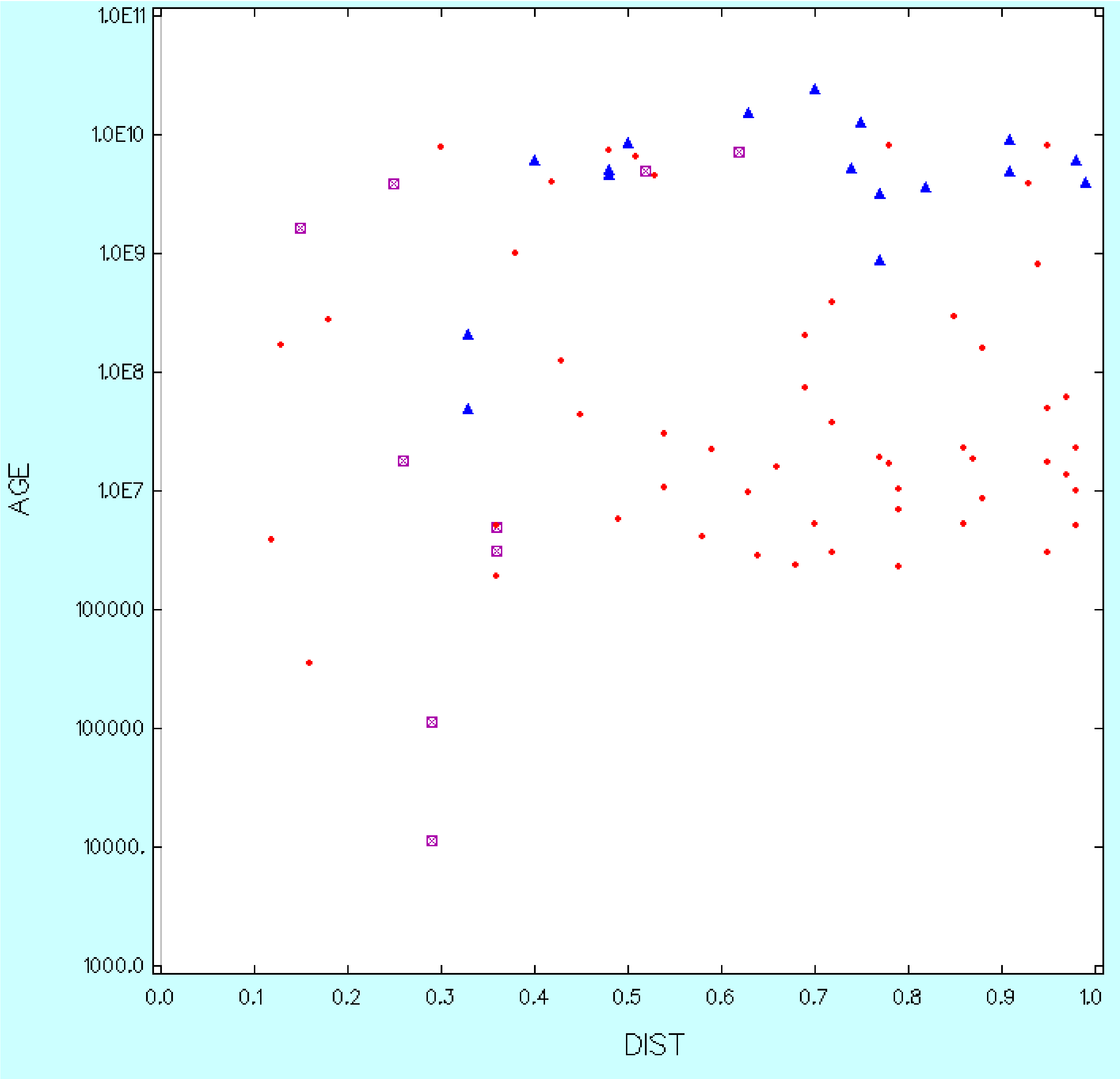
Comment: nature for Fermi spectrum;
antiprotons may set constraints on this picture

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 $p\gamma \rightarrow pe^+e^-$ interaction, with E γ =1eV, the threshold energy is at ~10^15 eV
- 3% converted e^+e^- can explain the ATIC or Fermi



Nearby pulsars



Astrophysical sources

- Nearby pulsars:

D. Hooper et al.

S. Profumo

……

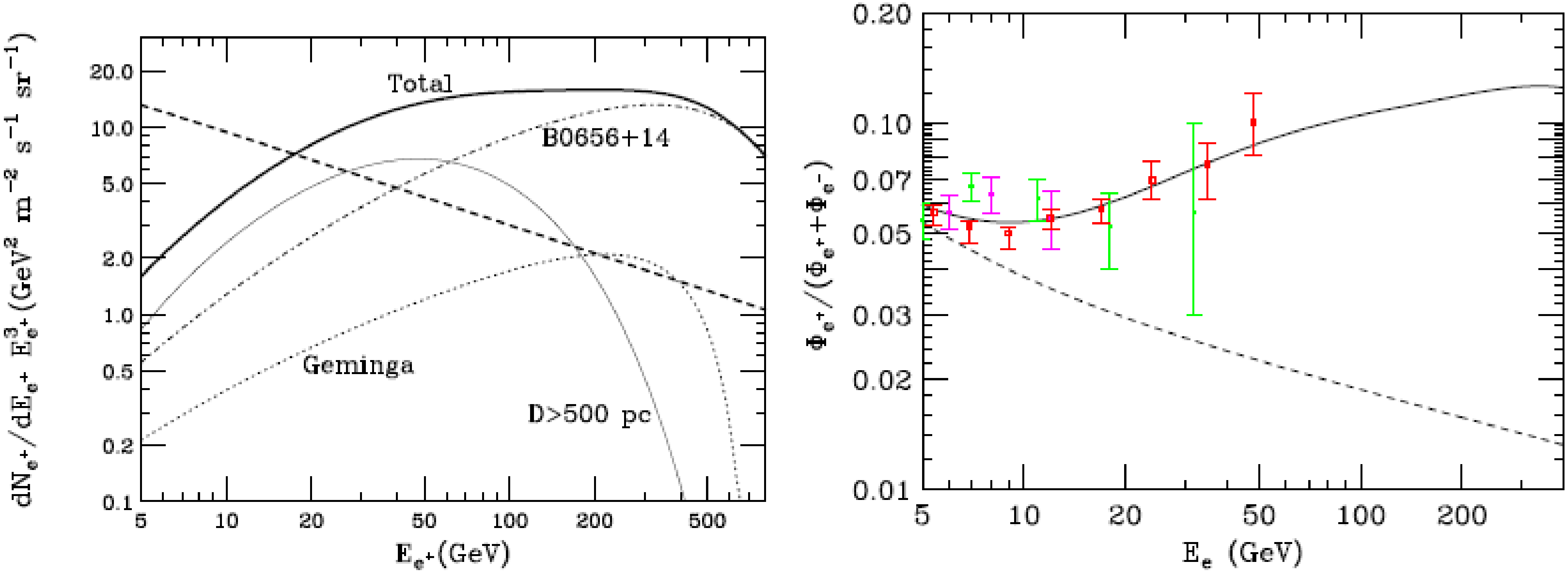


FIG. 4: The positron spectrum and positron fraction from the sum of contributions from B0656+14, Geminga, and all pulsars farther than 500 parsecs from the Solar System.

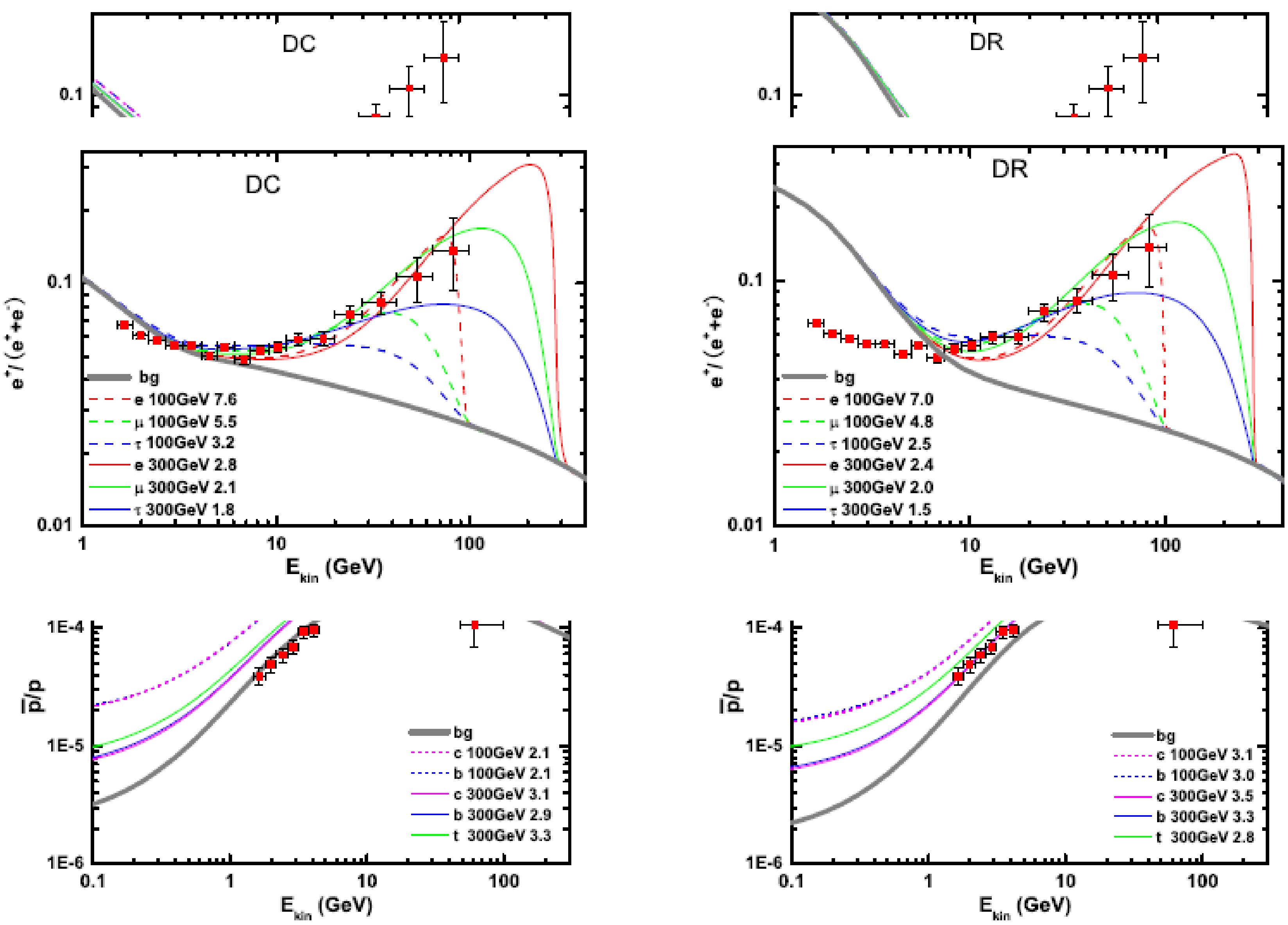
Primary positron/electrons from dark matter – implication from new data

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

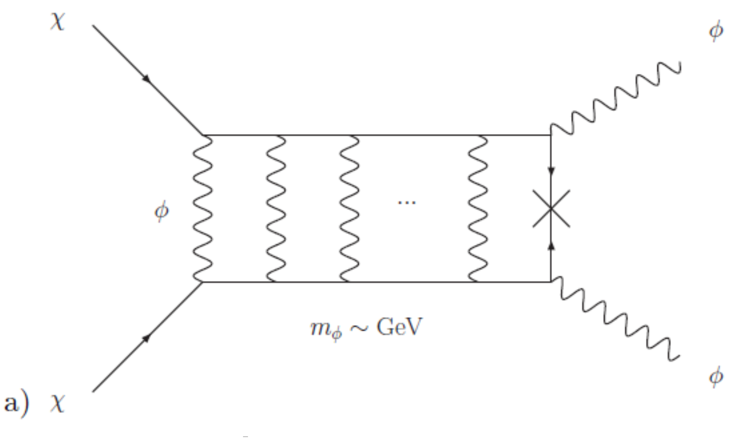
- Very large annihilation cross section, much larger than the requirement by relic density. (1) nonthermal production, 2) Sommerfeld enhancement, 3) Breit-Wigner enhancement, 4) dark matter decay.)

why should annihilate into leptons?

Yin, Yuan, Bi et al.
arXiv:0811.0176



Dark matter models to produce leptons



- Kinematically suppression

Mass of ϕ is about 1GeV, is

Kinematically suppressed to anti

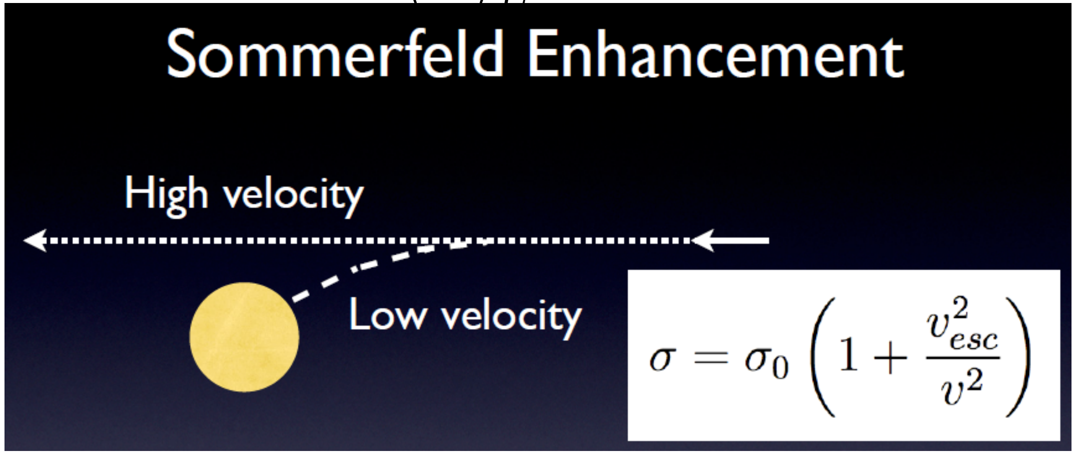
At the same time attractive interaction can enhance the annihilaition rate, Sommerfeld enhancement. (Arkani-Hamed et al. 0810.0713)

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

- (from N. Weiner)



Sommerfeld Enhancement

High velocity

Low velocity

$$\sigma = \sigma_0 \left(1 + \frac{v_{esc}^2}{v^2}\right)$$

- Sommerfeld enhancement
- For attractive Coulomb Potential $S_k \sim |\frac{\epsilon_v^{1/2}\alpha M}{Mv}|^2 = \frac{\alpha}{v}$
- To enhance the dark matter annihilation we have long range attractive force

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

Ibe, Murayama, Yanagida

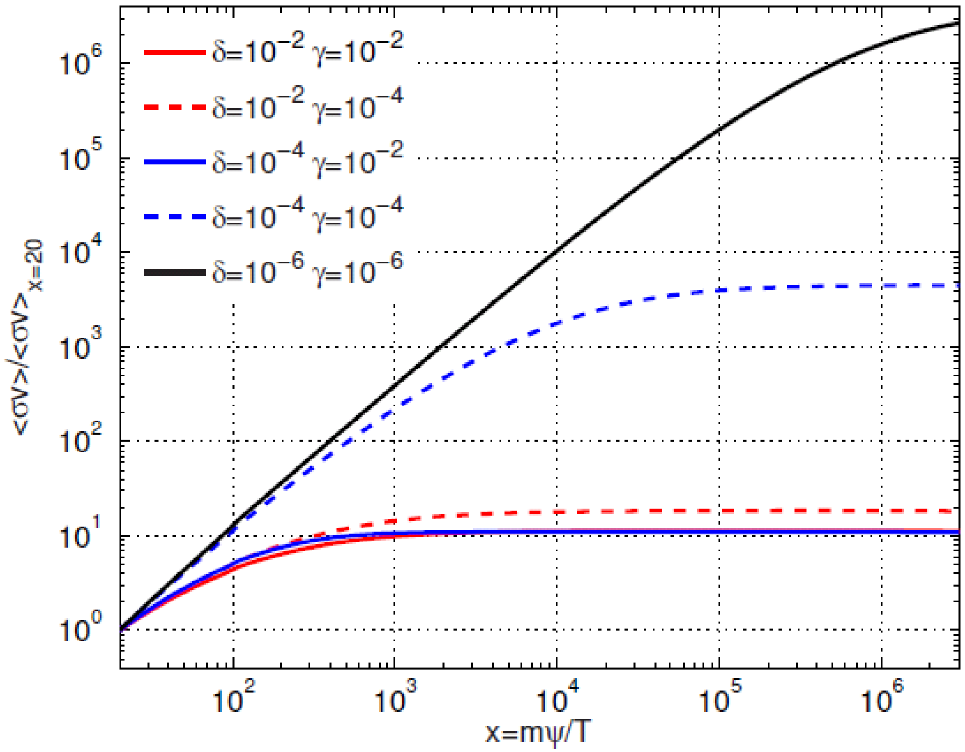
Guo, Wu

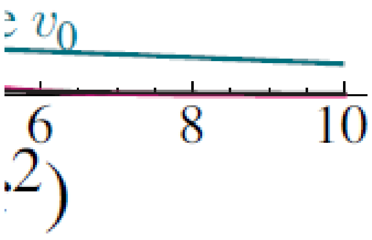
Bi, He, Yuan

Large flux

Breit-Wigner enhancement,

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





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

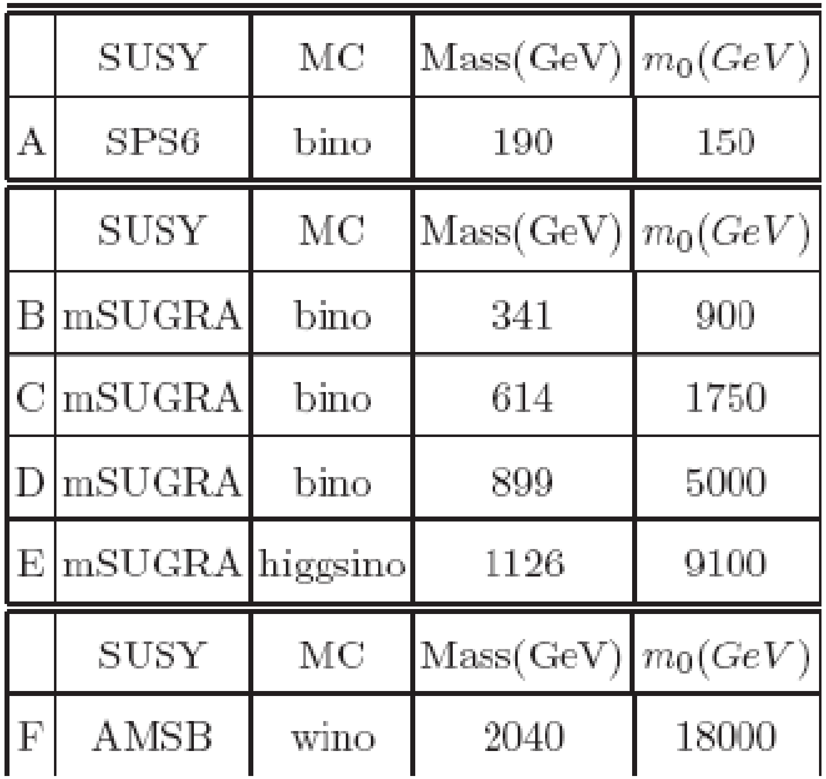
Decay dark matter with life time 10^{26}s

Yin, Yuan, Bi et al.

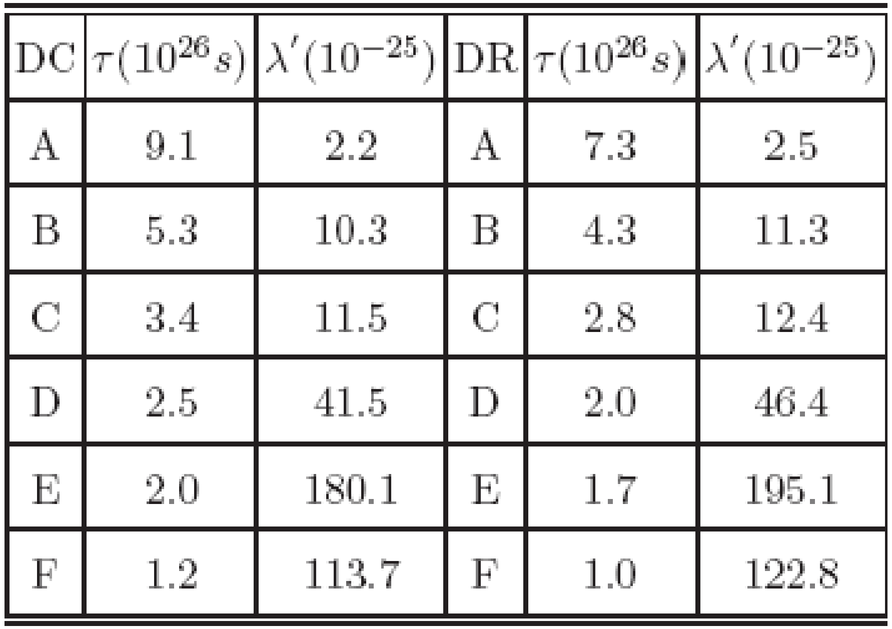
Chen, Nojiri et al

Ibarra, Tran

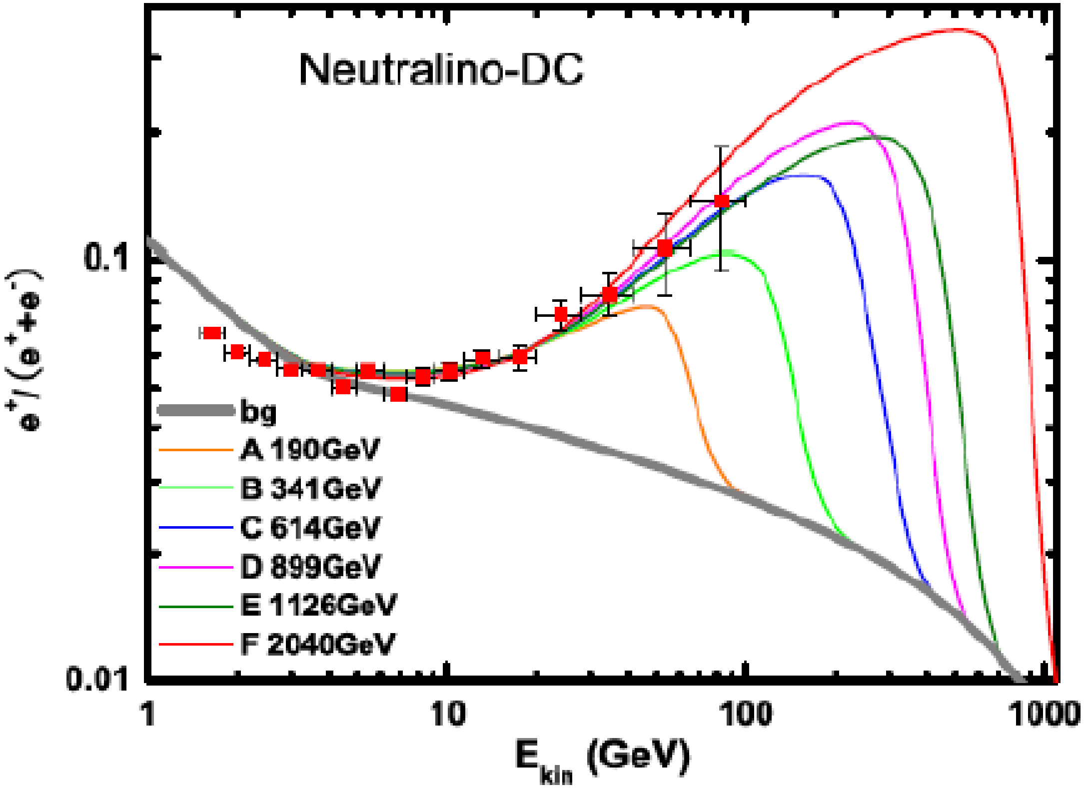
Hamguchi, Shirai, Yanagida



	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



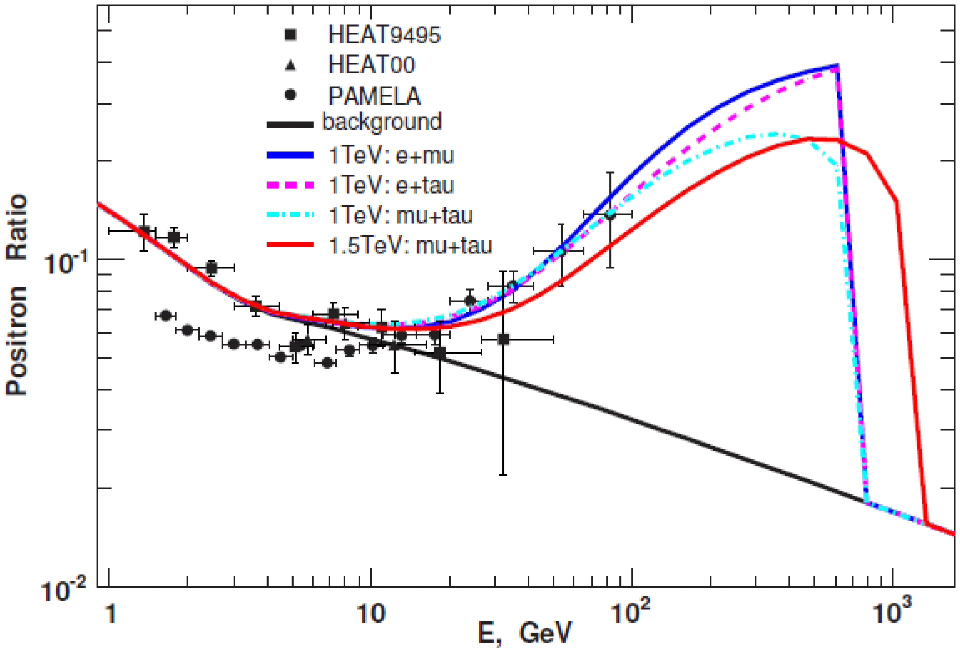
DC	$\tau(10^{26}s)$	$\lambda'(10^{-25})$	DR	$\tau(10^{26}s)$	$\lambda'(10^{-25})$
A	9.1	2.2	A	7.3	2.5
B	5.3	10.3	B	4.3	11.3
C	3.4	11.5	C	2.8	12.4
D	2.5	41.5	D	2.0	46.4
E	2.0	180.1	E	1.7	195.1
F	1.2	113.7	F	1.0	122.8

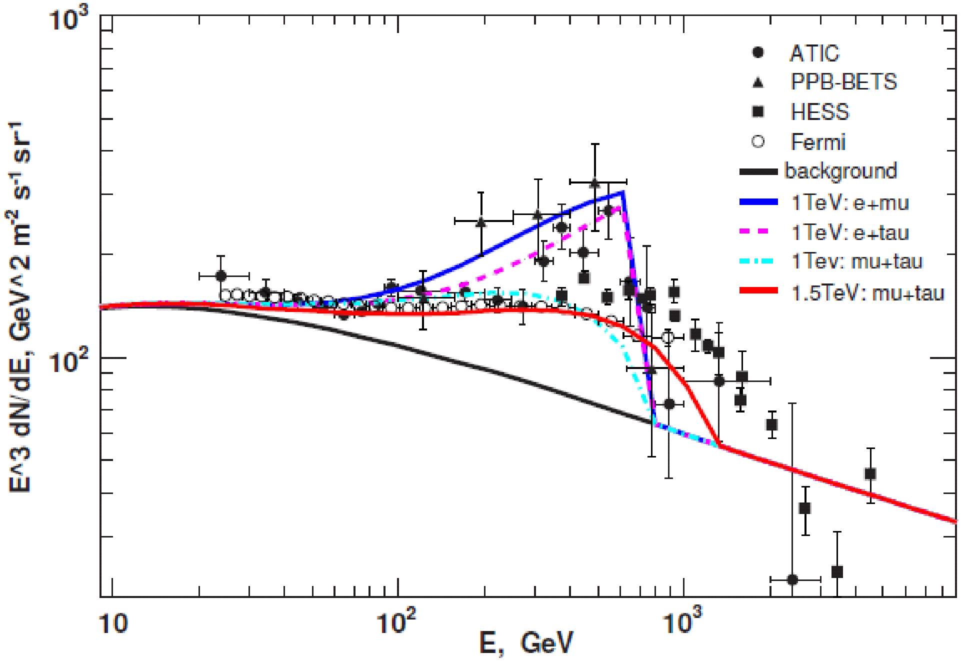


ATIC and Fermi

- Model of gauge $U(1)'_{e-\mu(\tau)}$
- 1TeV DM to e+mu, e+tau can explain ATIC
- 1.5 TeV DM to mu+tau can explain Fermi data
- All have similar annihilation rate

Bi, He, Yuan 0903.0122





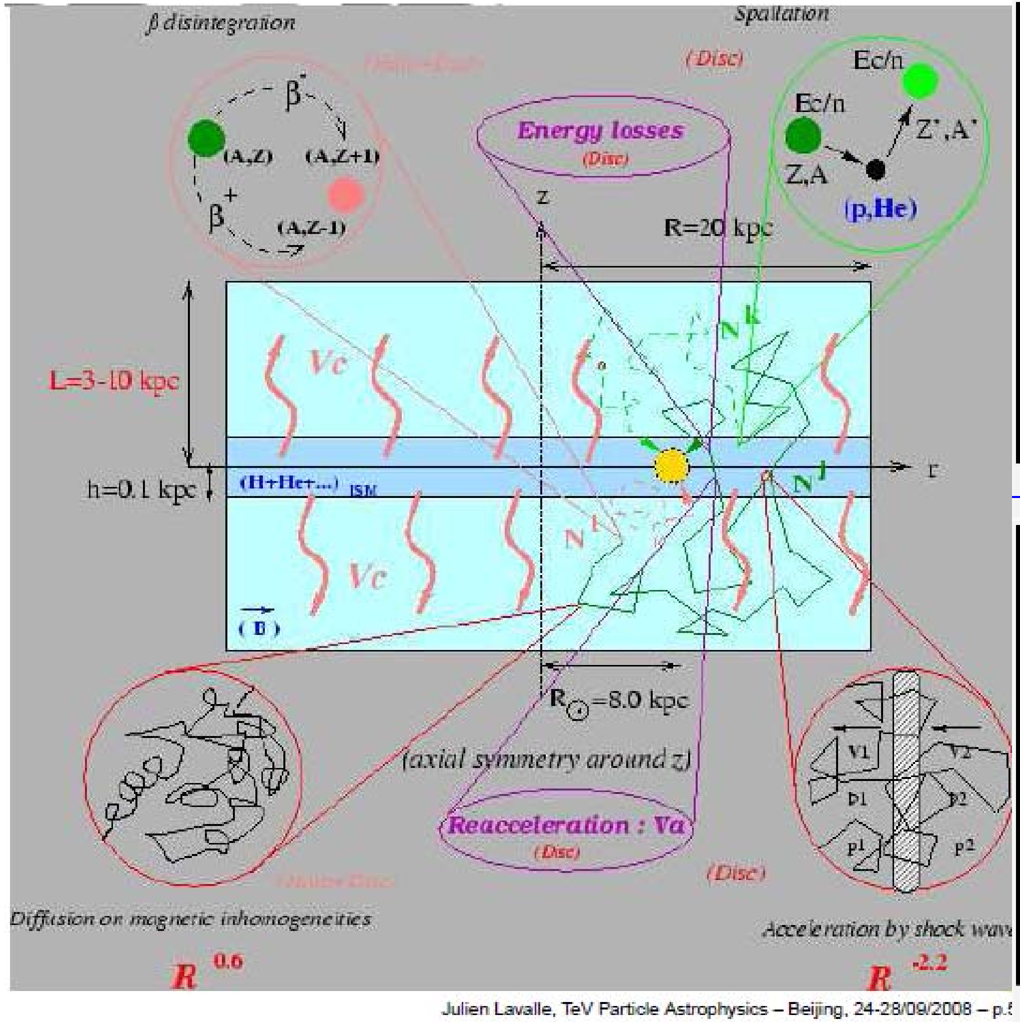
How DM models are constrained by the PAMELA and ATIC data

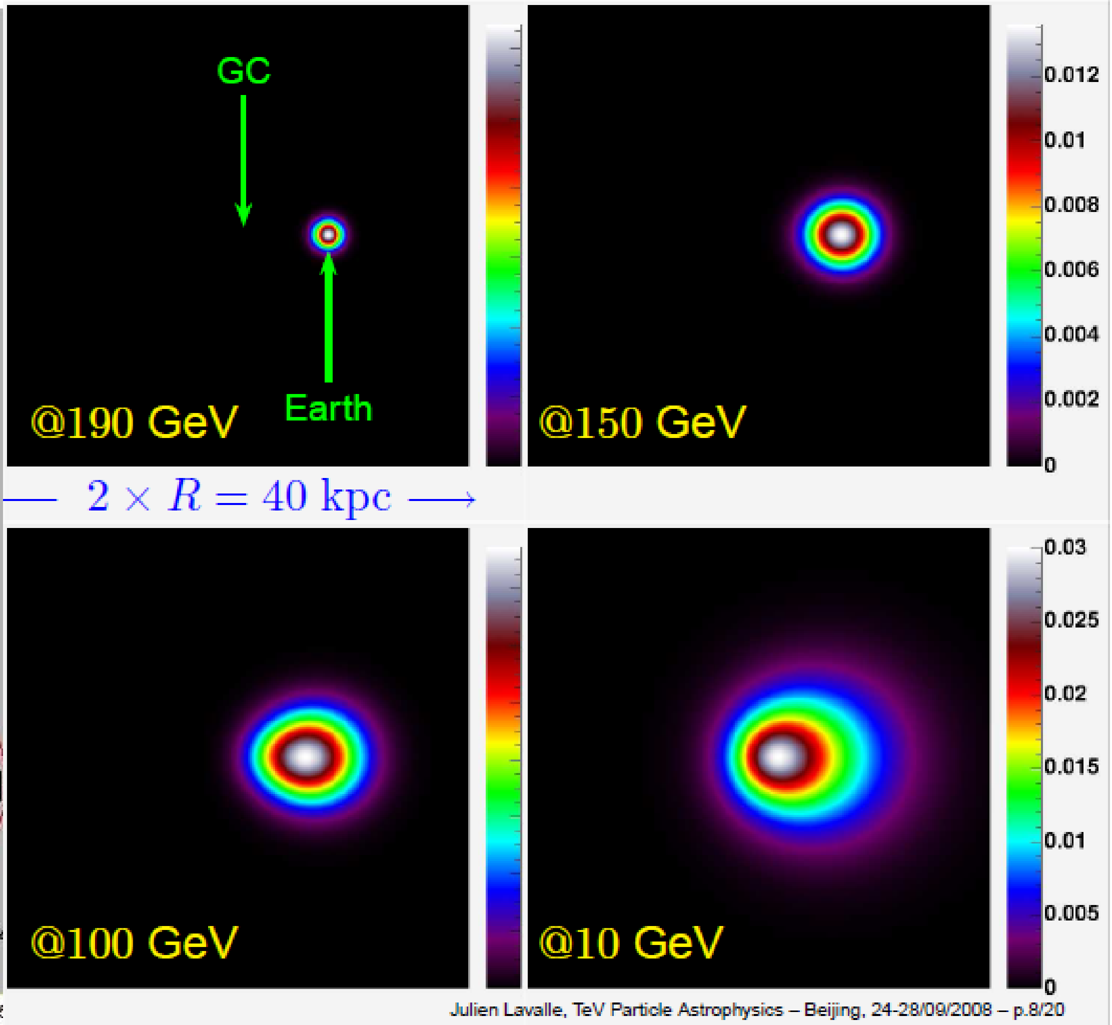
--- branching ratios to gauge bosons and quarks are constrained

Propagation of CRs

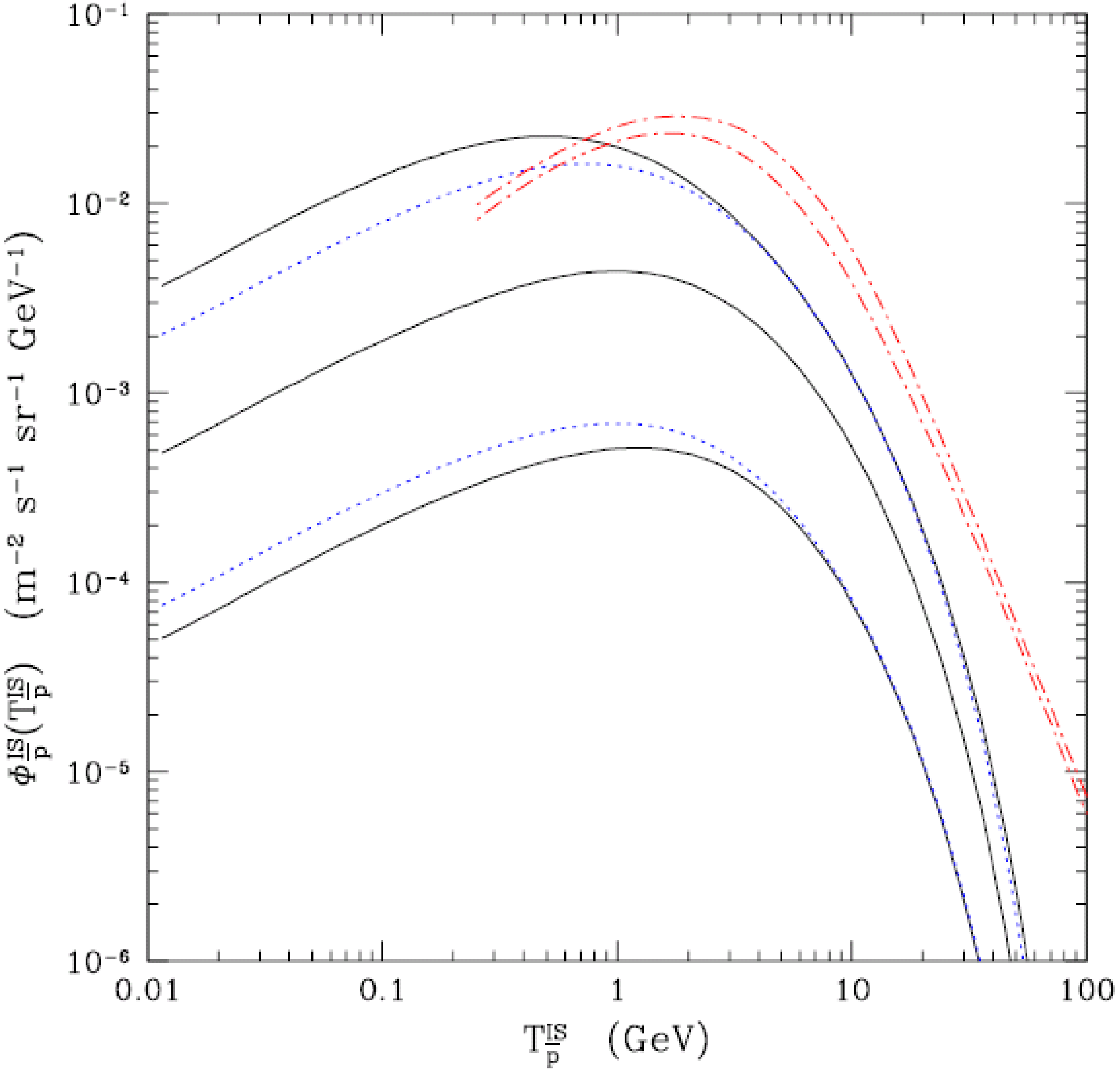
- Due to rapid energy loss of electron/positron the flux measured on Earth comes from nearby regions; antiproton can come from far regions
- Height of diffusion region is a crucial factor; astrophysical sources from the Galactic plane is less affected; however, DM signals will be affected significantly.

From Lavalla





Primary antiproton flux depends on the diffusion region heavily



F. Donato et al. 2003

For L=1, 4, 15kpc

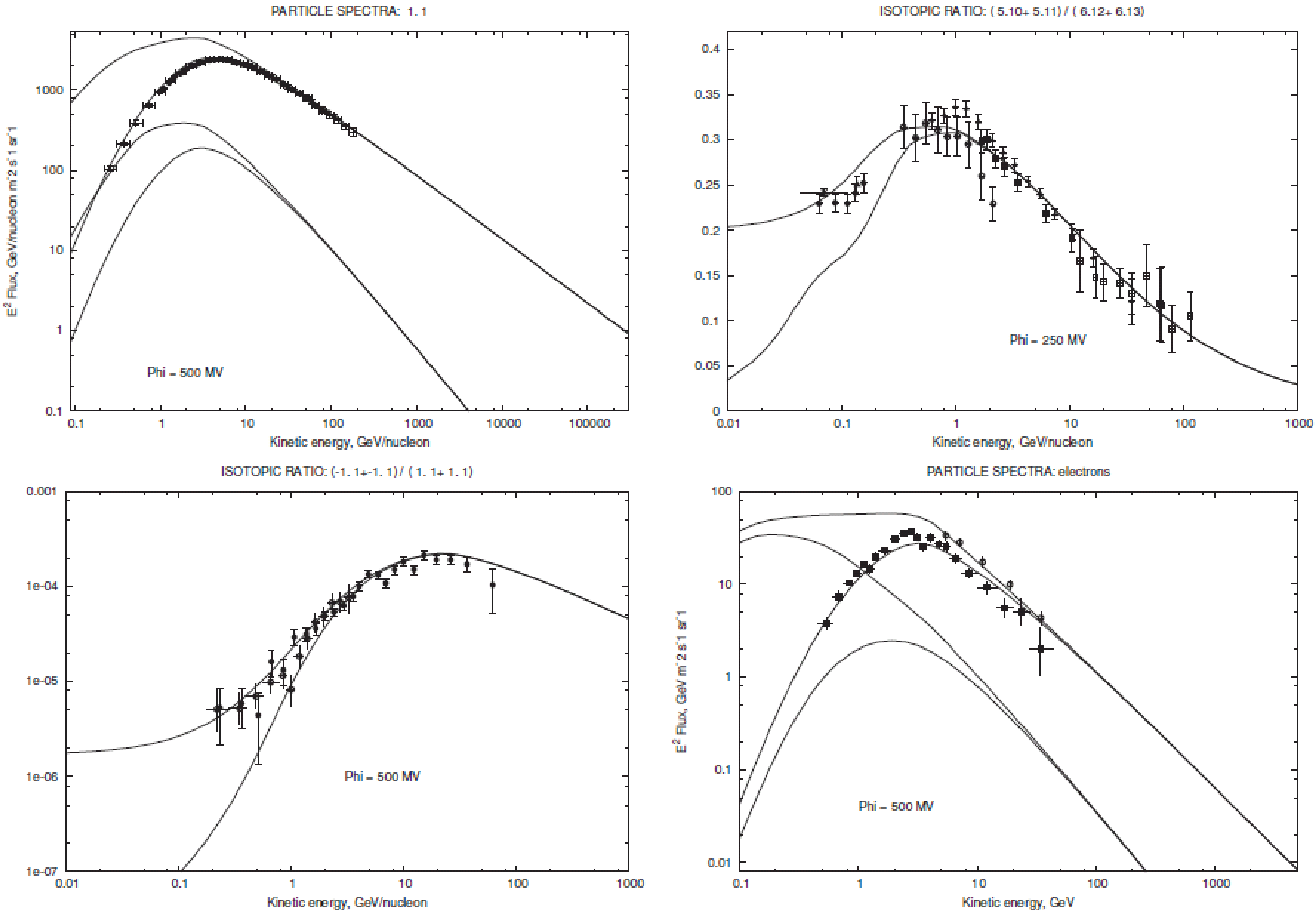
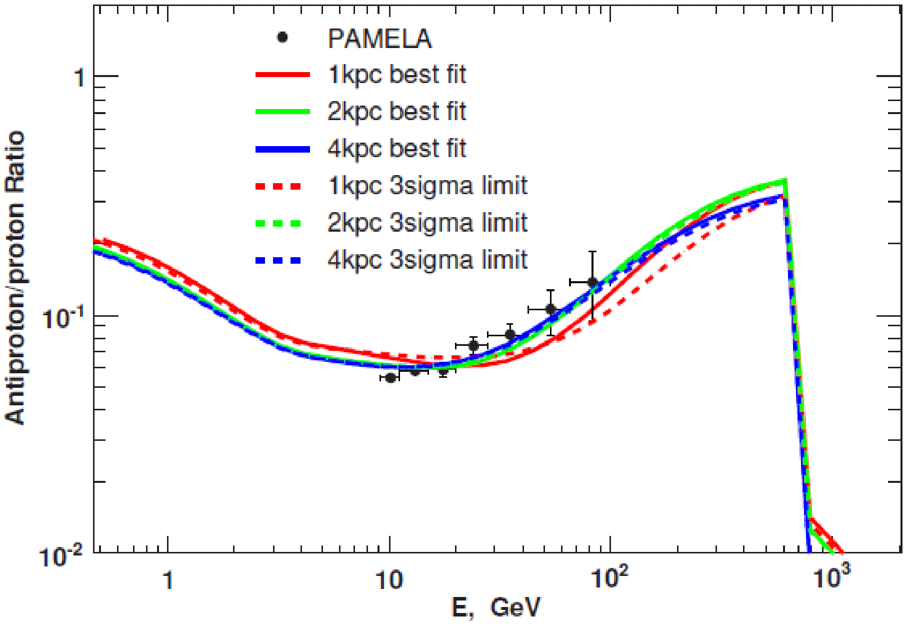
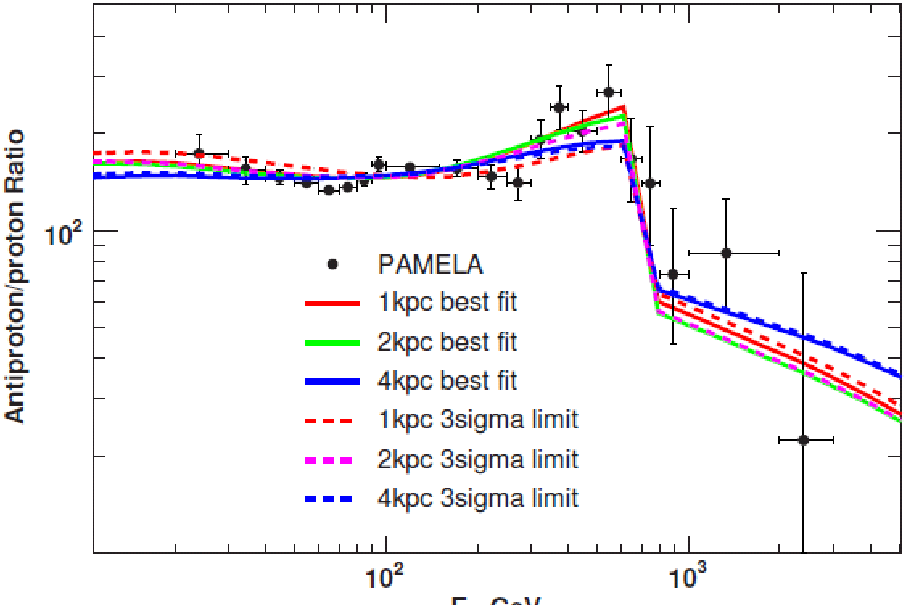


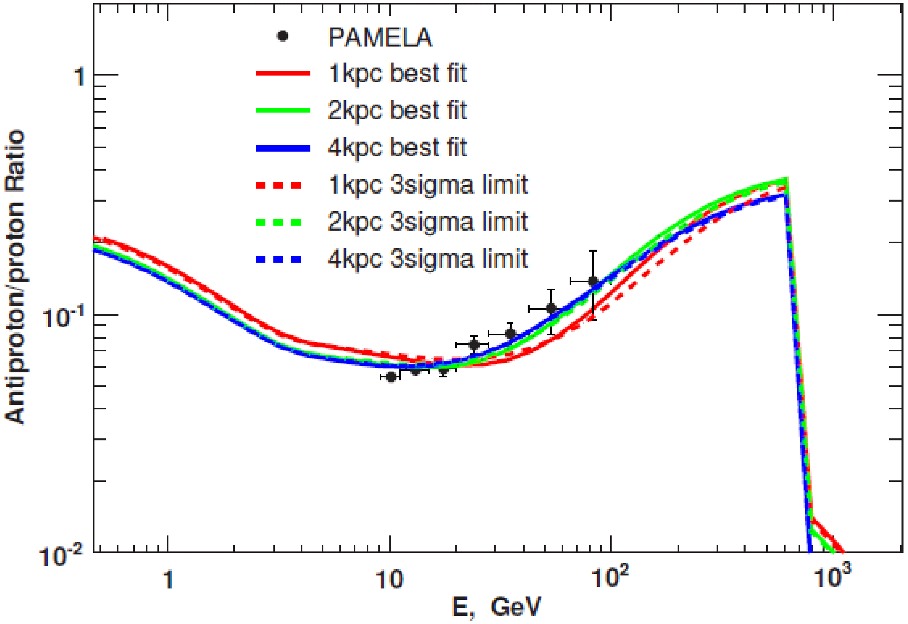
Figure 3: The background predictions of 4 kpc model.

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

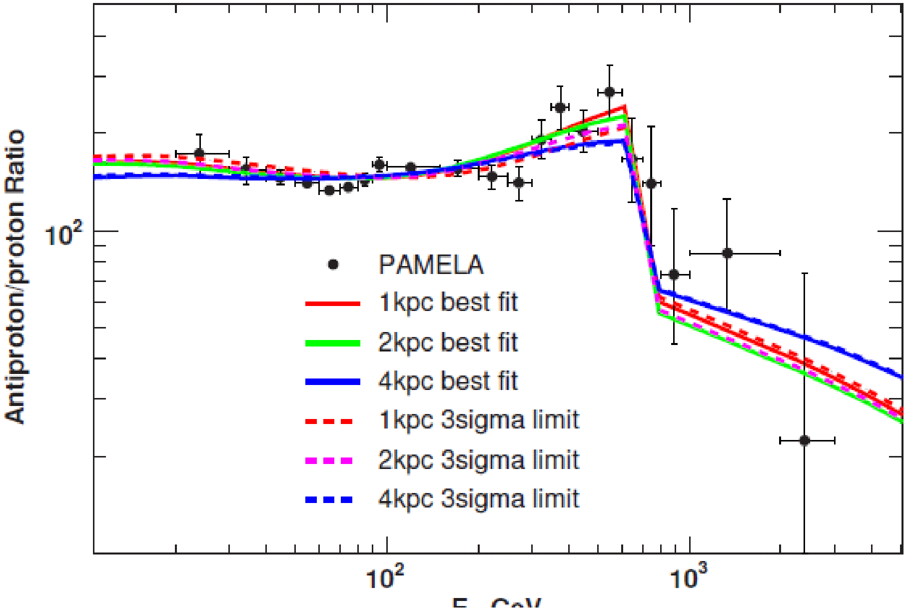


WW final state



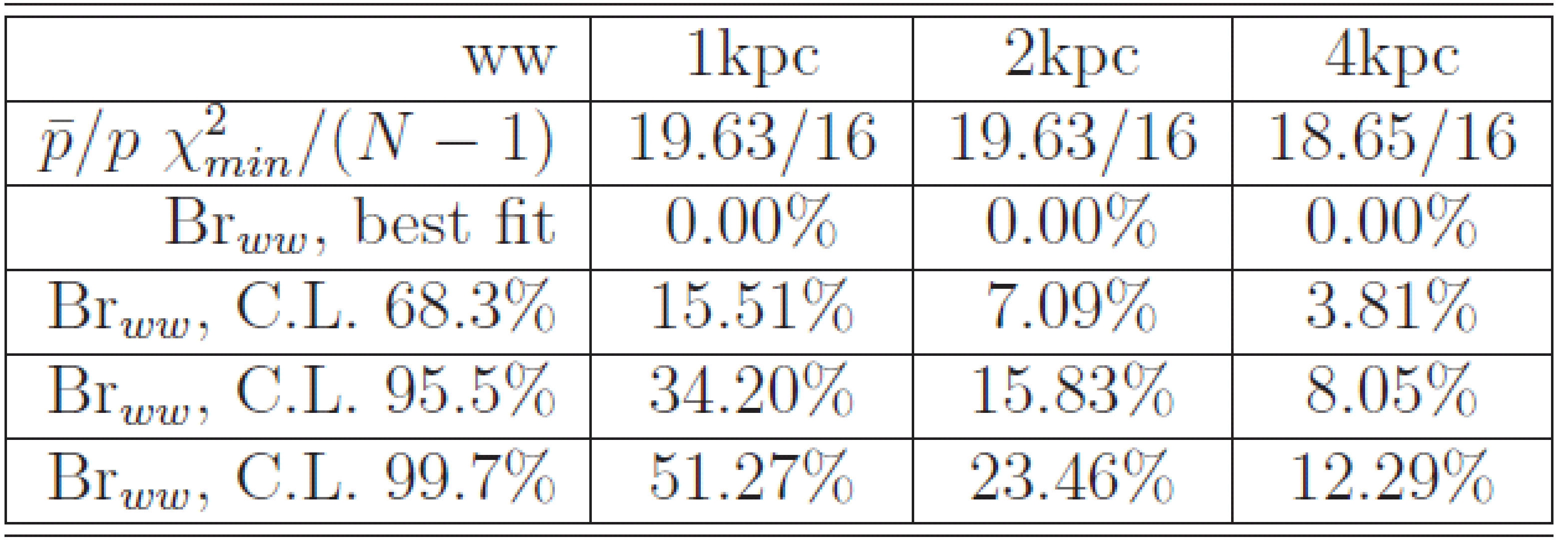


quark final state



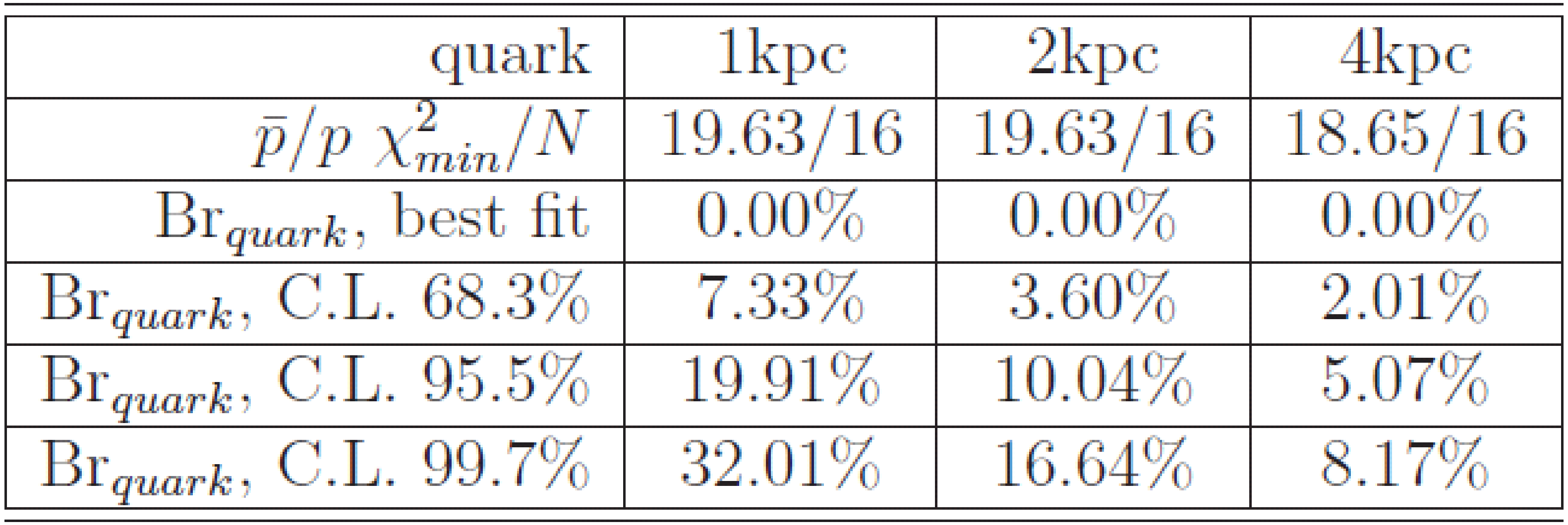
Upper bounds on the WW and quark branching ratios for M_{DM}=1TeV

Table 3: Results for ww and lepton final state



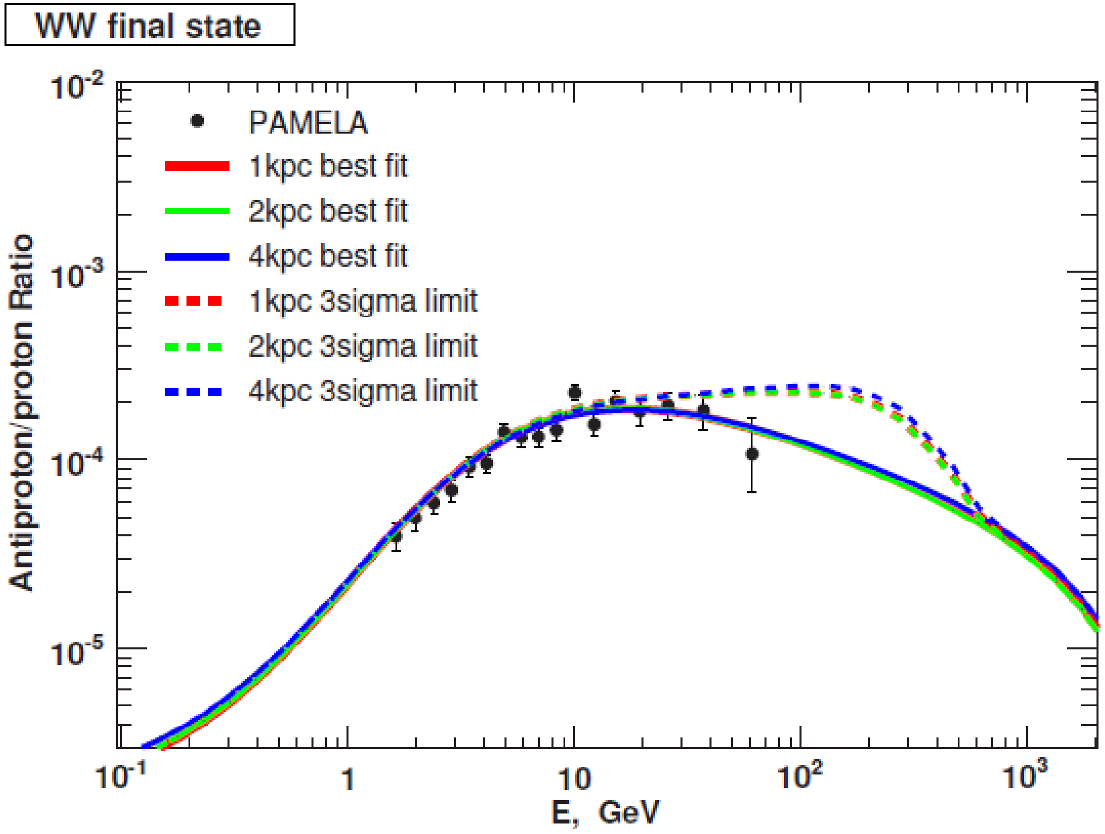
ww	1kpc	2kpc	4kpc
$\bar{p}/p\ \chi^2_{min}/(N-1)$	19.63/16	19.63/16	18.65/16
Br_{ww}, best fit	0.00%	0.00%	0.00%
Br_{ww}, C.L. 68.3%	15.51%	7.09%	3.81%
Br_{ww}, C.L. 95.5%	34.20%	15.83%	8.05%
Br_{ww}, C.L. 99.7%	51.27%	23.46%	12.29%

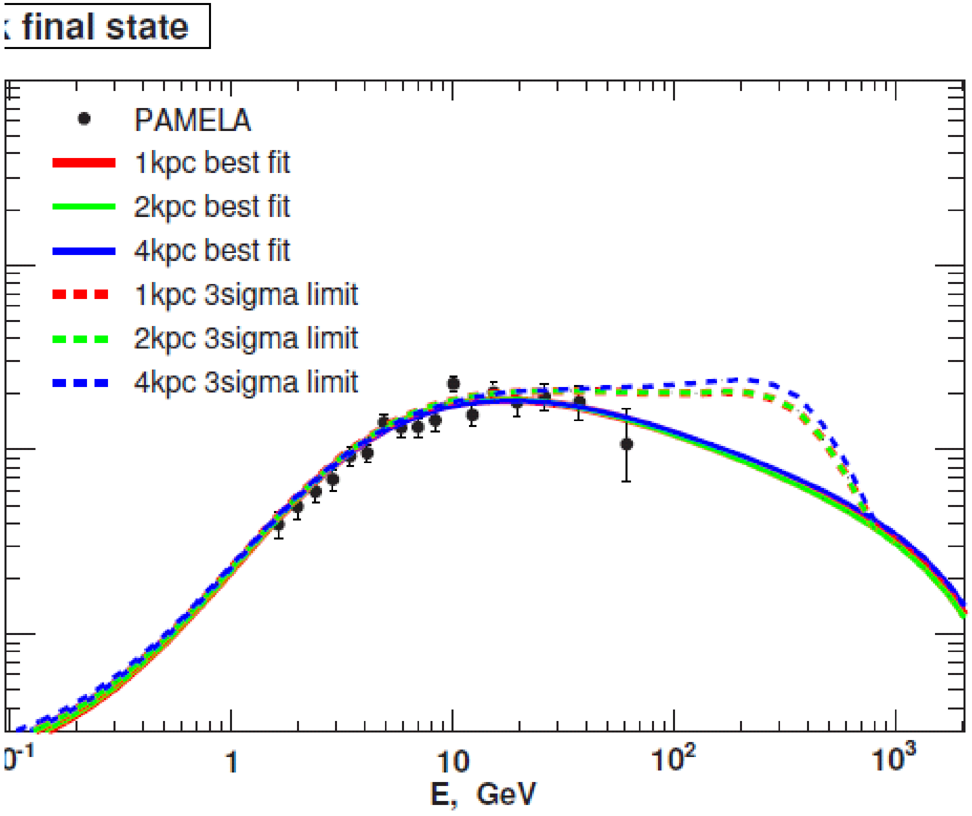
Table 5: Results for quark-pair and lepton final state



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 (universal KK mass); marginally allowed

- $U(1)'_{B\text{-}L}$, ~40% into quarks, slightly disfavored

- Leptophilic models $U(1)'_{e\text{-}mu(tau)}$, best fit data

For DM=300GeV

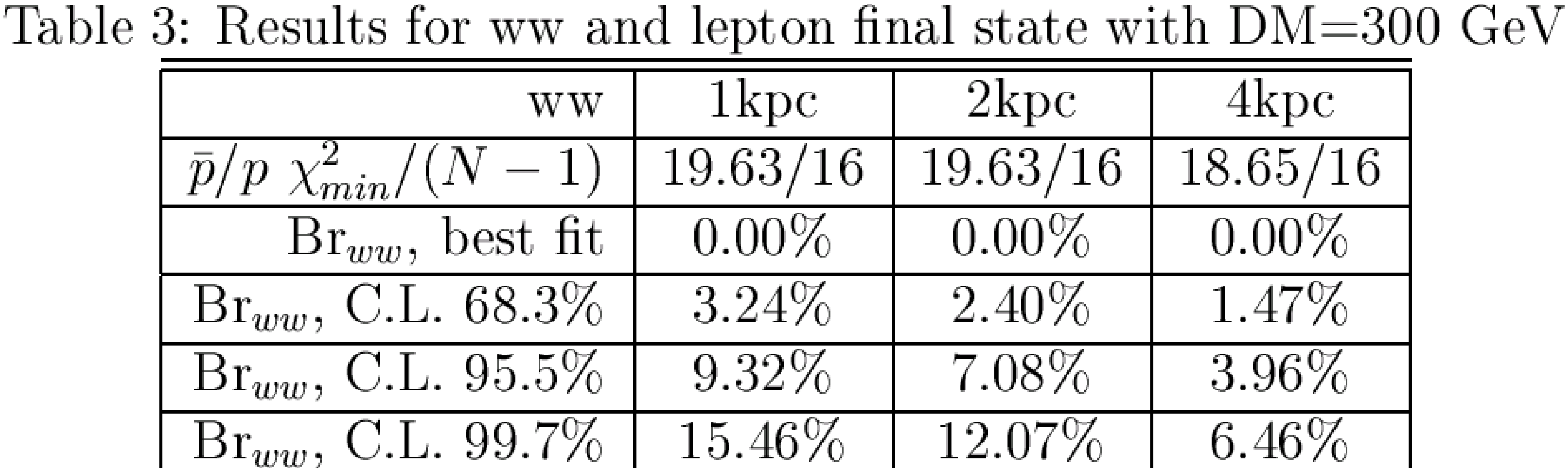
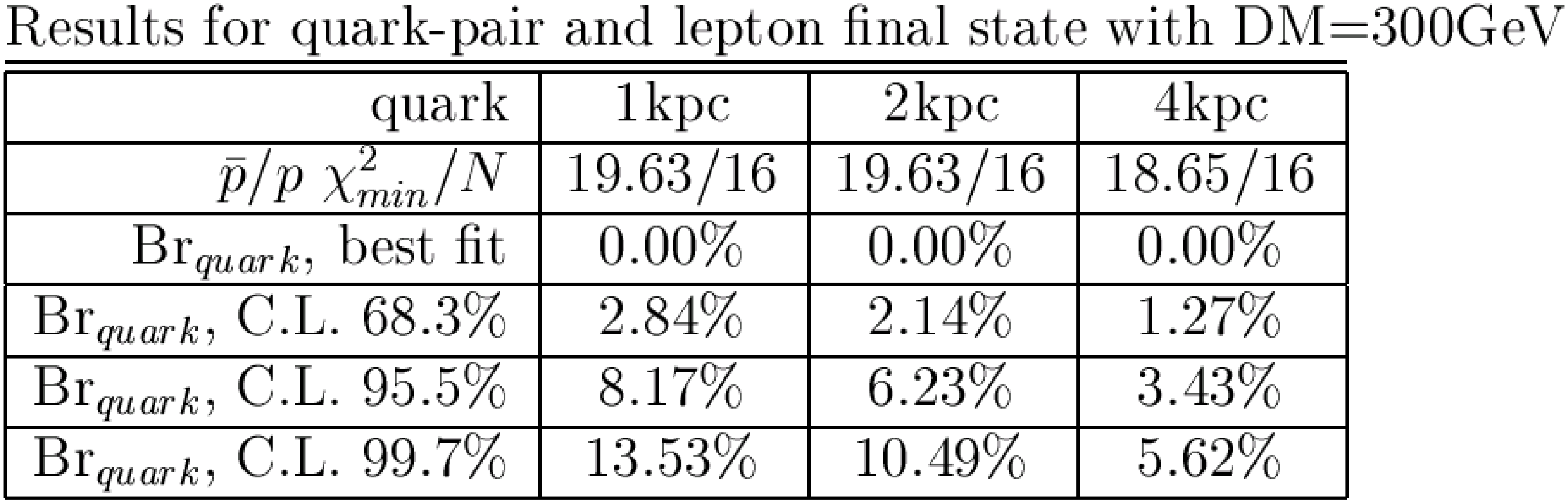


Table 3: Results for ww and lepton final state with DM=300 GeV

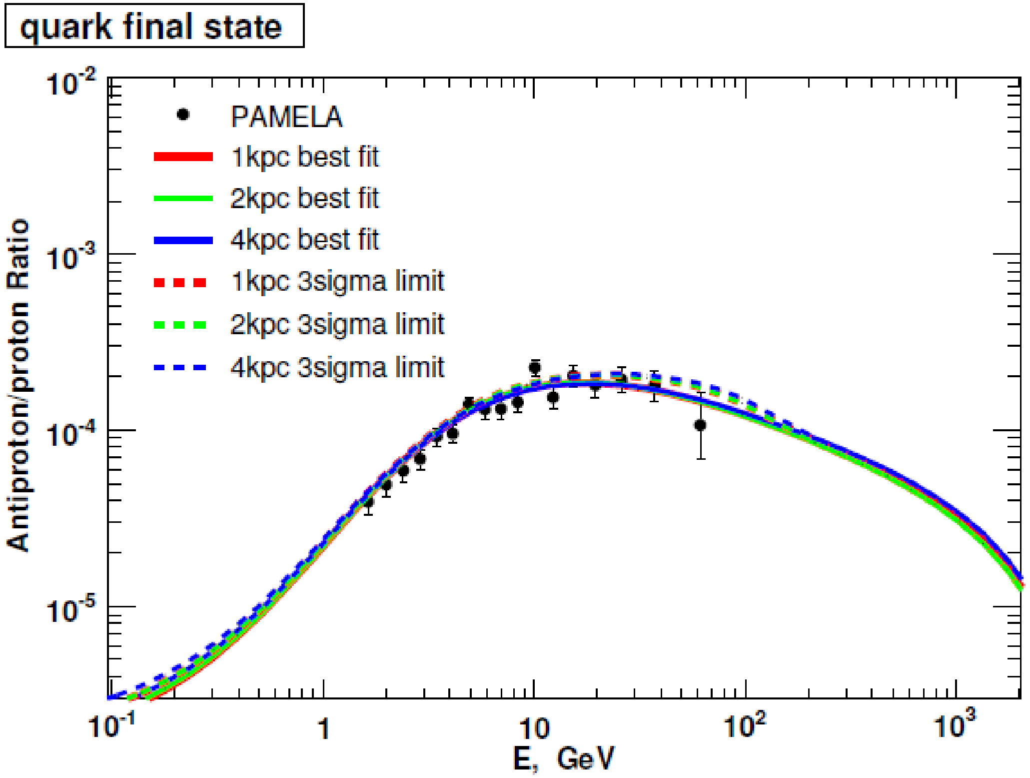
ww	1kpc	2kpc	4kpc
$\bar{p}/p\ \chi^2_{min}/(N-1)$	19.63/16	19.63/16	18.65/16
Br_{ww}, best fit	0.00%	0.00%	0.00%
Br_{ww}, C.L. 68.3%	3.24%	2.40%	1.47%
Br_{ww}, C.L. 95.5%	9.32%	7.08%	3.96%
Br_{ww}, C.L. 99.7%	15.46%	12.07%	6.46%

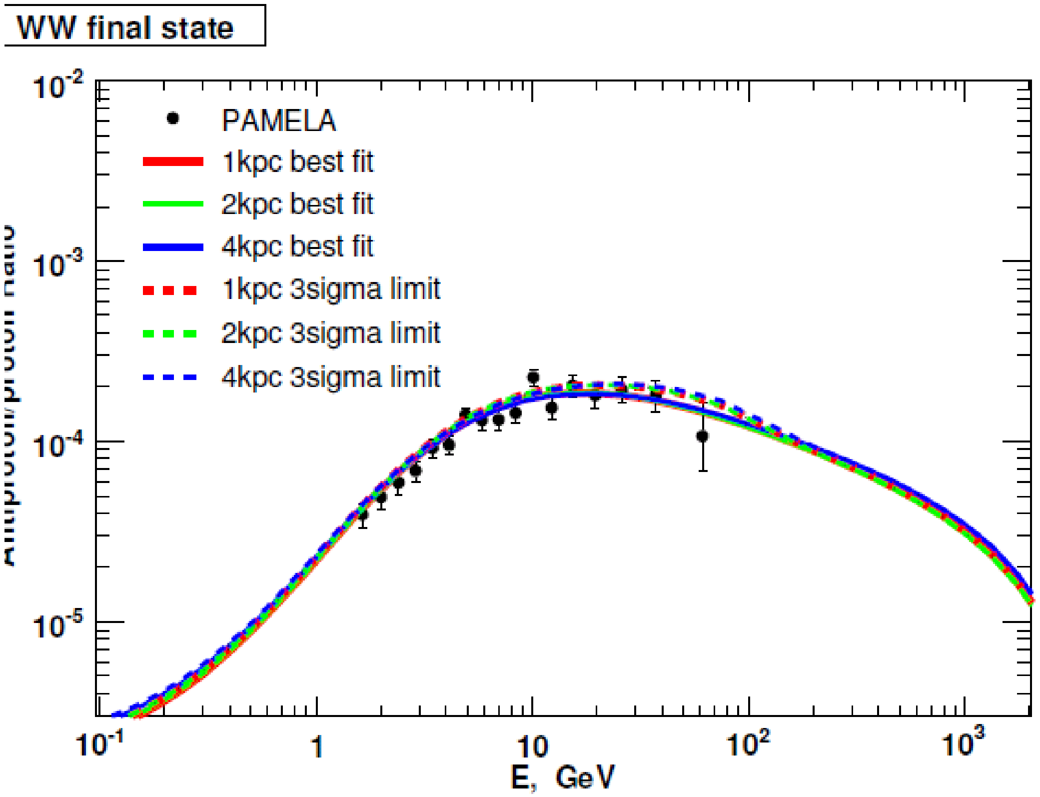


Results for quark-pair and lepton final state with DM=300GeV

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.

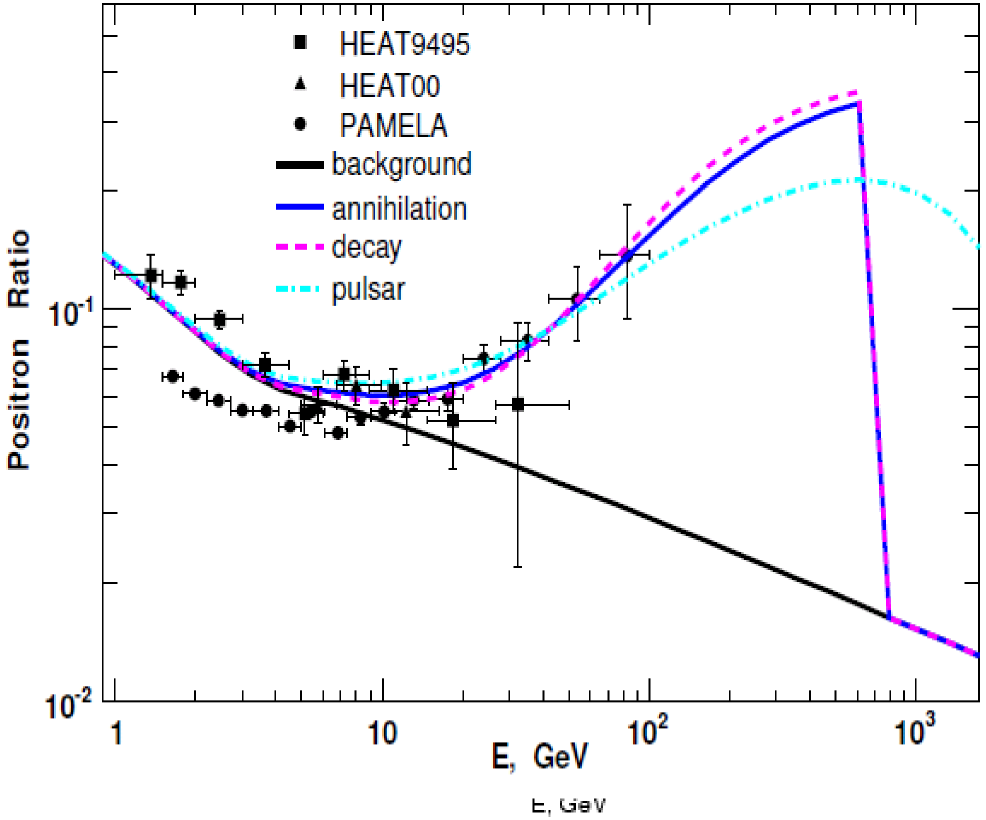
Radiations from these primary electrons/positrons to account for PAMELA and ATIC data

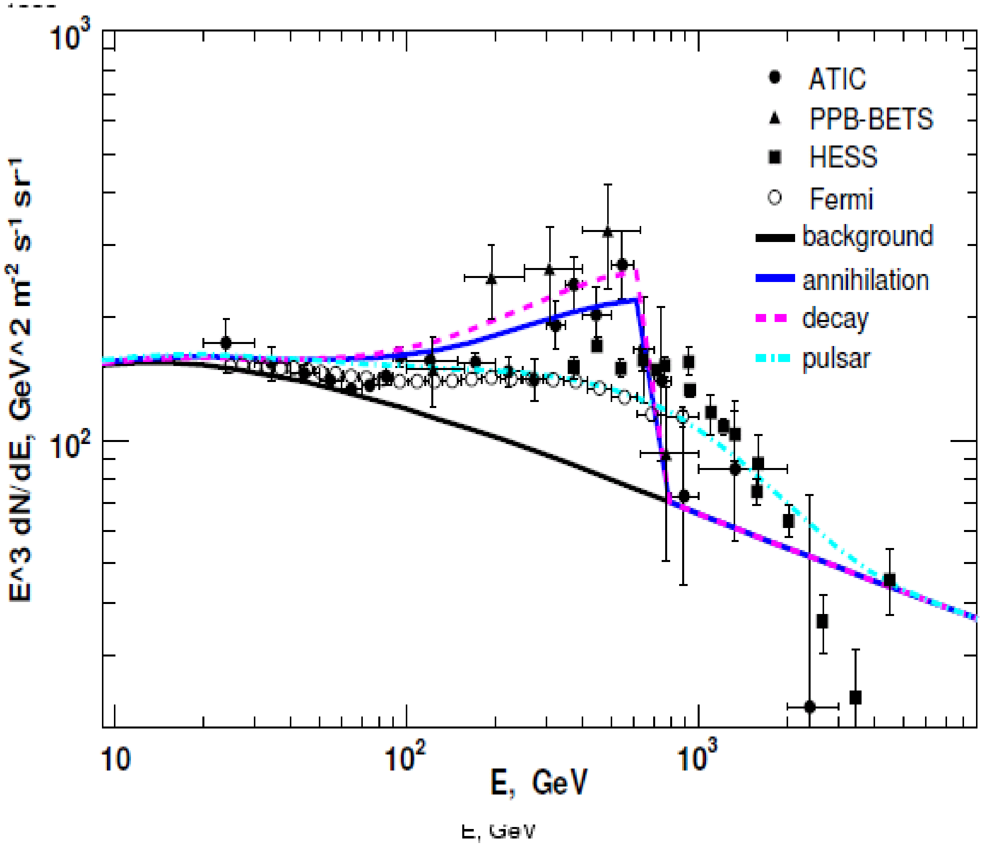
--- how to discriminate different scenarios?

Different models can work well

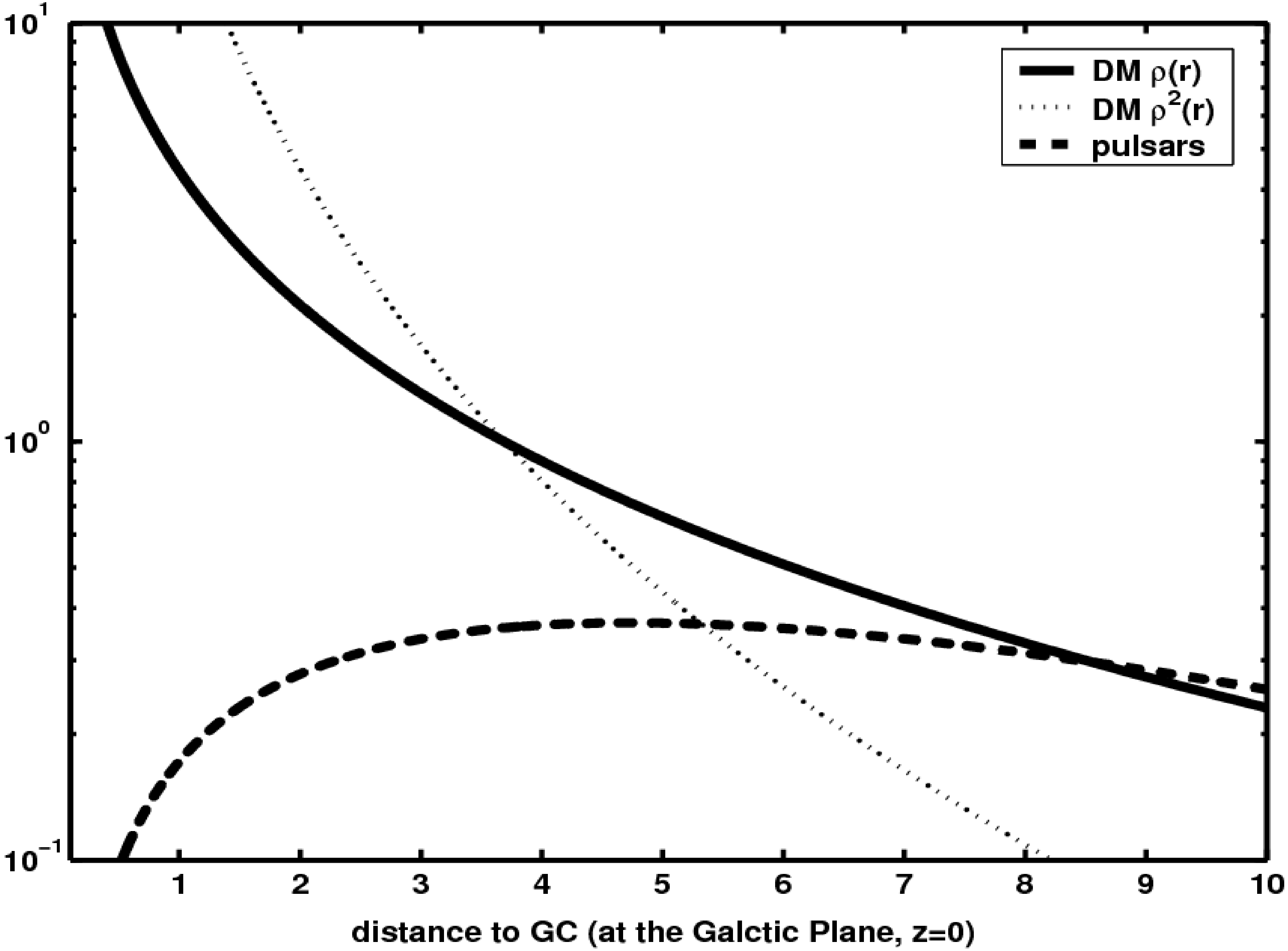
- Adjusting parameters, DM decay/annihilation, pulsars can all explain PAMELA and ATIC

Zhang, Bi, et al. 0812.0522





Source distribution

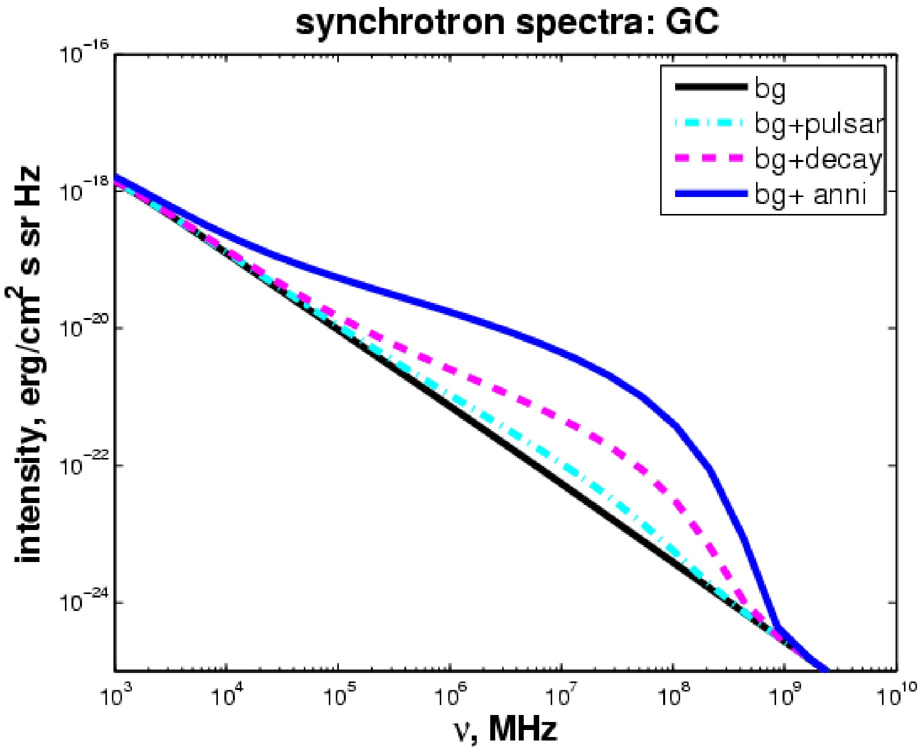


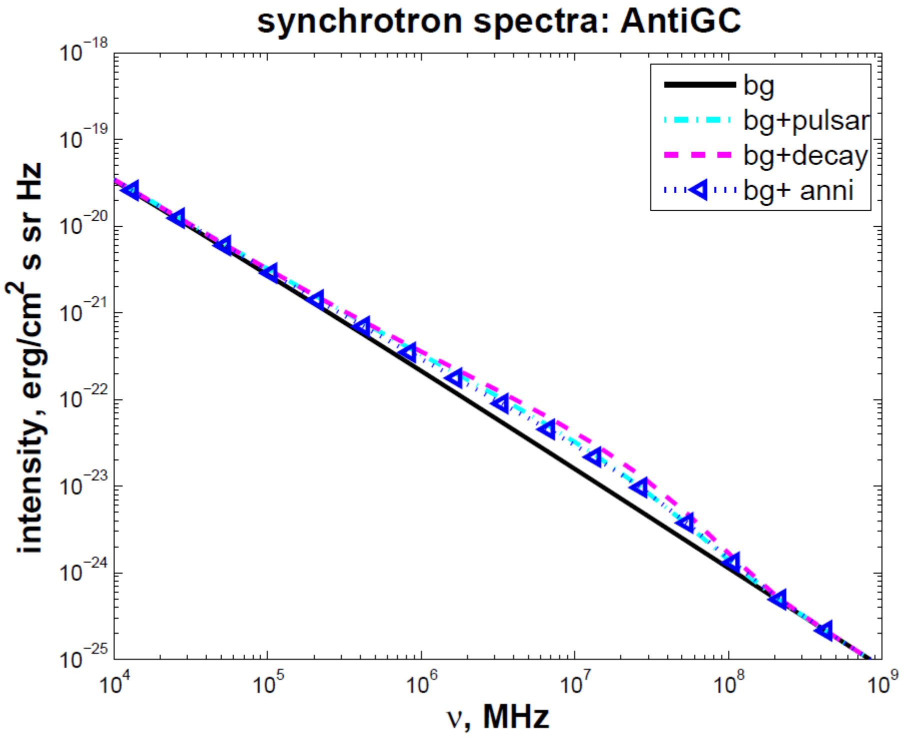
Galactic Pulsar source

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

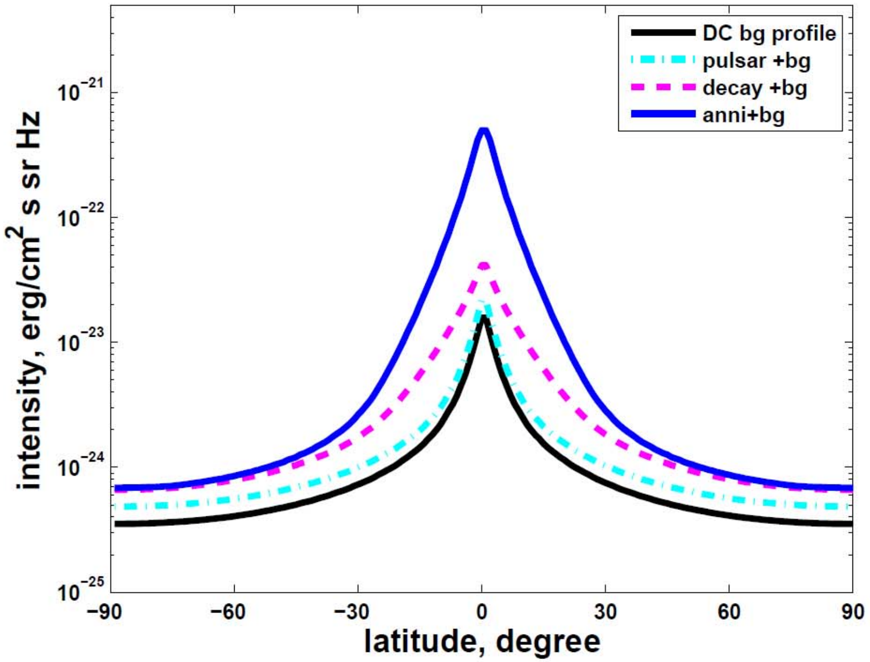
Can we test these scenarios?

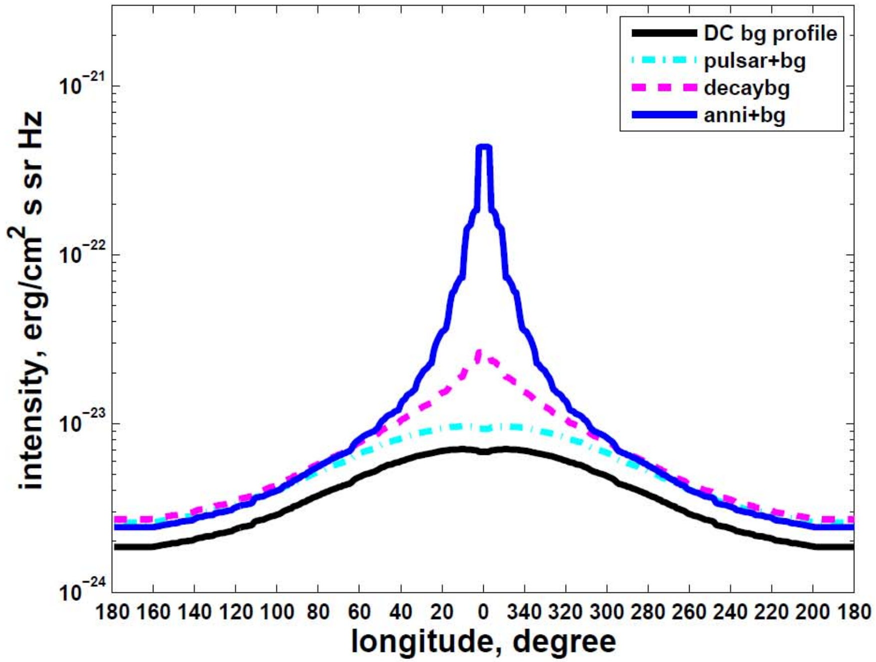
- Detect the synchrotron and IC gamma ray signals from the GC.

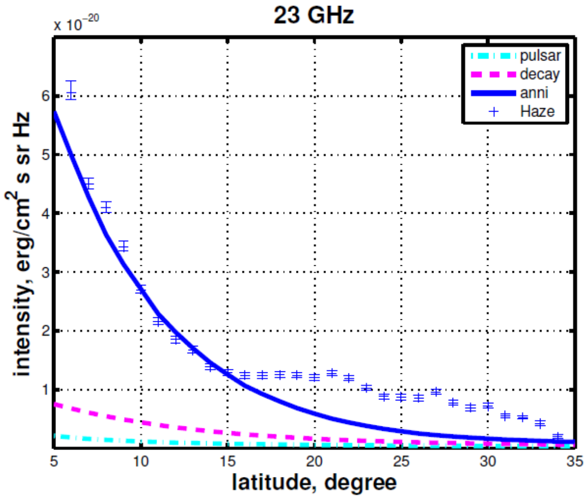


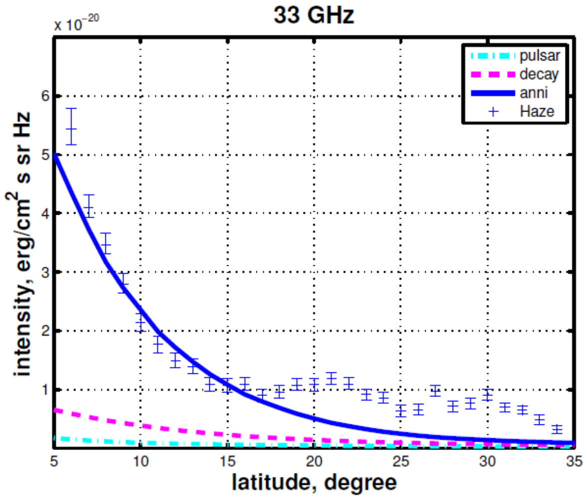


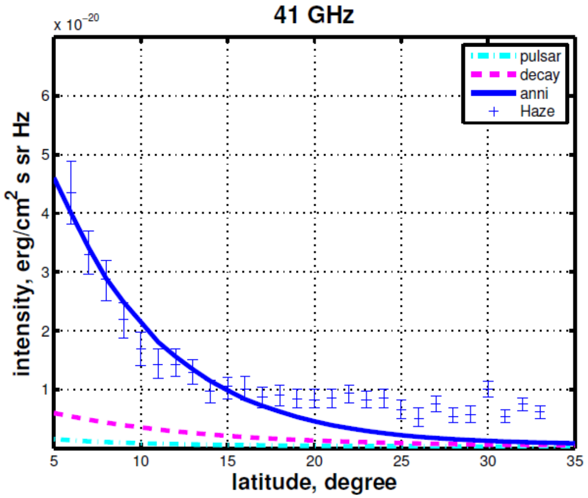
Synchrotron Profiles:

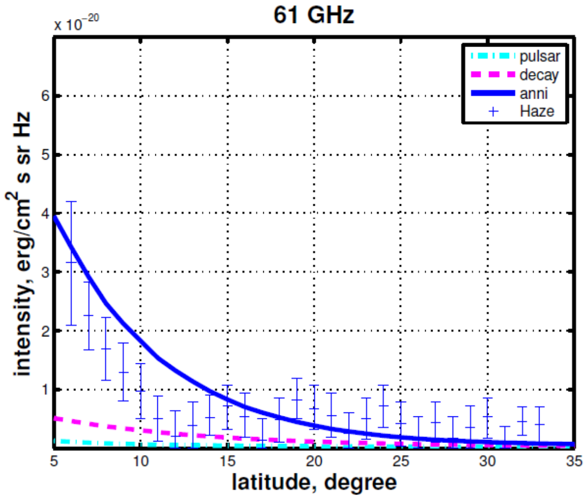




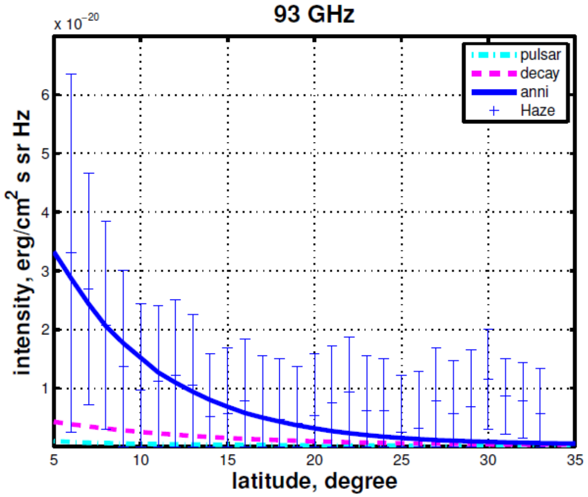




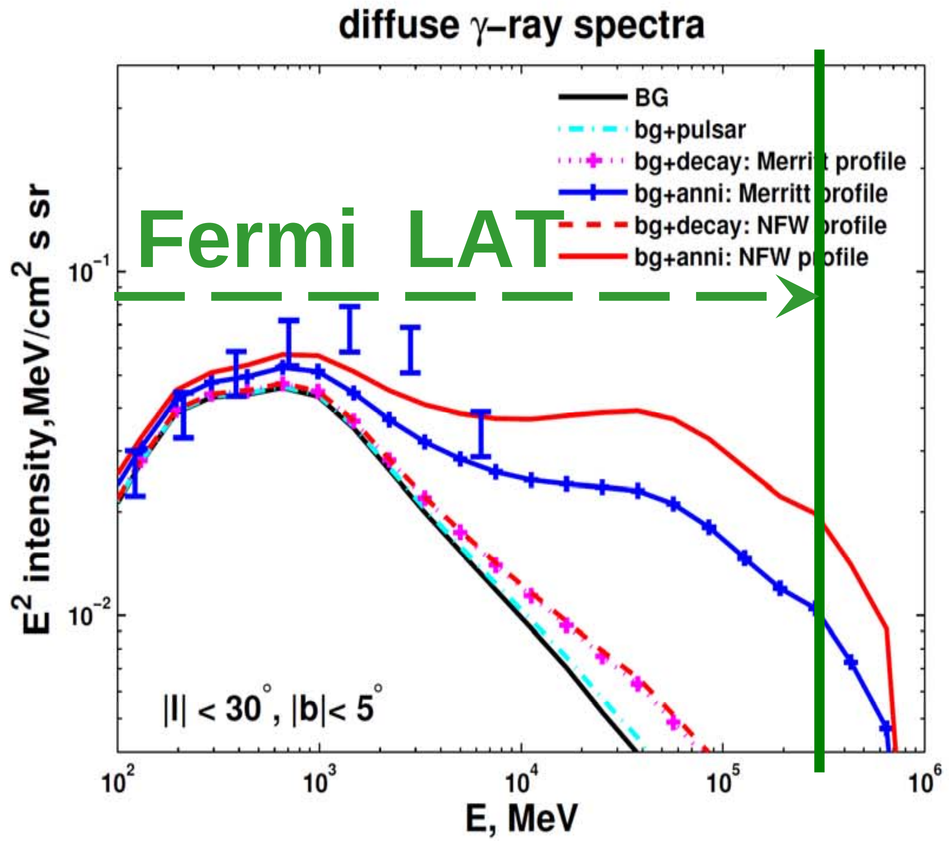


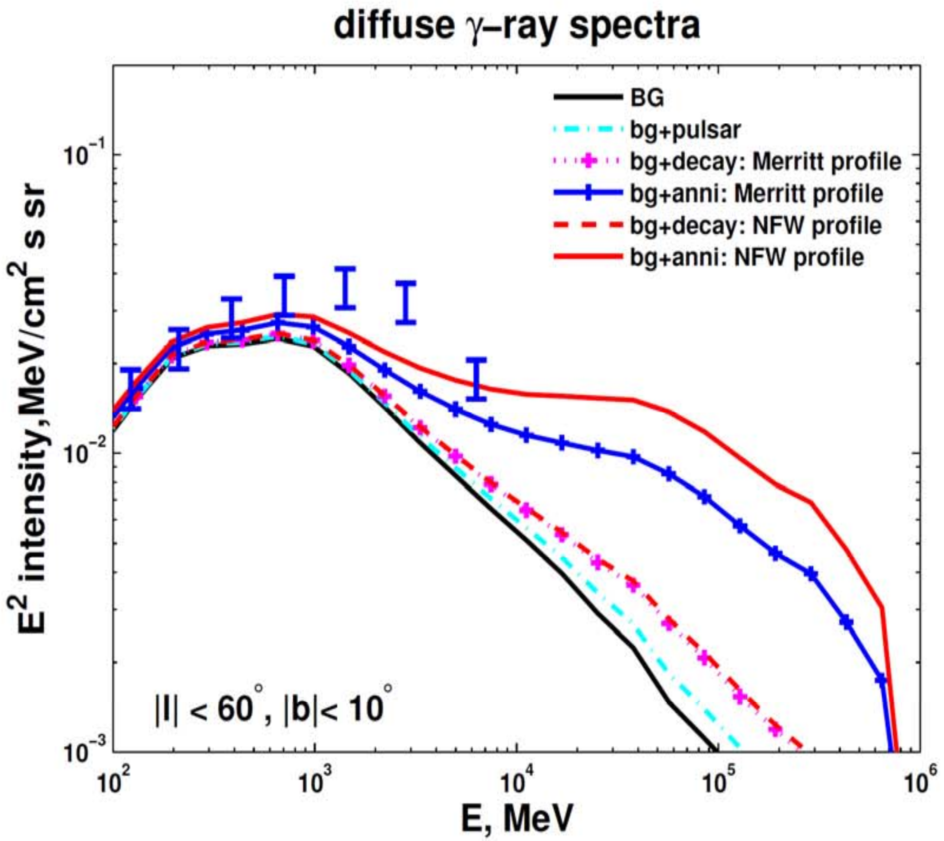


Compared with Haze data:



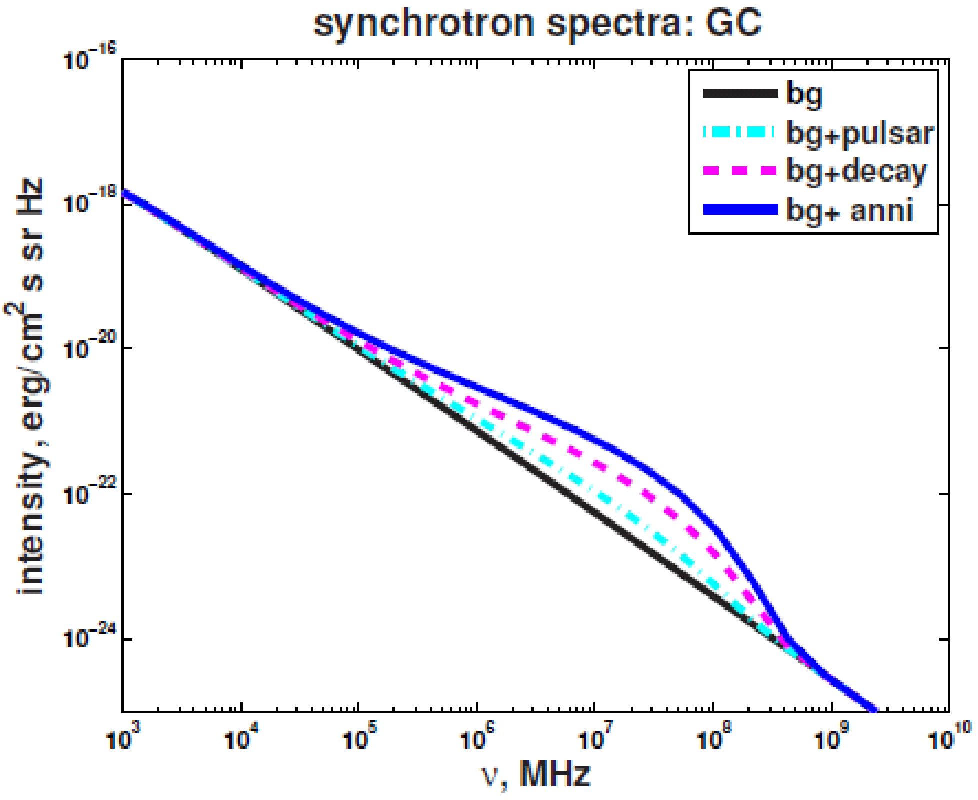
Diffuse gamma spectra:





Uncertainties of the prediction

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

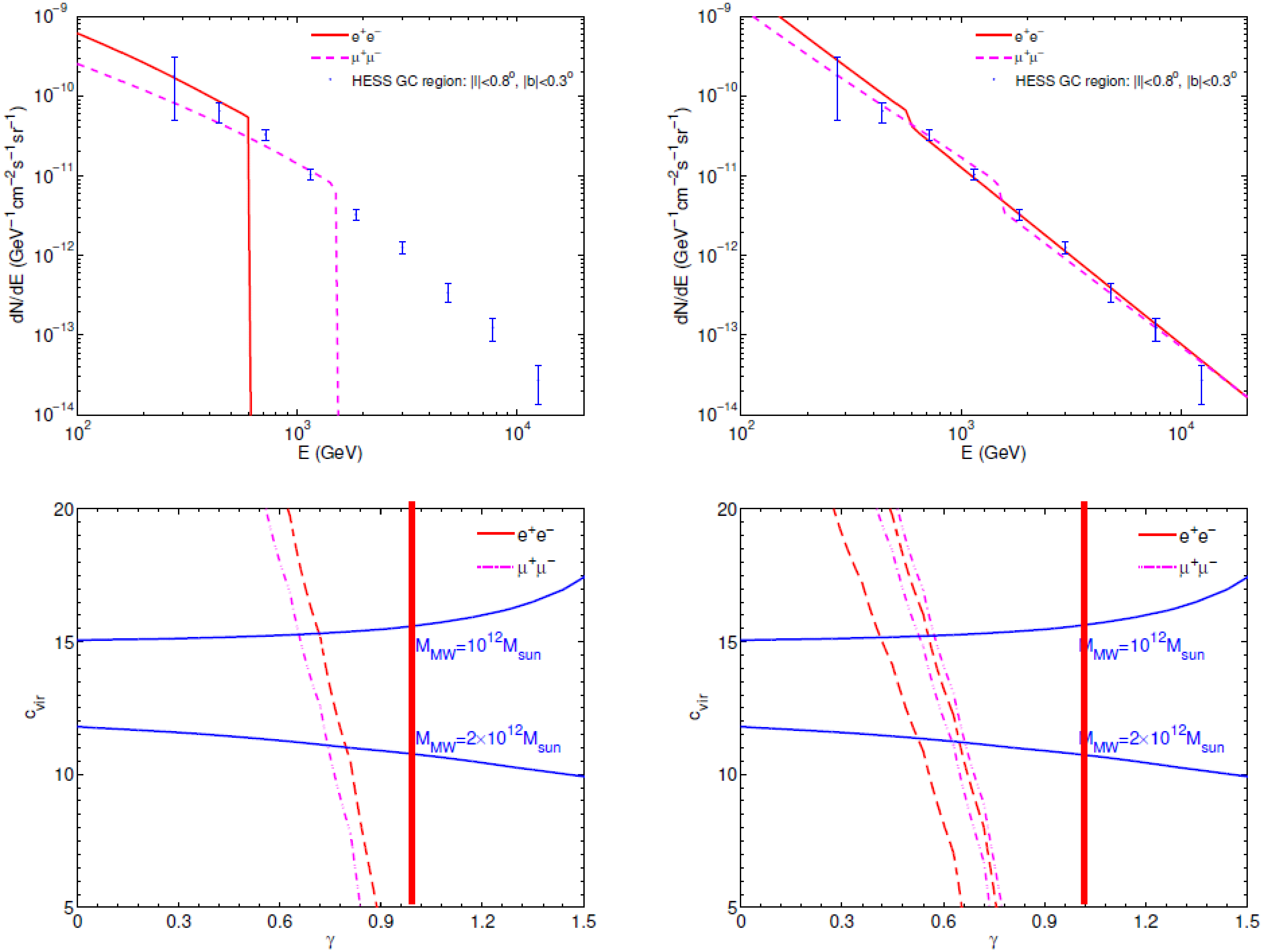


Emission from the GC

- Constraint on the central density of DM
- Tension

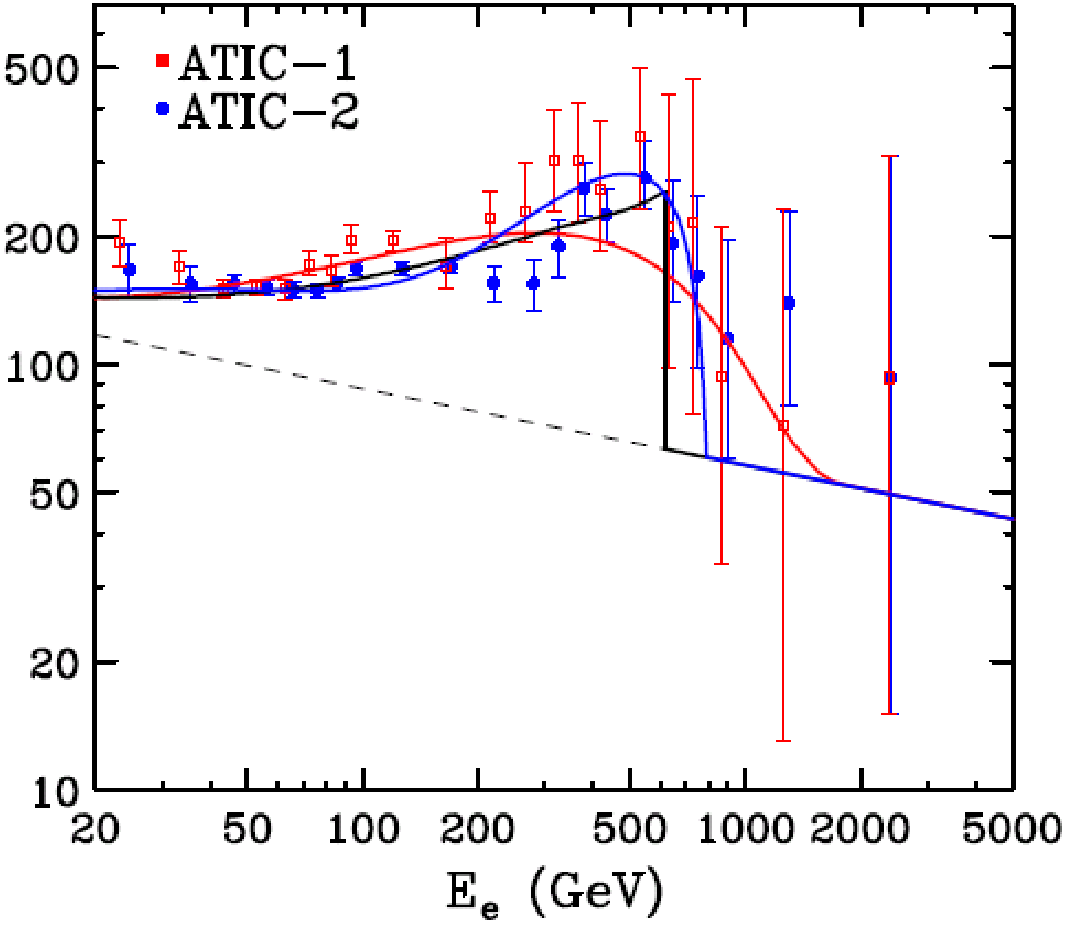
Exist for the annihilating DM scenario

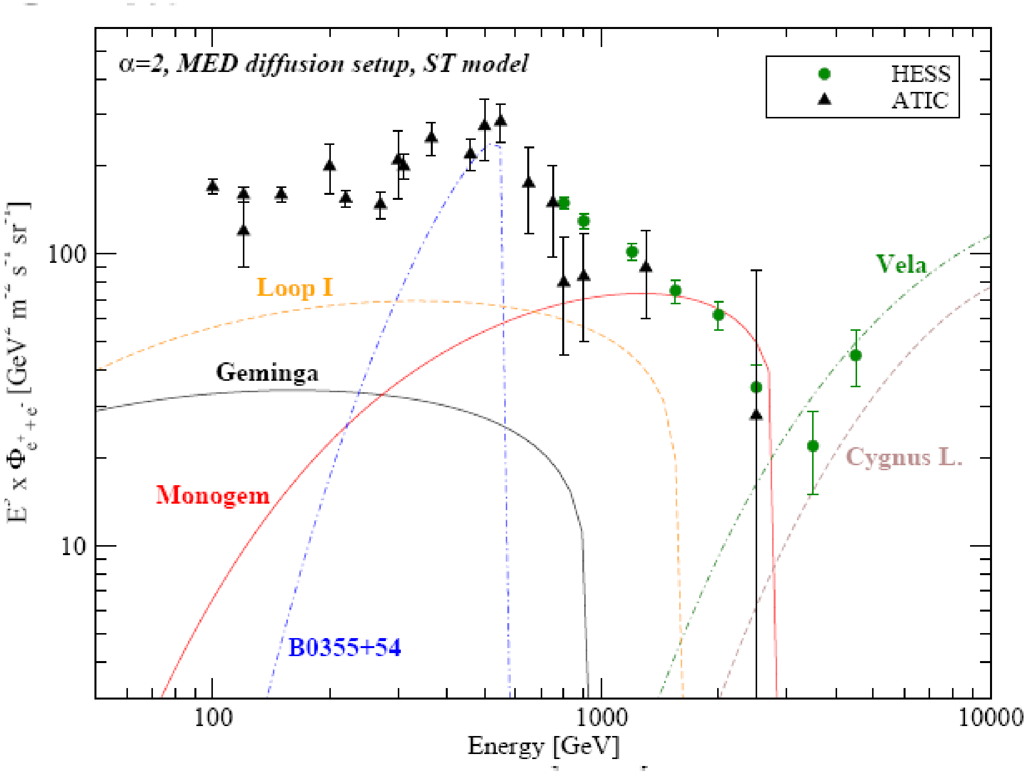
Bi et al., **0905.1253**



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

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

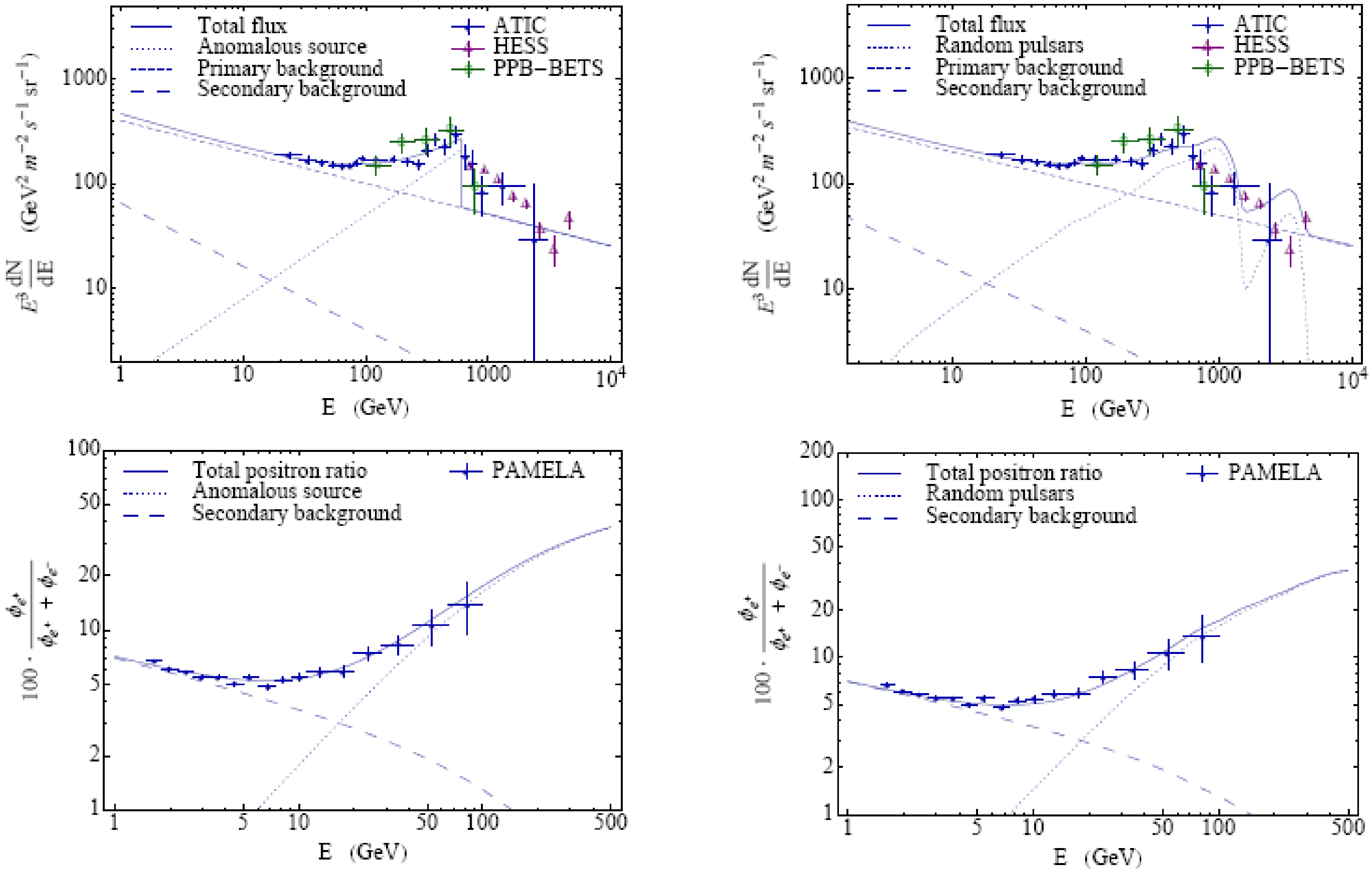




wever, pulsars can also result in sharp cut in some cases (Profumo, 0812.4457)

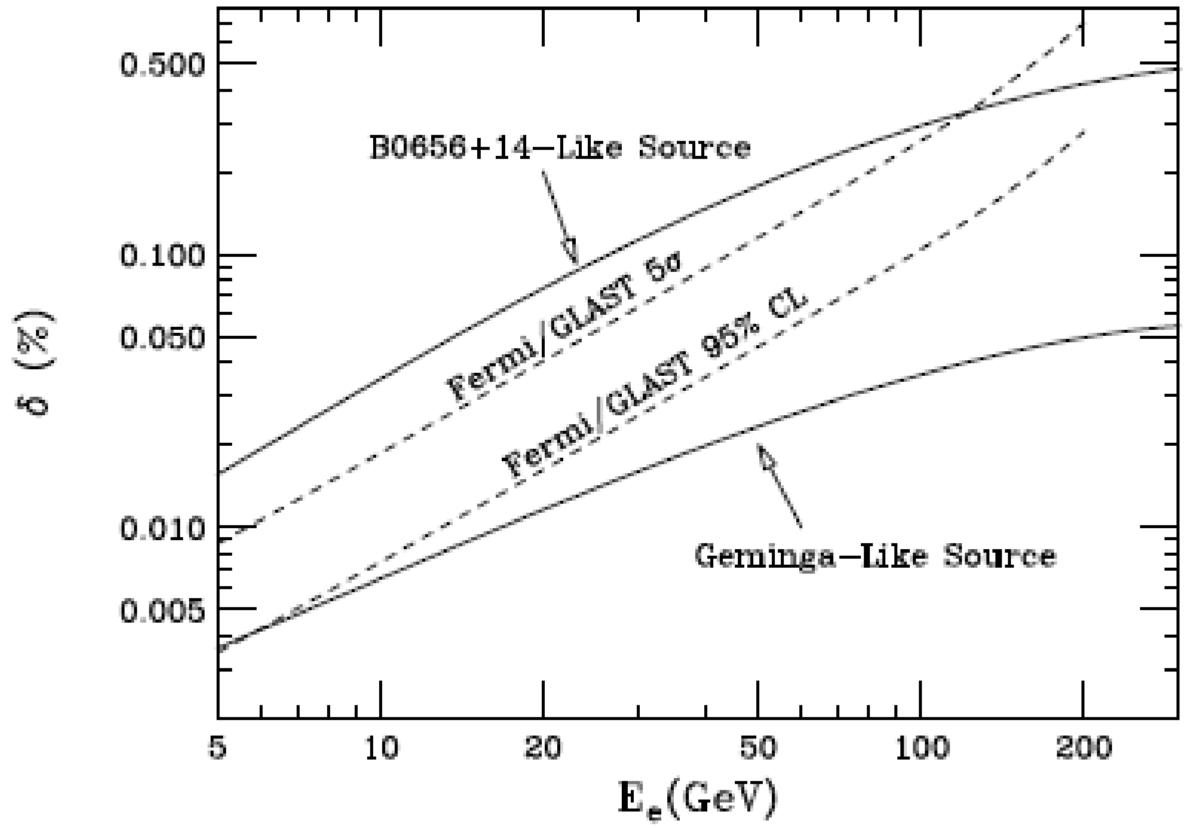
Discrimination I. precise electron spectrum (continued)

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.

Outlook

- PAMELA finally detect positron to 270GeV; antiproton to 190 GeV (published <100GeV)
- PAMELA detect e+e- to 2 TeV (not released)
- AMS02 launch at the end of 2009 (or 2010)
- Re-flight of ATIC for electrons (AREL) was proposed to NASA Mar. 2009
- Satellite detector for electron up to 10TeV proposed in China
- Fermi and HESS are cumulating more events