Neutrino Masses, Leptogenesis & Decaying Dark Matter

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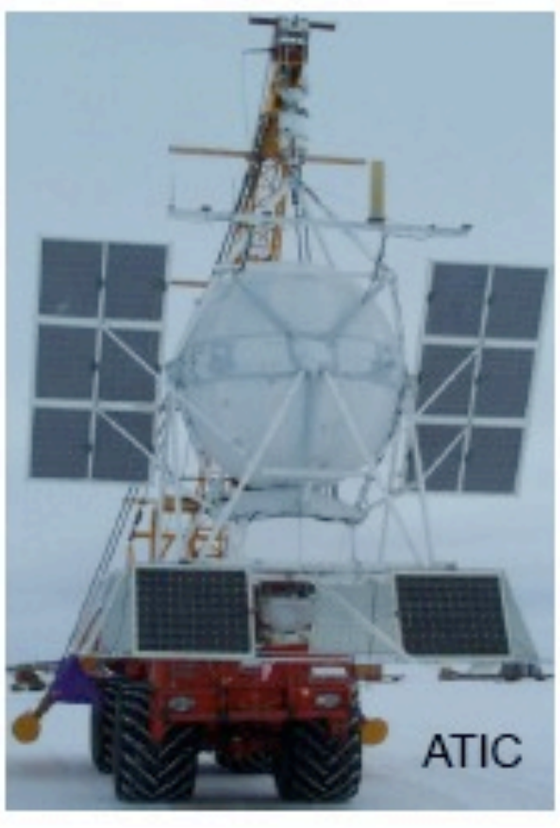
Dark matter interpretation on cosmic-ray anomalies

Dark Matter annihilates or decays in the halo / a place to positrons / some particles, which are detected by PAMELA/ATIC/Fermi… / an experiment.



Which DM can fit the data?

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Our Goals:

- To propose a model as simple as possible to resolve cosmic-ray anomalies

- To understand small neutrino masses

- To achieve leptogenesis

- To escape constraints from Gamma-ray data

- To have some LHC signatures

Fermionic Decaying DM model:

C.H.Chen, C.Q.Geng, D.Zhuridov, PLB675(09)77 [0901.2681 [hep-ph]]

New Particles: 1 scalar doublet η; 2 neutral leptons N_k

+ SM ← A minimal model

New particles are odd under Z_2 symmetry

The new Majorana mass term and Yukawa couplings can be written as

$$M_k N_k N_k + y_{ik} \bar{L}_i \eta N_k + \text{H.c.},$$

where L is the lepton doublet and i, k are the flavor indexes. We consider the mass spectrum $M_1 < M_2 < M_\eta$.

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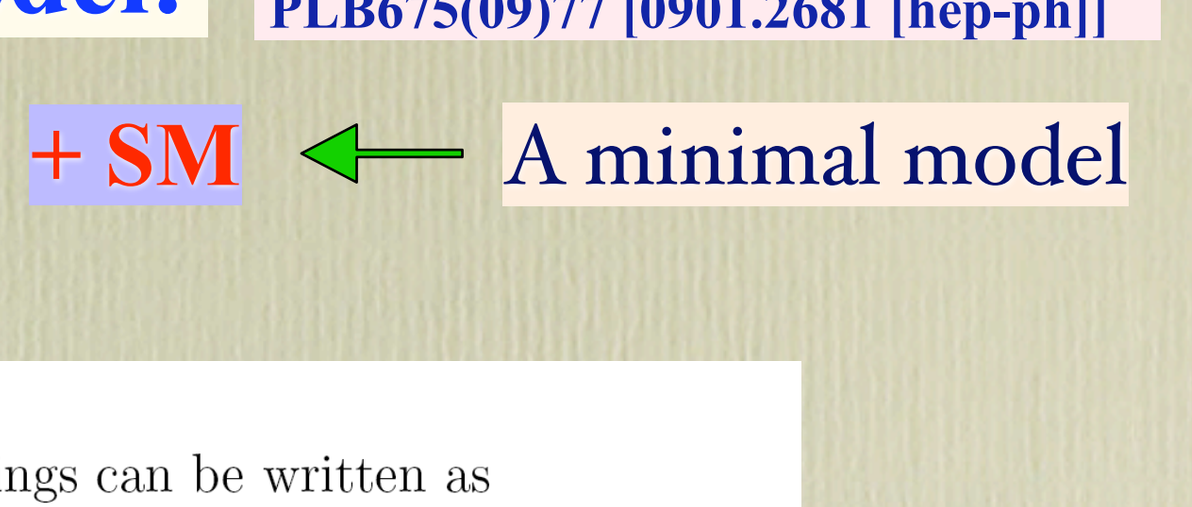
3-body DM decays:

$$\tau_{N_2} \simeq \frac{1}{\Gamma(N_2 \to N_1 \ell_i^\pm \ell_j^\mp)} = \frac{512(2\pi)^3}{5} \frac{M^4 M_2^3}{(M_{21}^2)^4},$$



where $M_{21}^2 = M_2^2 - M_1^2$ is the DM lepton mass splitting and $M \equiv M_\eta / y$ with $y \equiv |y_{ik}|$.

$$\frac{dN_e}{dE} = \frac{96 M_2^3}{(M_{21}^2)^4} \left[(M_{21}^2) E^2 - 2 M_2 E^3 \right]$$

The total electron and positron fluxes are

$$\Phi_{e^-} = \xi \Phi_{e^-}^{prim} + \Phi_{e^-}^{DM} + \Phi_{e^-}^{sec}$$

$$\Phi_{e^+} = \Phi_{e^+}^{DM} + \Phi_{e^+}^{sec},$$

Background:

Supernova shock and diffuse outward (primary)

$$\Phi_{e^-}^{prim}(E) = \frac{0.16 E^{-1.1}}{1 + 11 E^{0.9} + 3.2 E^{2.15}} \quad [\mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}]$$

collisions among cosmic ray nuclei and intersellar medium (secondary)

$$\Phi_{e^-}^{sec}(E) = \frac{0.7 E^{0.7}}{1 + 110 E^{1.5} + 600 E^{2.9} + 580 E^{4.2}} \quad [\mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}]$$

$$\Phi_{e^+}^{sec}(E) = \frac{4.5 E^{0.7}}{1 + 650 E^{2.3} + 1500 E^{4.2}} \quad [\mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}],$$

The DM component of the primary electron/positron flux is given by

$$\Phi_e^{DM}(E) = \frac{c}{4\pi M_2 \tau_{N_2}} \int_0^{M_{21}^2/(2M_2)} dE' G(E,E') \frac{dN_e}{dE'},$$

$$G(E,E') \simeq \frac{10^{16}}{E^2} \exp[a + b(E^{\delta-1} - E'^{\delta-1})]\theta(E'-E) \quad [\mathrm{cm}^{-3}\mathrm{s}]$$

TABLE I: Coefficients of the approximate positron Green function of the NFW halo profile and the diffusion parameter δ for the propagation models of M1, MED and M2, respectively.

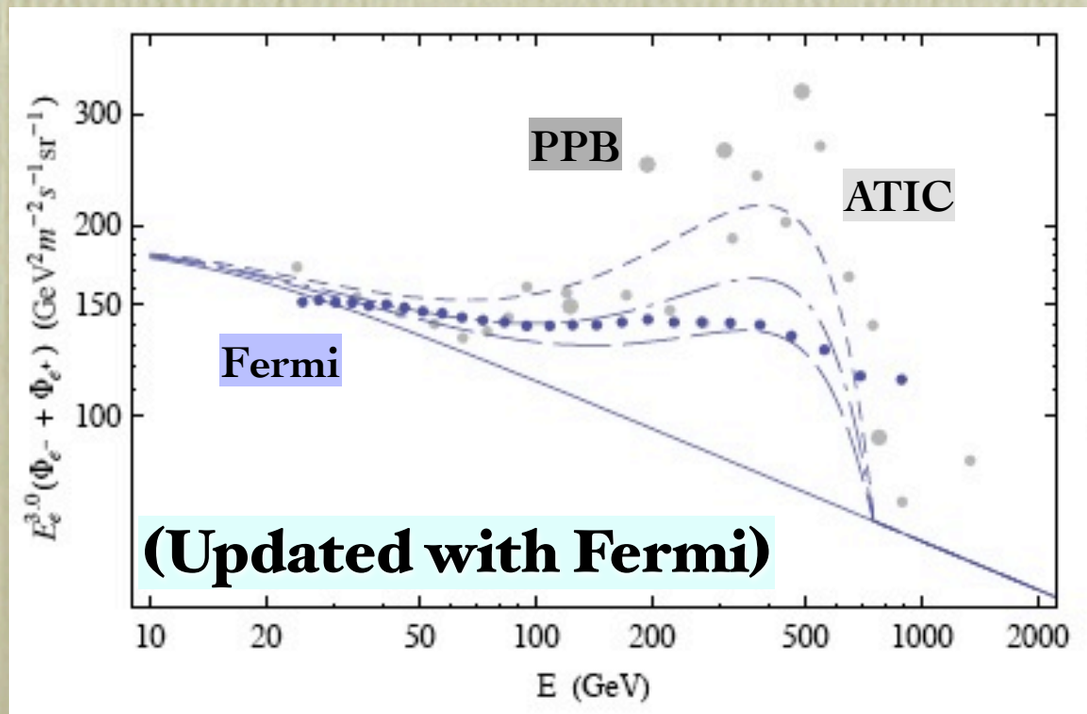
Model	δ	a	b
M1	0.46	−0.9809	−1.1456
MED	0.70	−1.0203	−1.4493
M2	0.55	−0.9716	−10.012

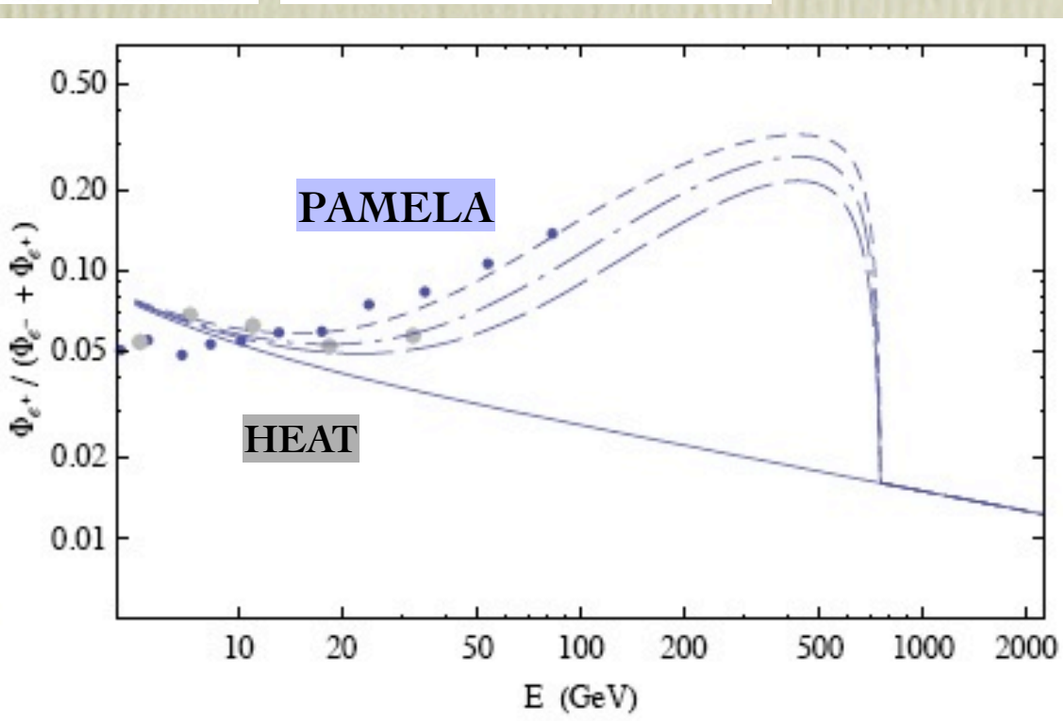
– – – – – – $M1$

— · — · — · — MED

— — — — — $M2$

$\tau_2 \sim 10^{24}\mathrm{s}$, $M_1 = 98.2$ TeV, $M_2 = 100$ TeV $M = 3 \times 10^{15}$ GeV





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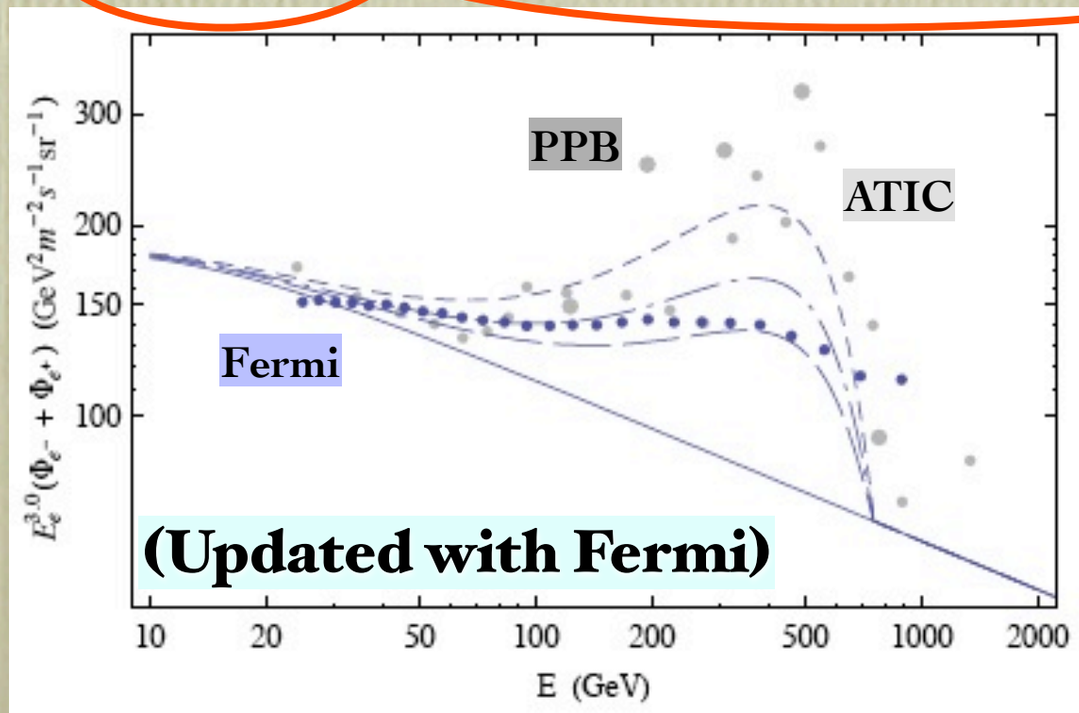
$10^{17}\ \mathrm{s} \ll \tau_2 \lesssim 10^{26}\ \mathrm{s}$

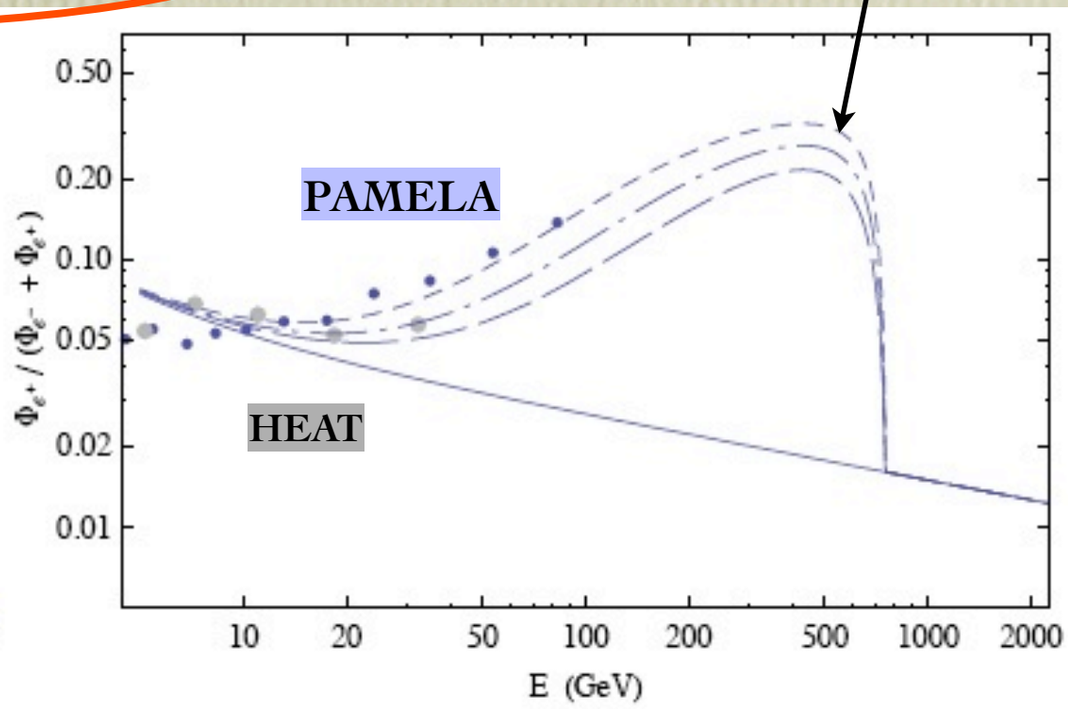
3-body: $M_{21}^2/(2M_2)$

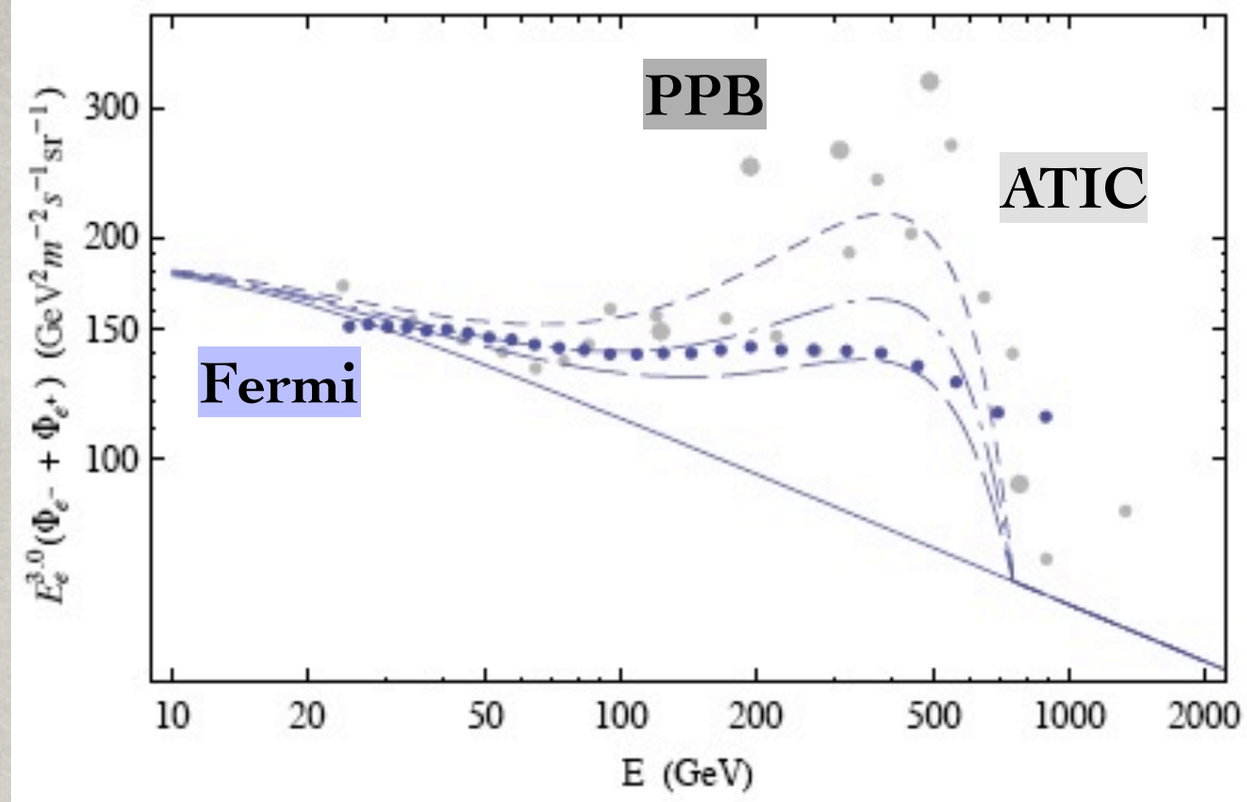
two-body decays

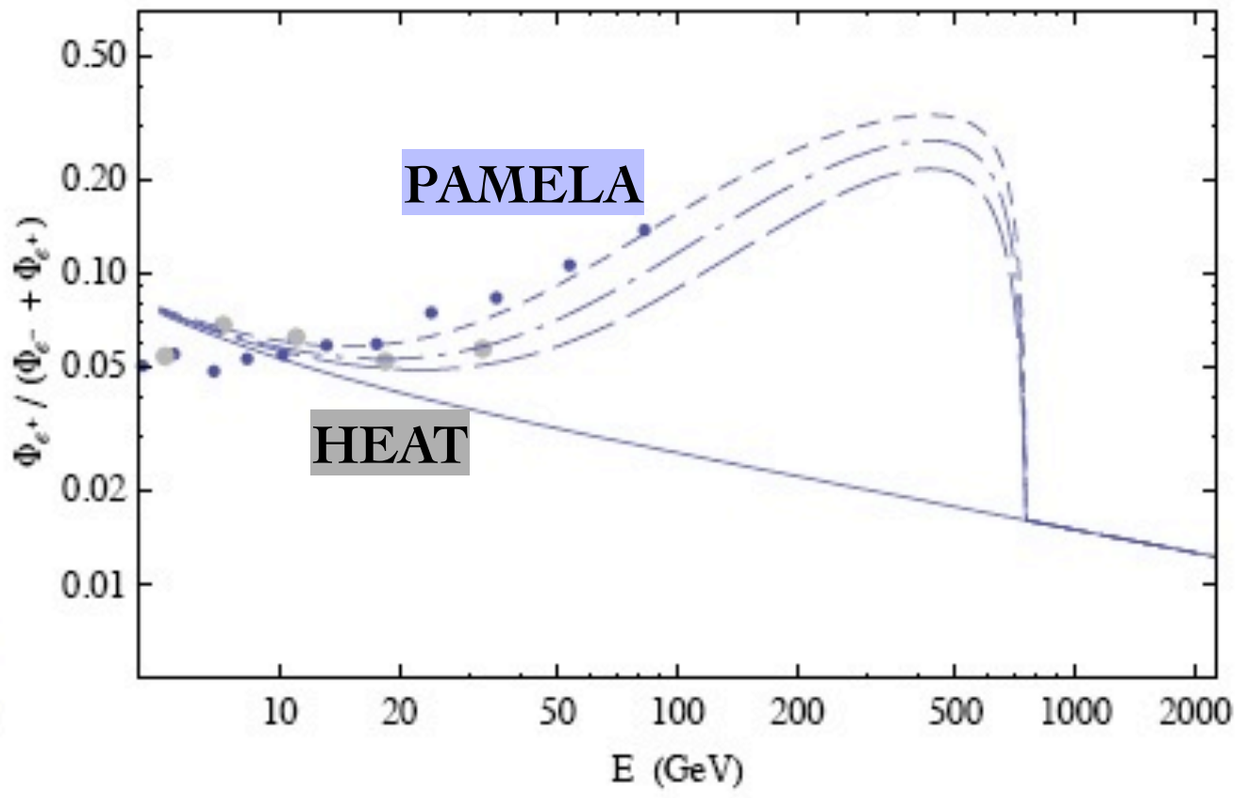
(DM mass)/2

$\tau_2 \sim 10^{24}\mathrm{s}$; $M_1 = 98.2\ \mathrm{TeV},\ M_2 = 100\ \mathrm{TeV}$ $M = 3 \times 10^{15}\ \mathrm{GeV}$









$\tau_2 \sim 10^{26}$s, $M_1 = 10$ GeV, $M_2 = 1.5$ TeV

MED propagation

$- - - - - - - M = 4 \times 10^{15}$ GeV

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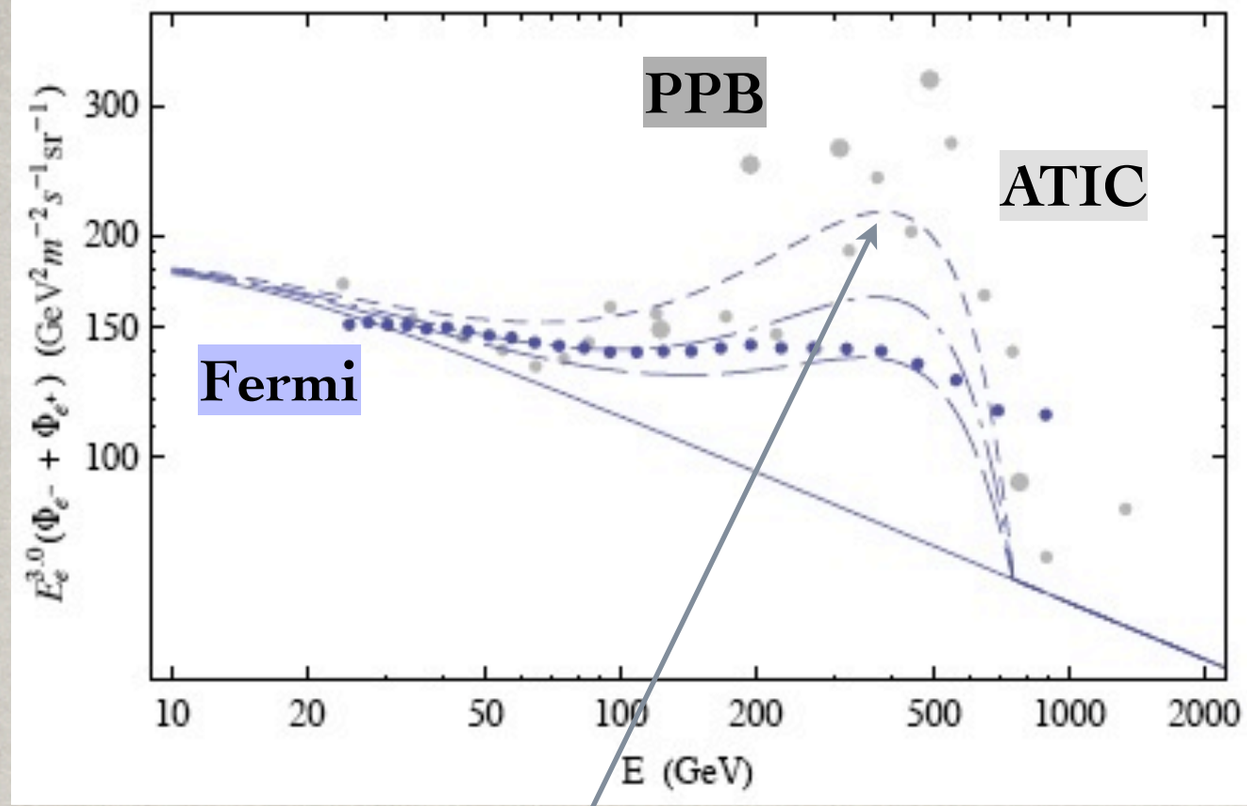

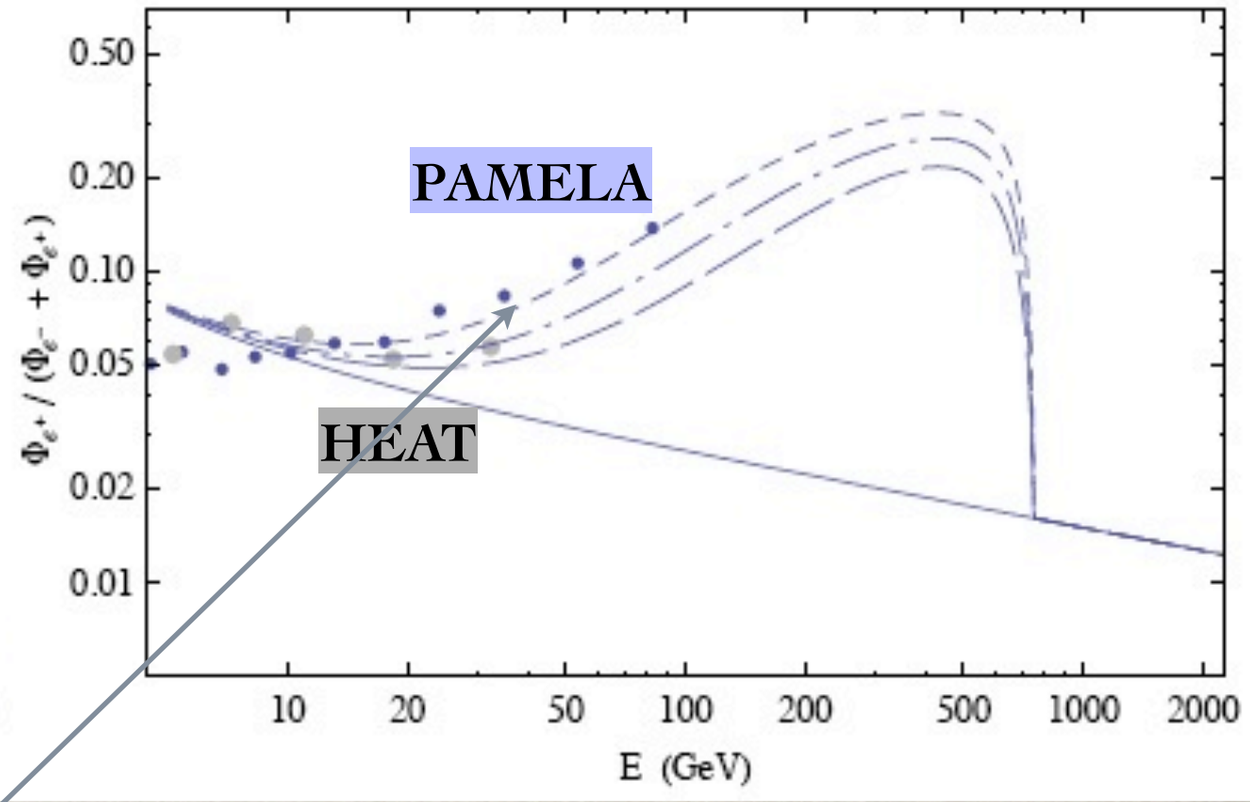

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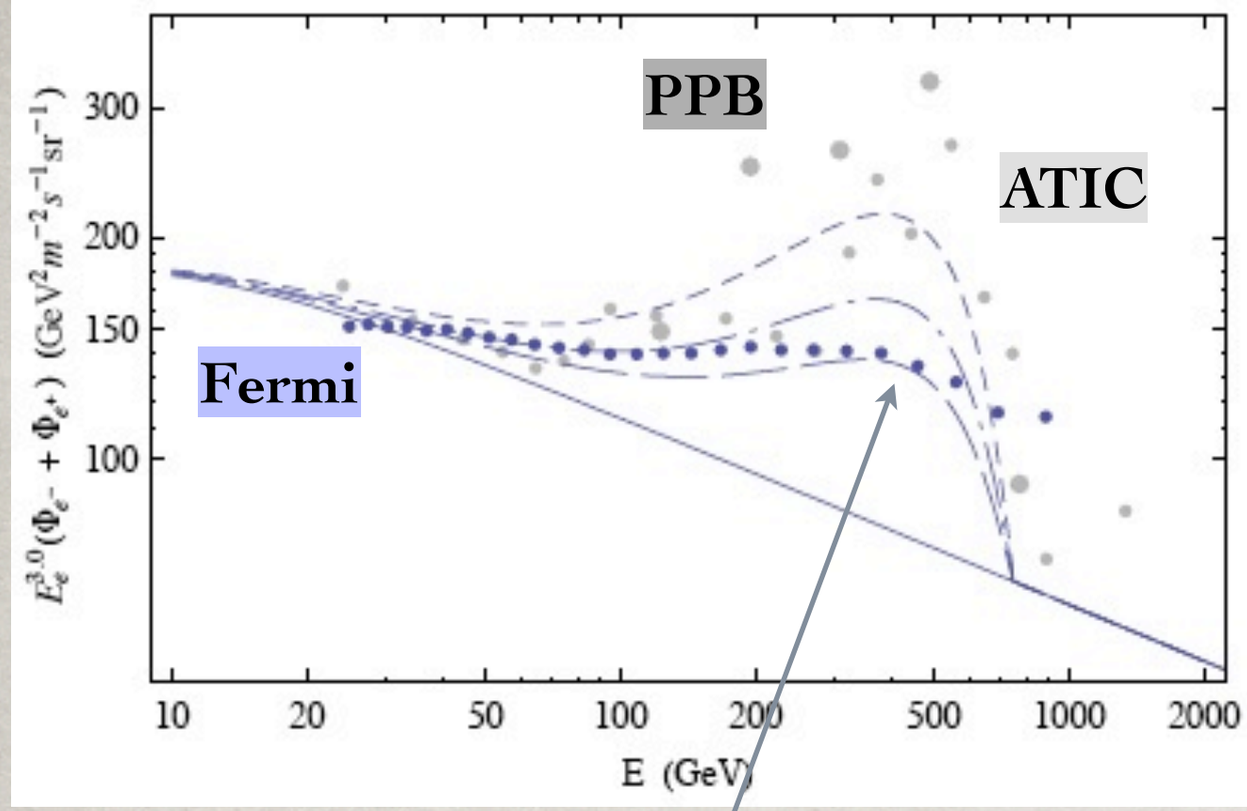
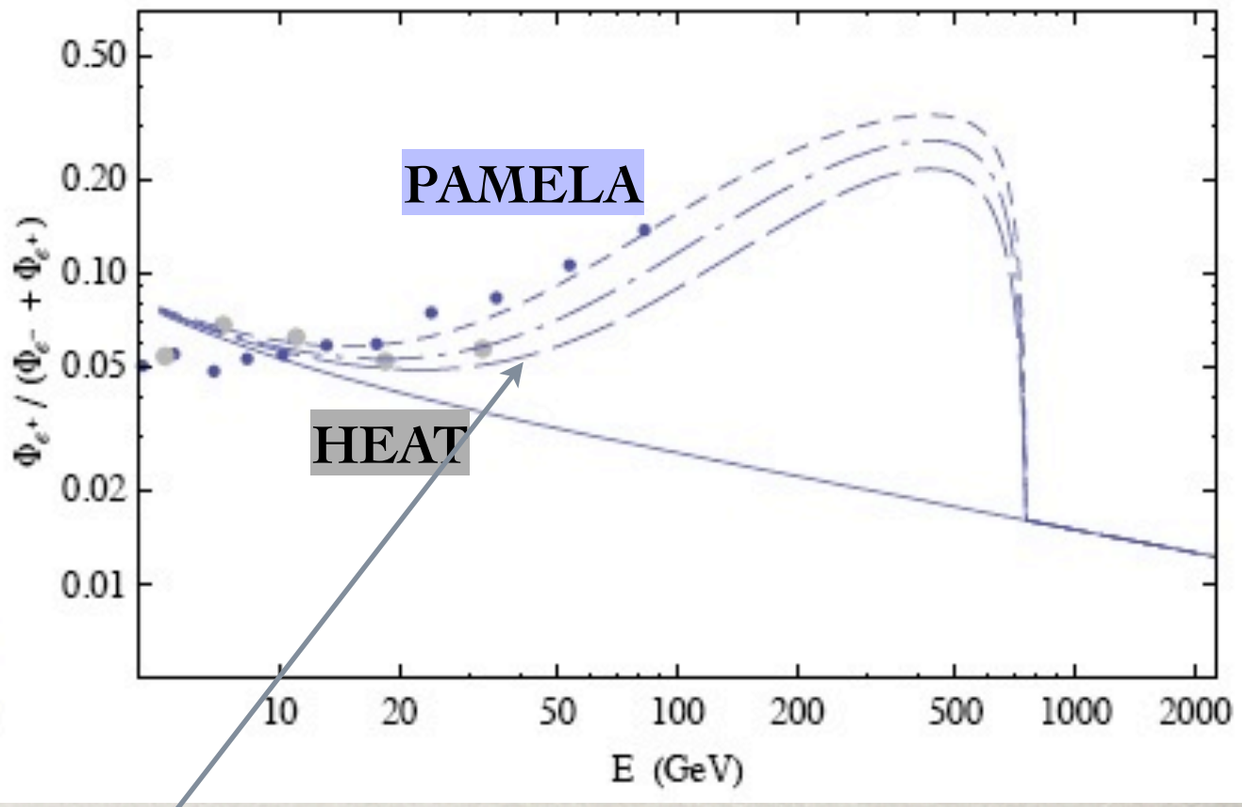
☞ **ATIC and PAMELA can be fitted well simultaneously**





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☞ **ATIC and PAMELA can be fitted well simultaneously**

BUT Fermi and PAMELA canNOT

A dark matter model with realistic neutrino masses and leptogenesis:

Chen, CQG and Zhuridov, JCAP 0910, 001 (2009), arXiv:0906.1646 [hep-ph]

Particle	ζ	η	N_i	N
Z_2	$-$	$+$	$-$	$+$
Z_2'	$+$	$-$	$+$	$-$

Z_2

$$\frac{M_{ij}}{2} N_i^T C N_j + \frac{M}{2} N^T C N + y_{ij} \bar{L}_i \zeta N_j + y'_i \bar{L}_i \eta N + \mu^2 \eta^\dagger \zeta + \text{H.c.},$$

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Z_2

Neutrino masses:

$$(m_\nu)_{ij} = \frac{\mathcal{O}(\lambda)}{16\pi^2} \sum_{k=1}^{2} \frac{y_{ik} y_{jk}}{M_k} v^2$$

$m_\nu = \mathcal{O}(0.01 - 0.1 \text{ eV})$ if $\lambda = \mathcal{O}(10^{-4})$, $y_{ij} = \mathcal{O}(10^{-3})$

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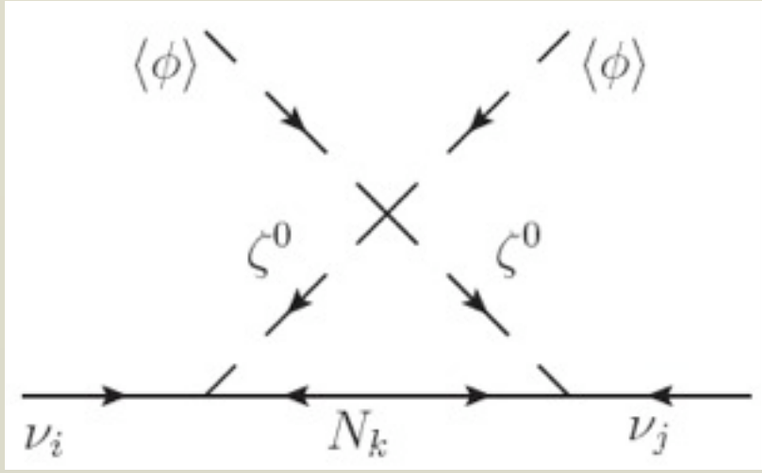

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ϕ is the SM Higgs boson.

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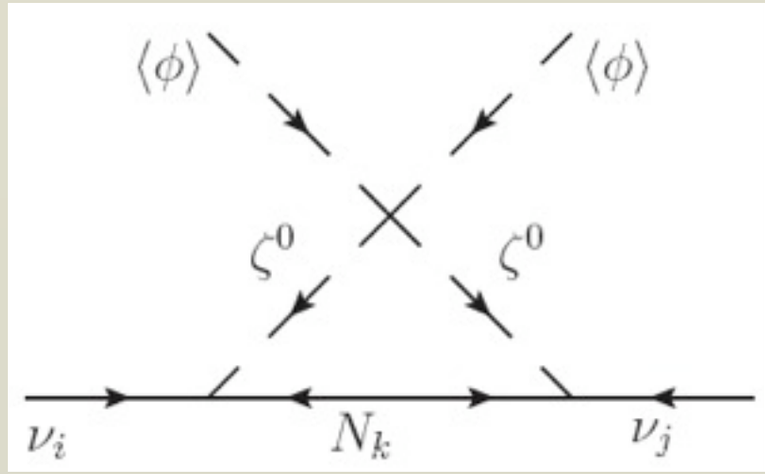

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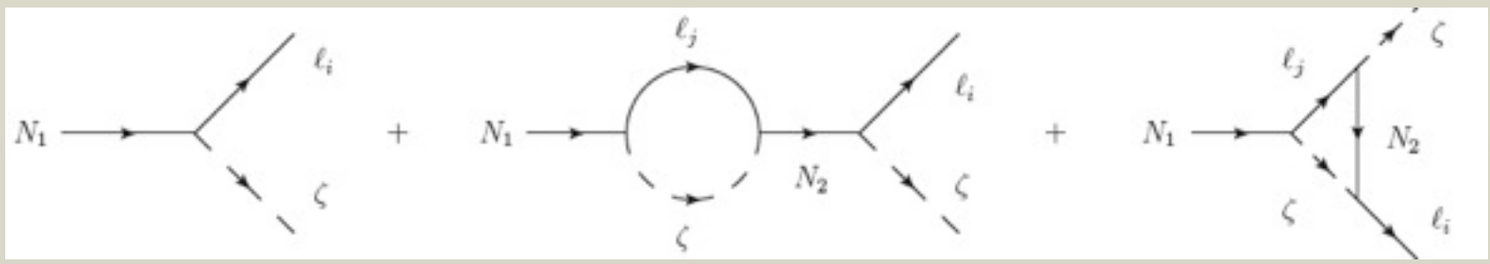
Leptogenesis:

$$\varepsilon \simeq -\frac{3}{16\pi} \frac{1}{(y^\dagger y)_{11}} \text{Im}\left[(y^\dagger y)^2_{12}\right] \frac{M_1}{M_2}.$$

$$\frac{n_B}{s} \simeq -\frac{1}{15} \frac{\varepsilon}{g_*} \simeq 10^{-10}$$

$$g_* \simeq 100$$



DM decays:

$$\Gamma_i = \frac{|y'_i|^2}{4\pi}\left(\frac{|\mu|}{M_\eta}\right)^4 \frac{M_-^2}{M}, \quad \tau_N = \frac{1}{4\sum_i \Gamma_i} = \frac{\pi A^4 M}{M_-^2}$$

$$A = \frac{M_\eta}{|\mu|(\sum_i |y'_i|^2)^{1/4}}, \qquad M_\pm = \frac{M^2 \pm M_\zeta^2}{2M} \qquad \varepsilon = |y'_\mu|^2/|y'_e|^2$$

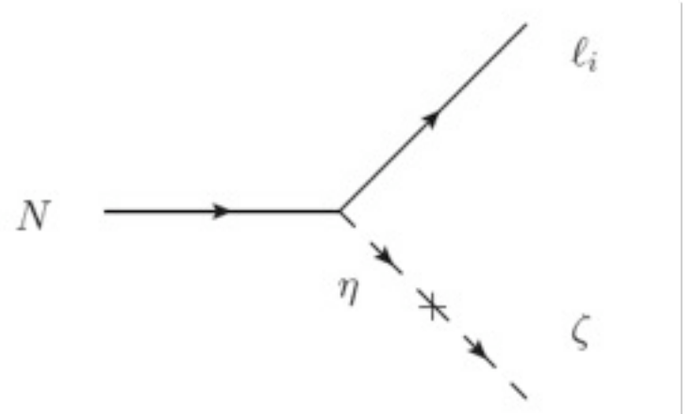


FIG. 3: Diagram for the DM decay.

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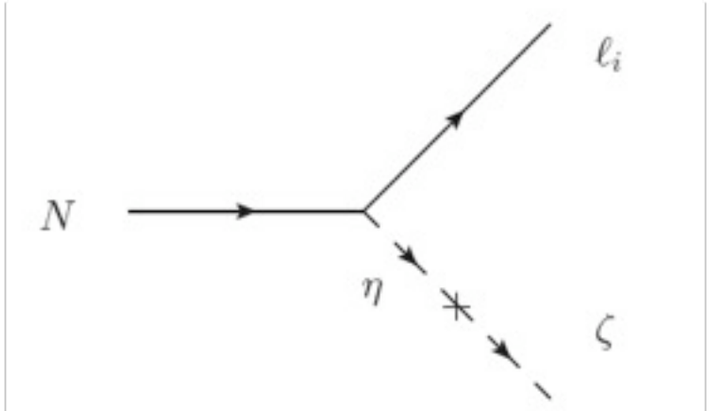
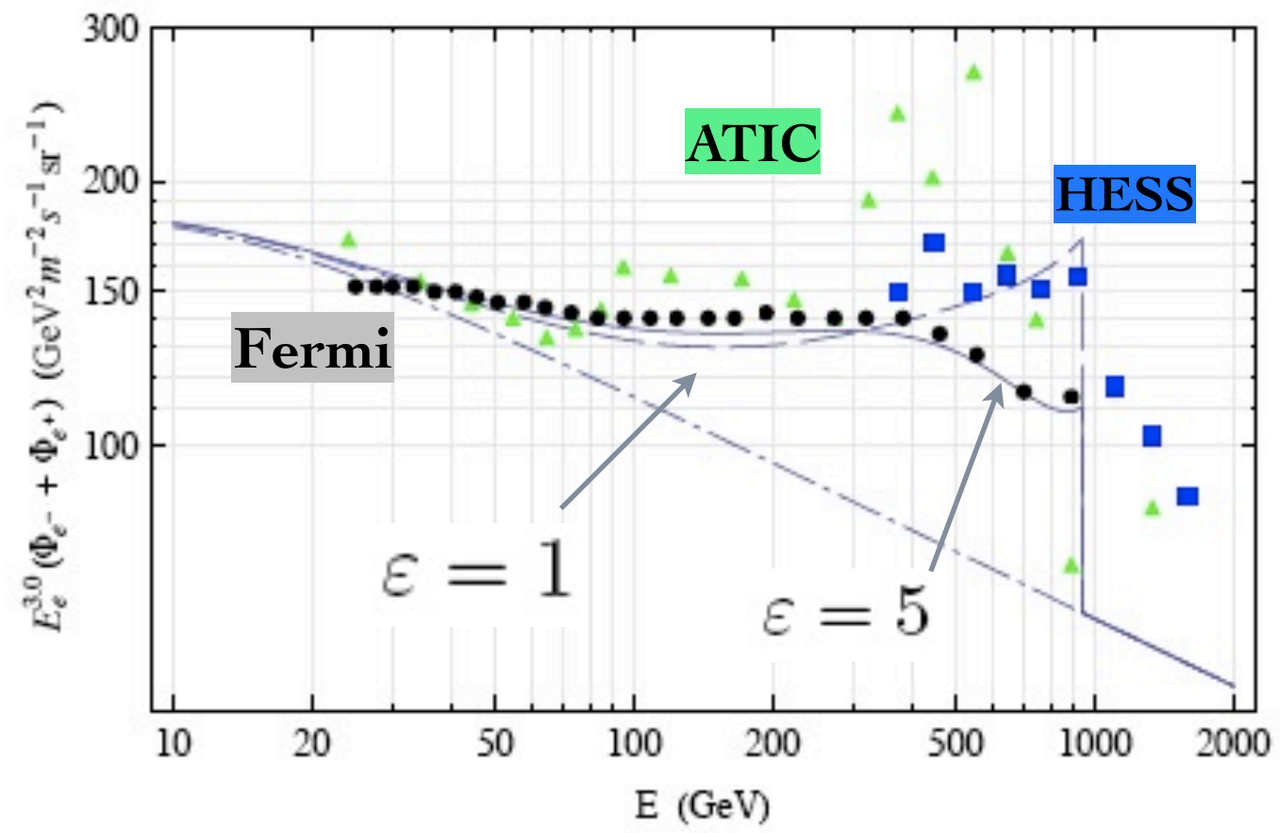
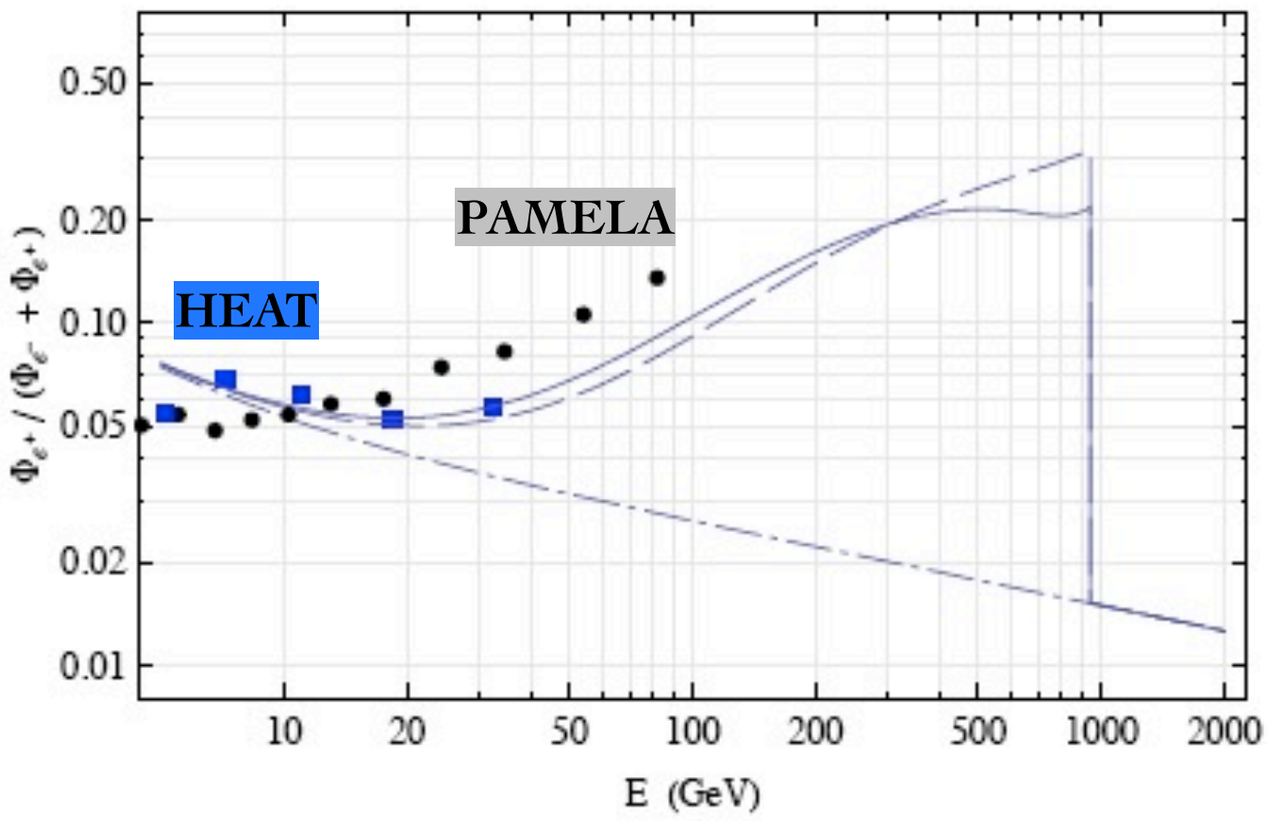


FIG. 3: Diagram for the DM decay.

$\tau_N = 2.5 \times 10^{26}$ s, $M = 2$ TeV, $M_\zeta = 500$ GeV $M_\eta = \mathcal{O}(100\ \text{TeV})$ $y_i' = \mathcal{O}(10^{-4})$, $\mu = \mathcal{O}(1\,\text{keV})$



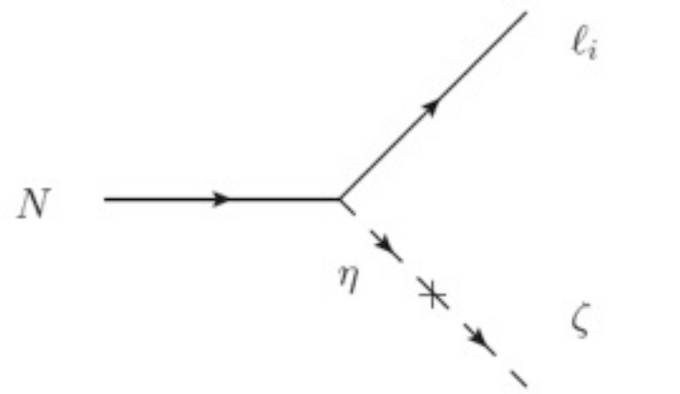


☞ **Fit Fermi and PAMELA well if the muon effect is large**

DM decays:

$$\Gamma_i = \frac{|y_i'|^2}{4\pi}\left(\frac{|\mu|}{M_\eta}\right)^4 \frac{M_-^2}{M}, \quad \tau_N = \frac{1}{4\sum_i \Gamma_i} = \frac{\pi A^4 M}{M_-^2}$$

$$A = \frac{M_\eta}{|\mu|(\sum_i |y_i'|^2)^{1/4}}, \qquad M_\pm = \frac{M^2 \pm M_\zeta^2}{2M} \qquad \varepsilon = |y_\mu'|^2/|y_e'|^2$$



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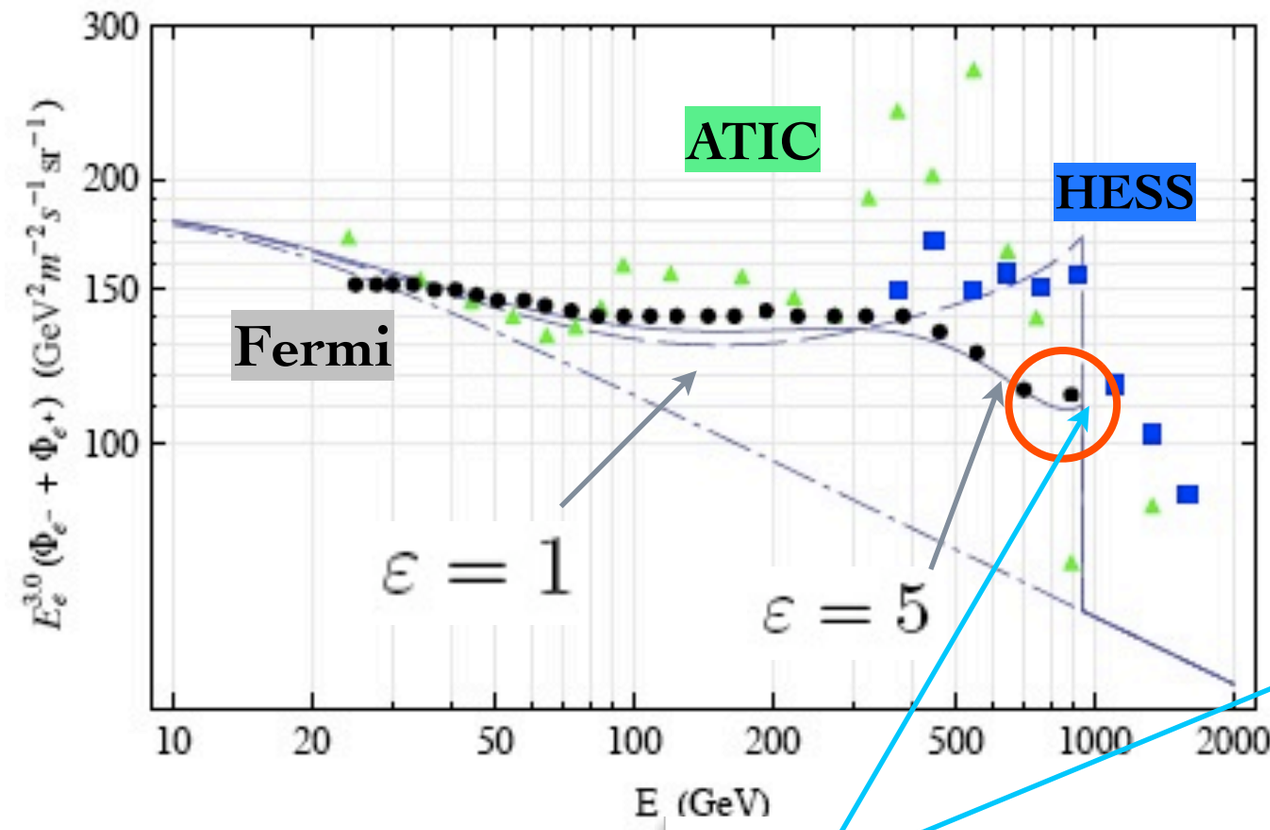

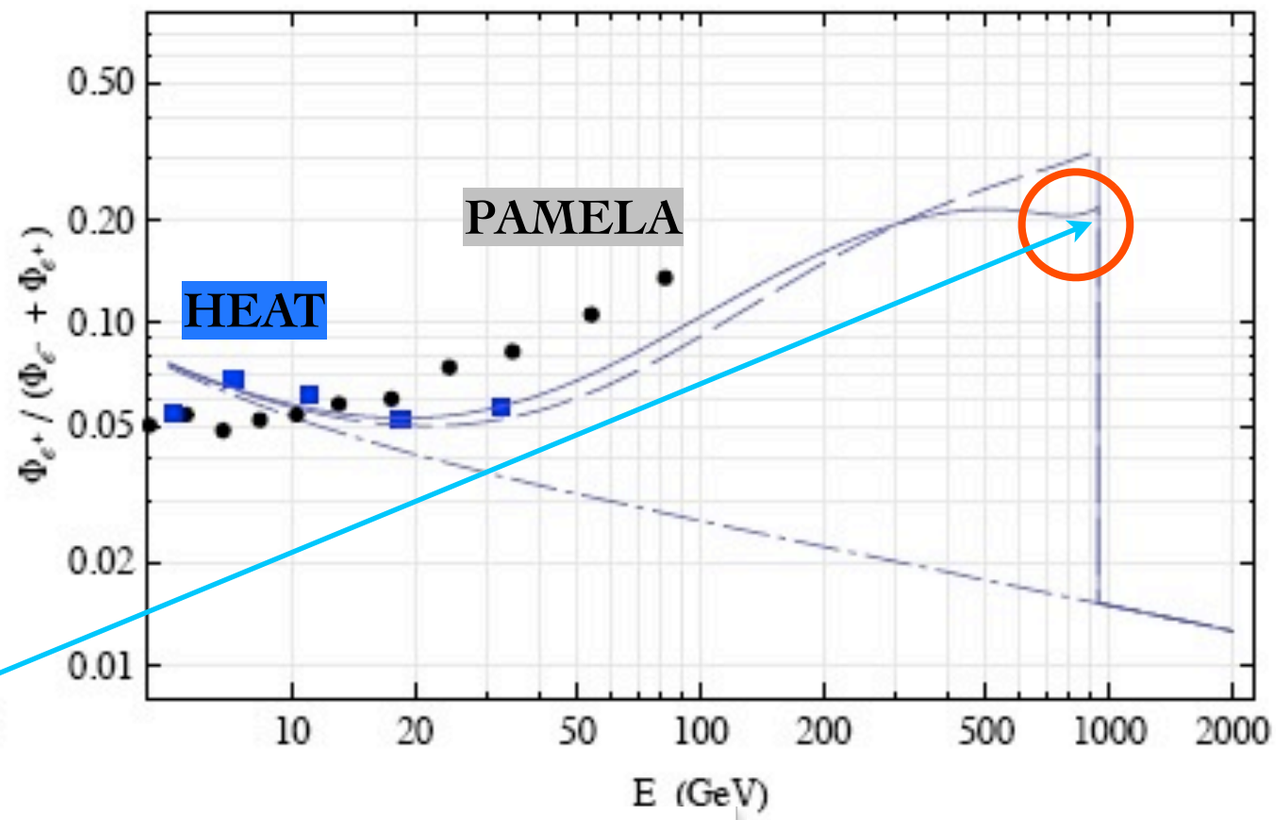

A rise due to the muon, confirmed by Fermi data!?

Fit Fermi and PAMELA well if the muon effect is large

Summary

- **A simple model with three-body DM decays:**
  ($M_{DM} \geq 1.5$ TeV, $\tau_{DM} \leq 10^{26}$s)
  which fits the ATIC and PAMELA data well.

- **An extended model with**
  small neutrino masses + leptogenesis,
  can fit both Fermi and PAMELA with the muon effect.

2nd International Workshop on

Dark Matter, Dark Energy
Matter-antimatter Asymmetry

暗物質、暗能量及物質-反物質不對稱

November 5~6, 2010 Dept. of Phys., National Tsing Hua Univ., Hsinchu, Taiwan

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With less than 5% of the energy content of the Universe identified as the ordinary baryonic matter, the understandings of both dark matter and dark energy as well as the matter-antimatter asymmetry are among the paramount problems in high energy physics today. This workshop is devoted to questions pertaining to dark matter, dark energy and the matter-antimatter asymmetry in the Universe. This meeting will bring together a wide range of international and local experts to discuss current ideas and models of the dark side and baryogenesis.

Topics

- **Dark matter theory and experiment**
- **Dark energy theory**
- **Baryogenesis and leptogenesis**
- **Modified gravity theory**
- **Inflation**

Speakers

Oversea Speakers:
- **K. Bamba (KMI, Japan)**
- **G. Belanger (LAPTH, France)**
- **R.G. Cai (ITP, Beijing)**
- **C.R. Chen (IPMU, Japan)**
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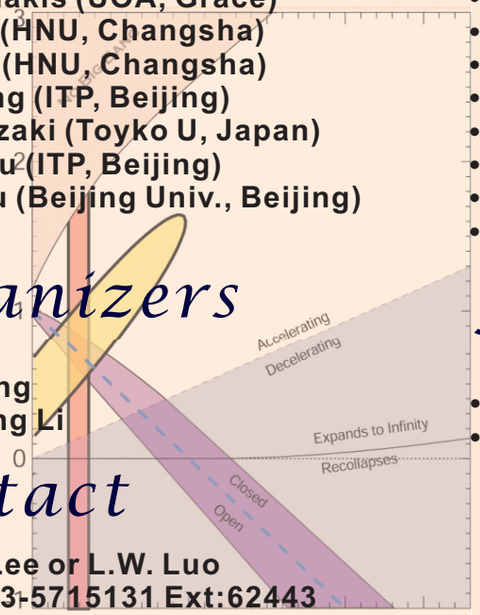

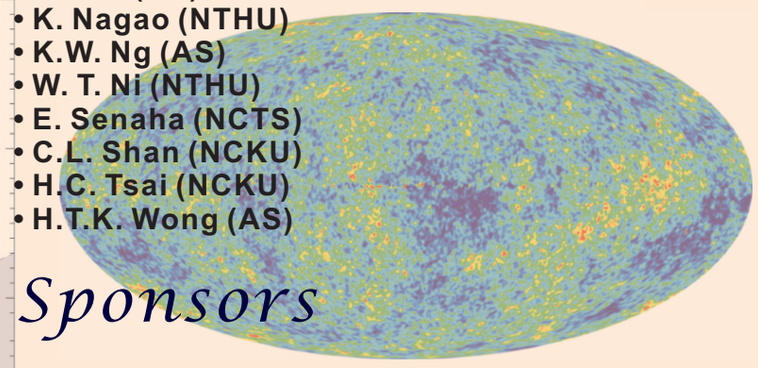

Organizers

- **C. Q. Geng**
- **Ling-Fong Li**

Sponsors

- **National Tsing Hua University (NTHU)**
- **National Center for Theoretical Science (NCTS)**

Contact

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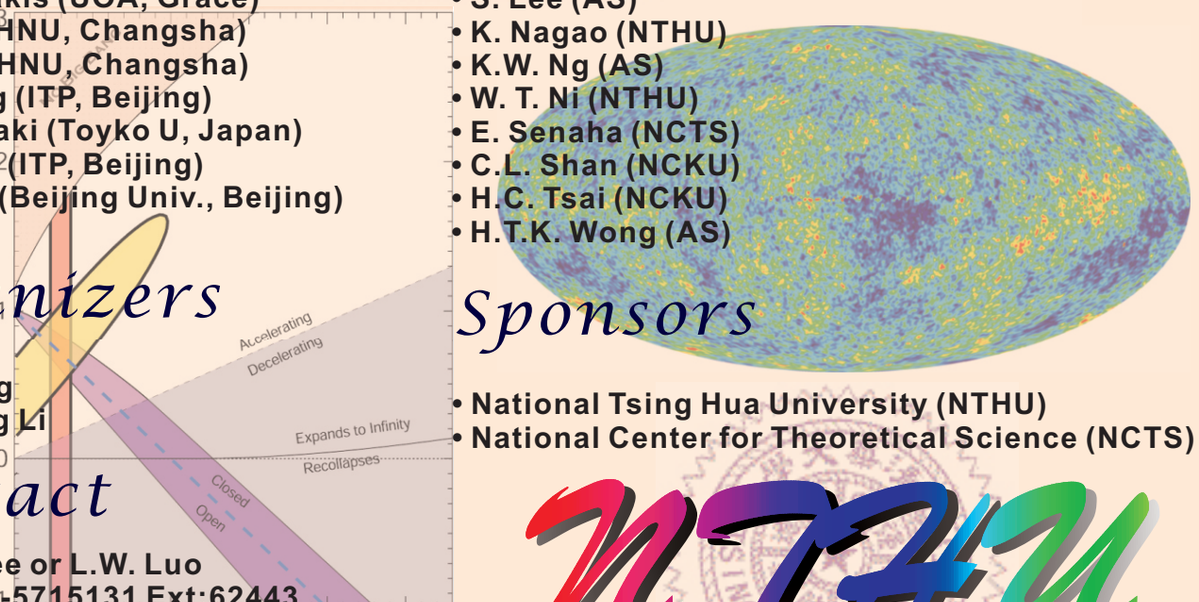

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We welcome students and professors to attend the workshop.

Thank you!

謝謝！