DM and PAMELA/Fermi Anomalies

PASCOS 09 (DESY)

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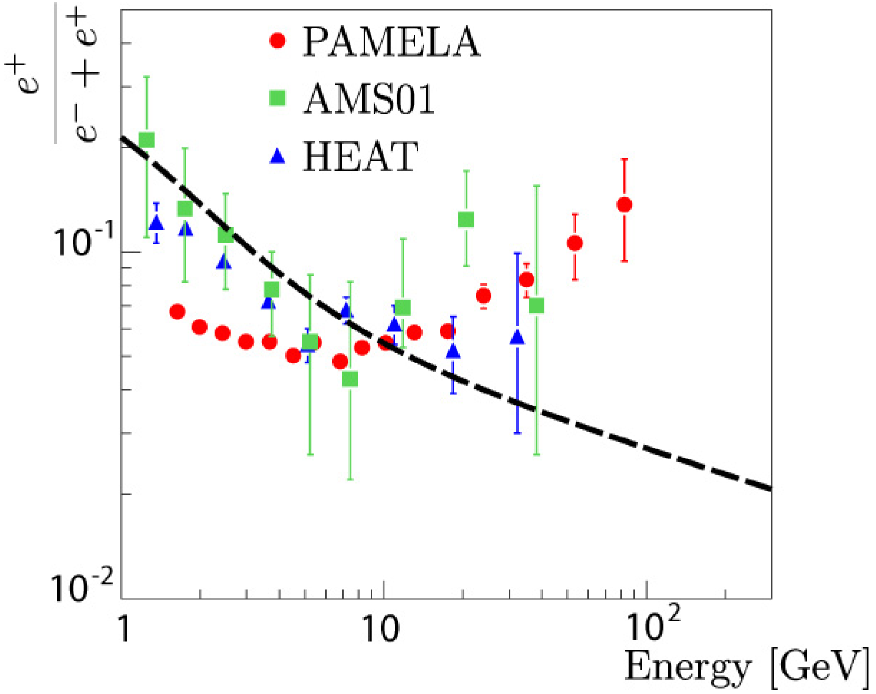
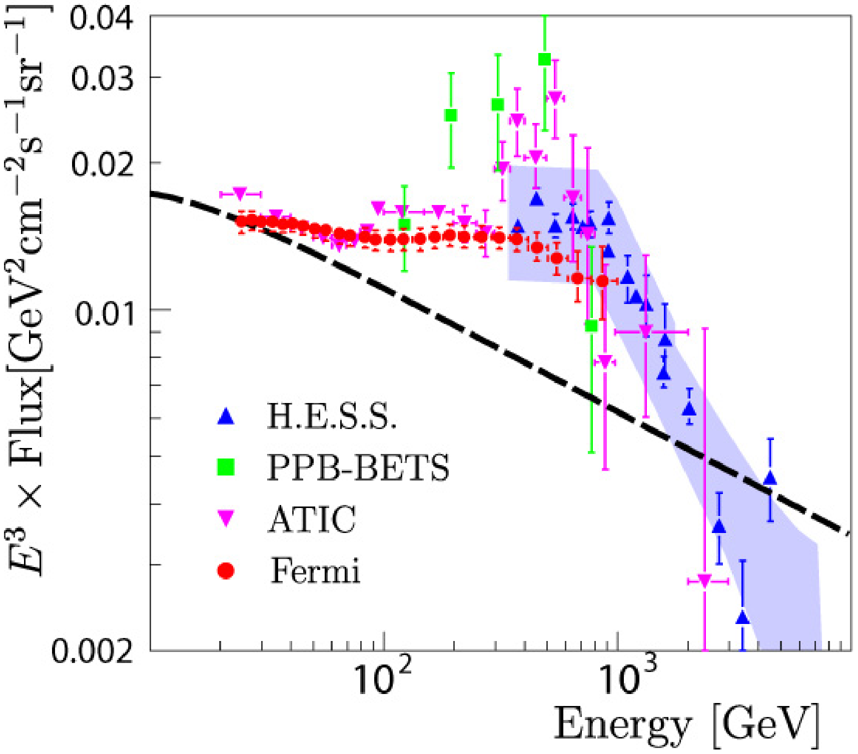
electron/positron excesses in PAMELA and Fermi





What is the source of the excesses ?

- Astrophysical Origins

- DM Decay/ Annihilation

DM source is more interesting

Explain the anomalies by DM decay
/annihilation

Fermi and HESS data suggest

$$m_{DM} = 1 - 10\text{TeV}$$

But, we have too many models for DM

Mass and interactions are free parameters

We can explain the data by choosing the free parameters

Too ambiguous and too arbitrary

Consider the DM in well motivated theories

DM in the SUSY Standard Model

(A) LSP DM

: Bino, Wino, Higgsino:

(B) DM in the SUSY-breaking sector

LSP in the SUSY SM

- The LSP is a combination of Bino, Wino and Higgsino
- It was in the thermal bath and its thermal relic can be the DM in the universe
- The mass of the DM depends on their mixing
- For the Wino dominated DM the mass is fixed as

$$m_{DM} \simeq 3\text{TeV} \;\; !!!$$

Hisano et al

$\longrightarrow$ **consider more on the Wino DM**

The Wino DM

- The wino DM is a natural prediction of the anomaly mediation of SUSY breaking

  murayama et al

  Randall et al

  The stability of the wino is guaranteed by the R parity

  A pair of winos annihilates mostly into a pair of weak bosons

$$\mathrm{wino} + \mathrm{wino} \to W^{+} + W^{-}$$

- However, a large annihilation cross section is required to explain the excesses observed in PAMELA and Fermi

$$BF \simeq O(10^{3-4})$$

- The sommerfeld enhancement is only a factor 10 Hisano et al

- We need a huge Boost factor !

Consider the DM decay

- R-parity violation induces the Wino decay
- We have a natural model for the small R-parity breaking

Shirai et al

- The lifetime is $\tau \simeq 10^{26}\text{sec}$
- The Wino decay

$$Wino \to \bar{e}_i \ell_j \ell_k$$

It fits the PAMELA/Fermi data very well

Small R parity breaking

First of all, recall that we need a constant term in the superpotential to cancel the vacuum energy

W= C + …….. ; C =m_{3/2}

Consider the C is a vev of some field X which has a R-charge 2

Then the continuous U(1)_R is broken down to Z_2 R (R-parity) by the condensation <X>

We have R-parity at low energy

- But, the previous argument is very dangerous, since U(1)_R has anomalies
- It seems more safe to assume only a discrete Z_nR which may be anomaly free
- If n= even, we have an exact R-parity
- However, if n=odd, the R is completely broken by <X>=m_{3/2}
- Magnitude of the R-parity breaking is determined only by m_{3/2} and n !!

For n=3, we find the lifetime of the Wino

tau = O(100) sec

For n=5, we get

tau = O(10^26) sec

For n=7, we get

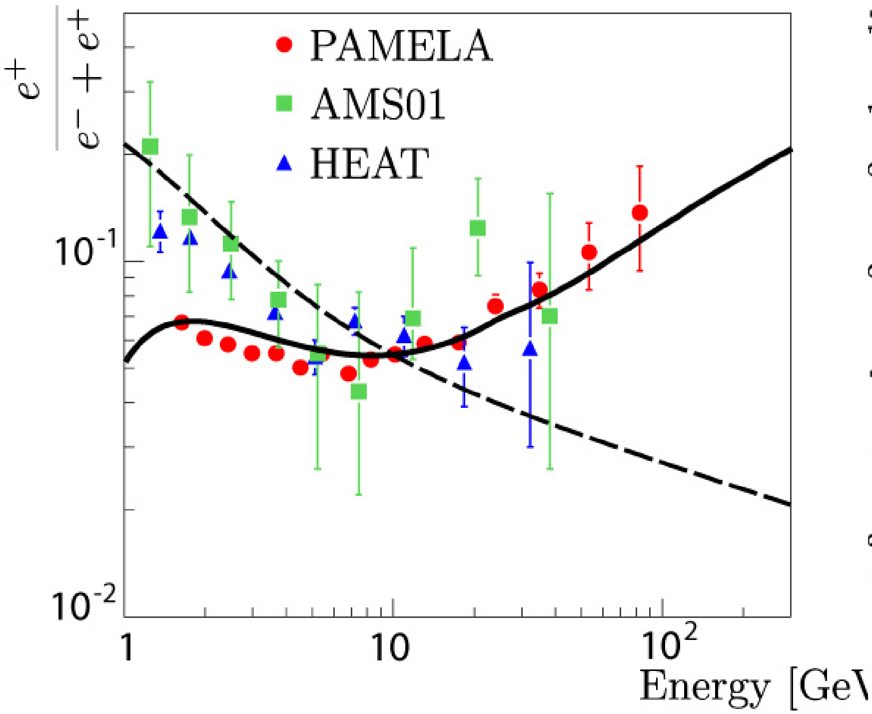
tau = O(10^50) sec

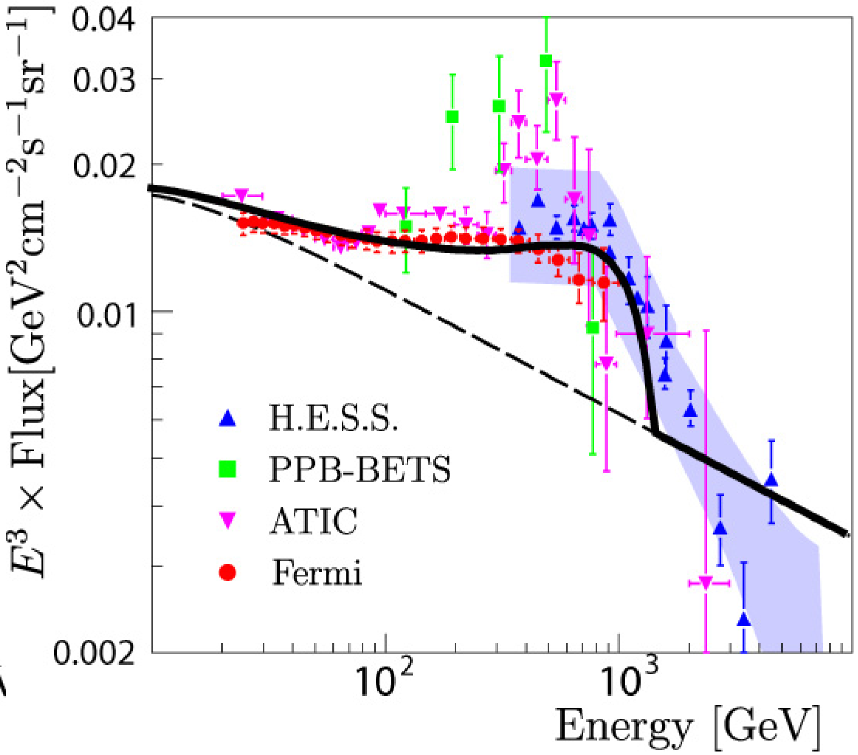
Lifetime = O(10^26) sec may be regarded as a prediction !!!

electron/positron excesses in PAMELA and Fermi

$\tau = 1.0 \times 10^{26}$ sec $m_{\rm DM} = 3.0$ TeV

$e_3 L_1 L_3$





BUT, SUSY particles are too heavy !

$$m_{\mathrm{gluino}} \simeq 18\mathrm{TeV}$$

They will be not found at LHC

$\longrightarrow$ **consider the other case**

DM in the SUSY Breaking Sector

Dimopoulos et al

- Low-scale gauge mediation suggests

$$\Lambda_{SUSY} = O(100)\,\mathrm{TeV}$$

- Then, stable baryons, if exist, in the hidden sector have masses O(100) TeV
- They are too large compared with the DM mass (1-10 TeV) suggested by Fermi data

Why $m_{DM} << \Lambda_{SUSY}$ **???**

Nambu-Goldstone DM

Ibe,Nakayama, Murayama, TTY

Annihilation cross section is too small for the pseudo NG DM

$$\sigma_0 v \sim \frac{m_{DM}^4}{\Lambda_{SUSY}^6}$$

Too many thermal relic DM

$\longrightarrow$ Enhance the annihilation

- If there is a **s-channel pole** near the DM threshold, the annihilation cross section is enhanced

$$\sigma v \sim \left(\frac{m_{DM}^2}{m_S^2-4m_{DM}^2}\right)^2 \times \sigma_0 v$$

Conditions for the Hidden Sector

I. Approximate global symmetry G

   $G \to H$ produces NG DM

II. A scalar boson near the DM threshold

III. The NG DM should be almost or absolutely stable

A SUSY-breaking Model

The IYIT SUSY breaking model

Izawa et al

Intriligator et al

SU(2) + 4 Quarks + 6 singlets

$$W = \lambda_{ij} Q_i Q_j S_{ij} \quad i, j = 1 - 4$$

The strong SU(2) interactions induce

$$W_{dyn} = X(Pf(QQ) - \Lambda^4)$$

$$\rightarrow \quad < QQ > = \Lambda^2 \rightarrow \quad F_S \neq 0$$

Then, SUSY is broken

- In the limit of $\lambda_{ij} = \lambda$ we have a global SO(6), which is broken down to SO(5) by the condensation $< QQ > \neq 0$

Then we have 5 NG bosons

$$m_{NG}^2 \simeq \Delta\lambda^2 \times \Lambda^2$$

We consider they are DM

$\frac{\Delta\lambda}{\lambda} \simeq 0.01 \rightarrow$ $m_{DM} \simeq 5\text{TeV}$ for $\Lambda \simeq 50\text{TeV}$

($\Delta\lambda = 0$ is an infrared fixed point in CFT)

- One combination of S_{ij} which has a SUSY-breaking F-term is **massless at the tree level !!**
- Fermion component is the goldstino
- One-loop corrections give a mass for its scalar component

$$m_s \simeq \frac{\lambda}{4\pi} \times \Lambda$$

We may have $m_s \simeq 2m_{DM}$

Domain wall problem in IYIT model

$$W_{\text{eff}} = X(M^2 - \Lambda^4) + \lambda M S$$

$$M \equiv QQ$$

We have an exact discrete symmetry

$$M \to -M, \quad S \to -S$$

- M condensation $< M >= \Lambda^2$ breaks the discrete symmetry and domain walls are formed !!

A solution is to **gauge a U(1)** subgroup of the global SU(4)

U(1) charges

$$Q^1(+1/2), Q^2(+1/2), Q^3(-1/2), Q^4(-1/2)$$

We have two charged mesons M^+, M^-
and 4 neutral mesons M^0

Then,

$$W_{\rm eff} = X(2M^{+}M^{-} + M^{0}M^{0} - \Lambda^{4}) + \lambda' M^{+}S^{-} + \lambda' M^{-}S^{+} + \lambda M^{0}S^{0}$$

If $\lambda' < \lambda$, $< M^{+} > = < M^{-} > = \frac{1}{\sqrt{2}}\Lambda^{2}$

The Parity is defined as before

$$M^{\pm} \to -M^{\pm}, \quad M^{0} \to -M^{0}$$

$$S^{\pm} \to -S^{\pm}, \quad S^{0} \to -S^{0}$$

However, the parity on the charged mesons M^+, M^- is embedded into the gauged U(1)

Thus, the condensation of the charged mesons breaks only the U(1) gauge symmetry

No domain wall is formed !

The parity on the neutral mesons remains unbroken $M^0 \to -M^0$

Big Bonuses

(I) The NG boson DM $\in M^0$

Under the Parity: DM $\longrightarrow$ -DM

Thus, NG DM is stable

The Parity is broken only by higher dimensional operators suppressed by

$$1/M_{PL}^2$$

The DM has a long lifetime !!

$$\tau_{DM} \simeq 10^{26}\mathrm{sec}$$

Ibe, Murayama, Shirai, TTY

(II) U(1) gauge interactions induce R-symmetry breaking

Dine et al

$$\langle S^+ \rangle = \langle S^- \rangle \simeq \Lambda$$

We have a R axion A

The R axion decays into a pair of electrons or muons

$$A \rightarrow e^+ + e^- \text{ or } \mu^+ + \mu^-$$

R breaking is necessary

- For the DM bosons to annihilate through the flaton s pole

$$DM(0) + DM(0) \rightarrow {}''s(2)'' \rightarrow A + A$$

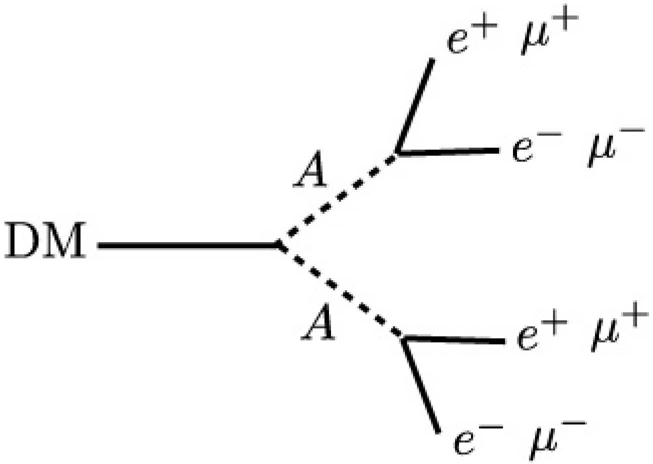
- To generate the gaugino masses in the SUSY SM

$$m_i \lambda_i(1) \lambda_i(1)$$

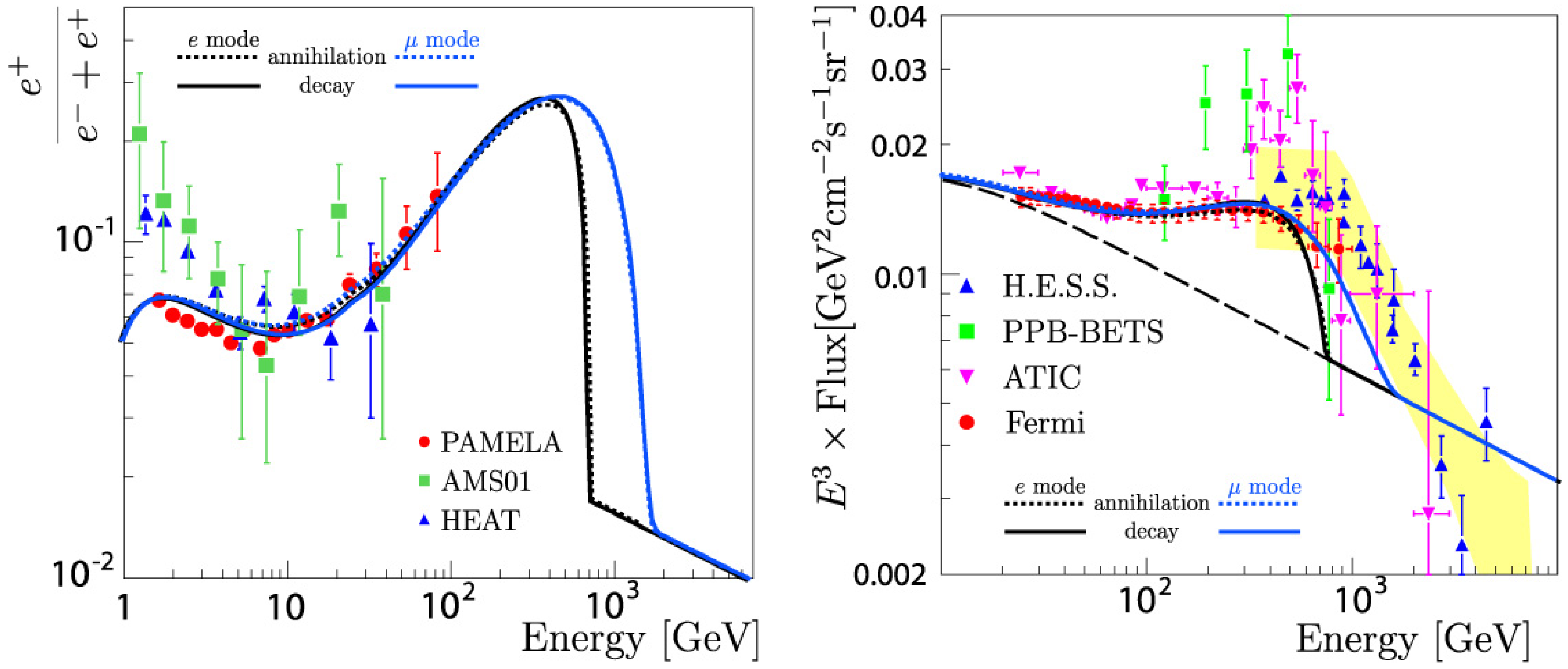
The possible higher dimensional operator such as

$W = \frac{1}{M_{PL}^2} QQ < QQ > S$ generates DM and s mixing

Then, the NG DM decays dominantly into a pair of the R axions



Arkani-Hamed et al
Nomura et al


e^+ / (e^- + e^+)
e mode
annihilation
μ mode
decay
10^-1
10^-2
1
10
10^2
10^3
Energy [GeV]
PAMELA
AMS01
HEAT
E^3 × Flux[GeV^2cm^-2s^-1sr^-1]
0.04
0.03
0.02
0.01
0.002
10^2
10^3
Energy [GeV]
H.E.S.S.
PPB-BETS
ATIC
Fermi
e mode
annihilation
μ mode
decay

Conclusions

(I) The NG DM fits the PAMELA/Fermi data very well

For $\delta = \frac{m_s - m_{DM}}{m_s + m_{DM}} < 0.1$ the DM density is determined only by the dynamical scale

We found $\Lambda_{SUSY} \simeq 30 - 50\,\mathrm{TeV}$

The gravitino mass is

$$m_{3/2} = O(1)\,\mathrm{eV}$$

We need a direct gauge mediation

We have found a gauge mediation model

In general, the flaton s necessarily couples to a pair of gluinos

$$c_g m_{\text{gluino}} \frac{s}{<s>} \lambda^2_{\text{gluino}}$$

The DM dcays into a pair of gluinos, too

$$\text{Br}(DM \to \lambda_{\text{gluino}} + \lambda_{\text{gluino}}) \simeq 0.05 |c_g|^2 (\frac{m_{\text{gluino}}}{500\text{GeV}})^2$$

The decay to gluinos produces antiprotons

From the constraint for the antiproton flux given by PAMELA, we have an upperbound on the gluino mass

$$m_{\mathrm{gluino}} < 1\mathrm{TeV}$$

(II) The 3 TeV Wino decay fits the data as well as

However, the gravitino mass is

$$m_{3/2} = O(10^3)\,\mathrm{TeV}$$

SUSY particles are too heavy for LHC

A New Proposal

$\rightarrow$ Consider the anomaly mediation with O(100) GeV Wino DM

Then, the Wino production should be non-thermal

The most natural non-thermal Wino production is the **gravitino decay** in the early universe $T_R \simeq 10^{10}\mathrm{GeV}$

The gravitinos are produced by thermal particle scattering

The produced gravitinos decay into Winos

The Wino density may explain the observed DM density if $T_R \simeq 10^{10}\mathrm{TeV}$

This temperature is good for the thermal leptogenesis ! Buchmuller et al

A crucial point is that **the gravitino decay into all particles** if they are lighter than the gravitino

If there is a hidden U(1) gaugino, then it is also produced by the gravitino decay

If the hidden gaugino is stable, it may be a part of the DM

Its fraction may depend on a model for the hidden U(1) gauge theory

The mass and decay of the hidden gaugino depends on details of the model

But, if $m_{\lambda_X} = 3 - 5\,\mathrm{TeV}$ and $\tau_X \simeq 10^{26}\,\mathrm{sec}$

the decay of the **hidden gaugino** may explain the PAMELA/Fermi data

Shirai et al ; Ibarra et al