Probing Gravitino Dark Matter with PAMELA and Fermi

Fumihiro Takayama

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with W.Buchmuller, A.Ibarra, T.Shindou, D.Tran

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Dark matter

One of the best motivation to consider exotic new particles

Requirement

→ not SM particles = new particles!

→ stable= parity

Decaying dark matter (the lifetime is longer than the age of the universe)

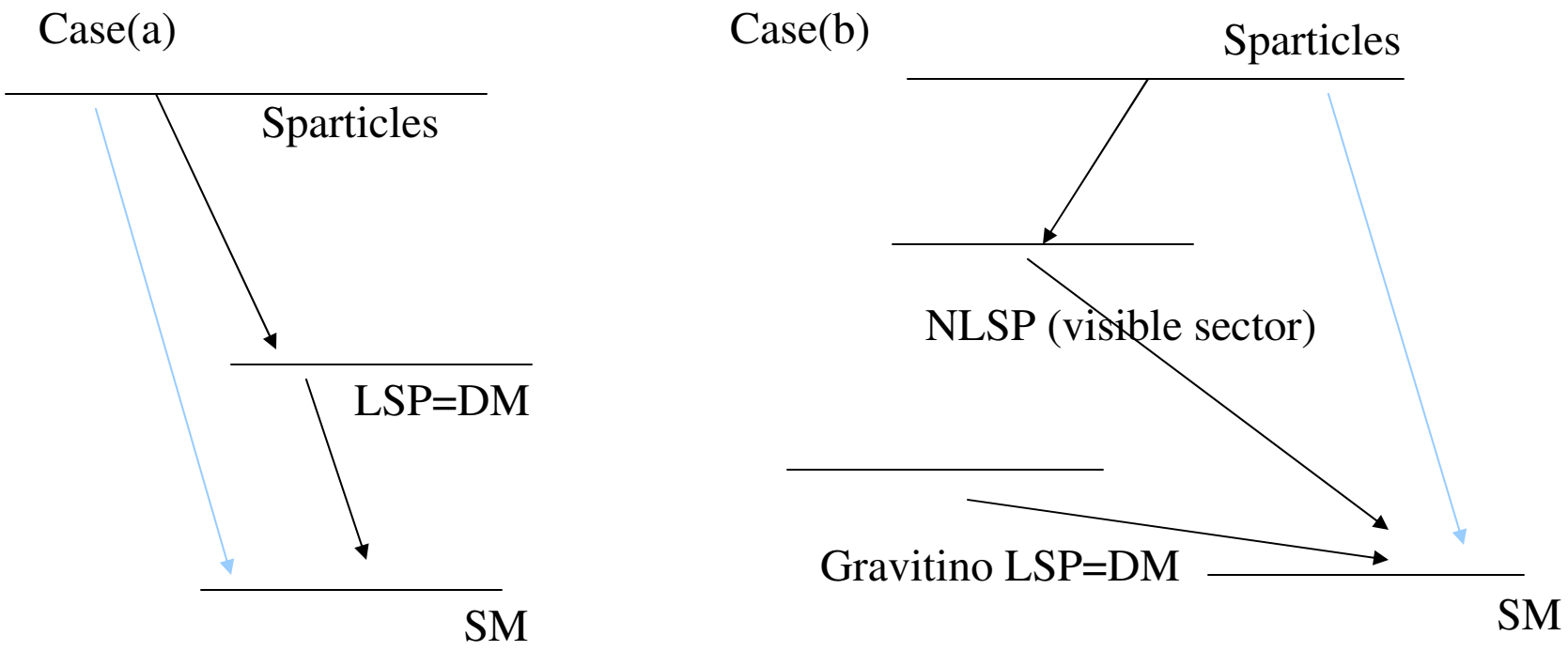
Why so long-lived ?

(a)very tiny couplings?=invisible in pheno other than DM physics

(b)Higher dimensional operators $(\Lambda >> m_{DM})$

Just split dark sector(=dark matter) from our visible sector(SM)

→ In visible sector, we do not need parity for DM stability…



Different signatures from annihilation models (WIMPs)

Boost factor ? (=crucial for the appearance in indirect DM detection)

Dark matter clustering or long range force for annihilation models
…Annihilation rate is proportional to (number density)^2.

Decays become relevant in late universe
…Decay rate is proportional to number density.
(Hubble~T^2 versus constant lifetime)

(→The extra galactic contributions of DM decays are
insensitive to dark matter distributions)

….concrete examples?

R-parity violation vs dark matter stability (= $\tau >> 10^{17}$sec)

Two scenarios

WIMP type DM (Neutralino/Sneutrino LSP)

R-parity violating couplings are very very small

e.g Mpl suppressed:V.Berezinsky,A.Joshipura,J.Valle(1996), S.Shirai, F.Takahashi. T.Yanagida(2009)

→ the scenario is same story as neutralino LSP with R-parity at collider experiments

superWIMP type DM (Gravitino LSP)

R-parity violating couplings in MSSM sector may not be very small

but the LSP decay is suppressed through the gravitational couplings.

F.Takayama, M.Yamaguchi(2000)

→ various kinds of metastable NLSP possible

(Stable gravitino DM ←→ BBN problem (See next talk for neutralino NLSP))

rich L-(or B-)number violating phenomenon at collider phyiscs

Completely different prospects for collider experiments!!

Simultaneous solution to…

BBN = SBBN

Lifetime of NLSP G.Giudice,R.Rattazzi(1998)….

$\tau \sim 10^3 (\lambda/10^{-14})^2 (m/100\text{GeV})$ sec

No wash out primordial BAU (vs neutrino mass)
(W.Buchmuller, A.Ibarra,L.Covi,K.Hamaguchi,T.Yanagida(2007)

→upper bound for R-parity violating couplings ($\lambda < 10^{-7}$)

If collider experiment put upper lower bound for R-parity violating couplings (lifetime of NLSP),

→ Lower bound for gravitino mass

Effective operators of gravitino LSP R-parity violating decays

W.Buchmuller,A.Ibarra,T.Shindou,F.Takayama,D.Tran(2008)

R-parity violations → huge number of new couplings, so complicated?

No!!

Let's see the effective interaction of quarks/leptons/SM higgs/gravitino allowed by SM gauge group (SUSY higgs decoupling limit).

$$\mathcal{L}_{\rm eff} = \frac{i\kappa}{\sqrt{2}M_{\rm Pl}} \left\{ \bar{l}\gamma^\lambda\gamma^\nu D_\nu \phi \psi_\lambda + \frac{i}{2}\bar{l}\gamma^\lambda \left(\xi_1 g' Y B_{\mu\nu} + \xi_2 g W_{\mu\nu}\right)\sigma^{\mu\nu}\phi\psi_\lambda \right\} + \text{h.c.} \ ,$$

Three body decays induced by 4-Fermi may be suppressed by additional powers of mG/mSUSY

Signatures for decaying gravitino dark matter on antimatter searches under HEAT/EGRET anomaly
(before PAMELA and Fermi LAT)

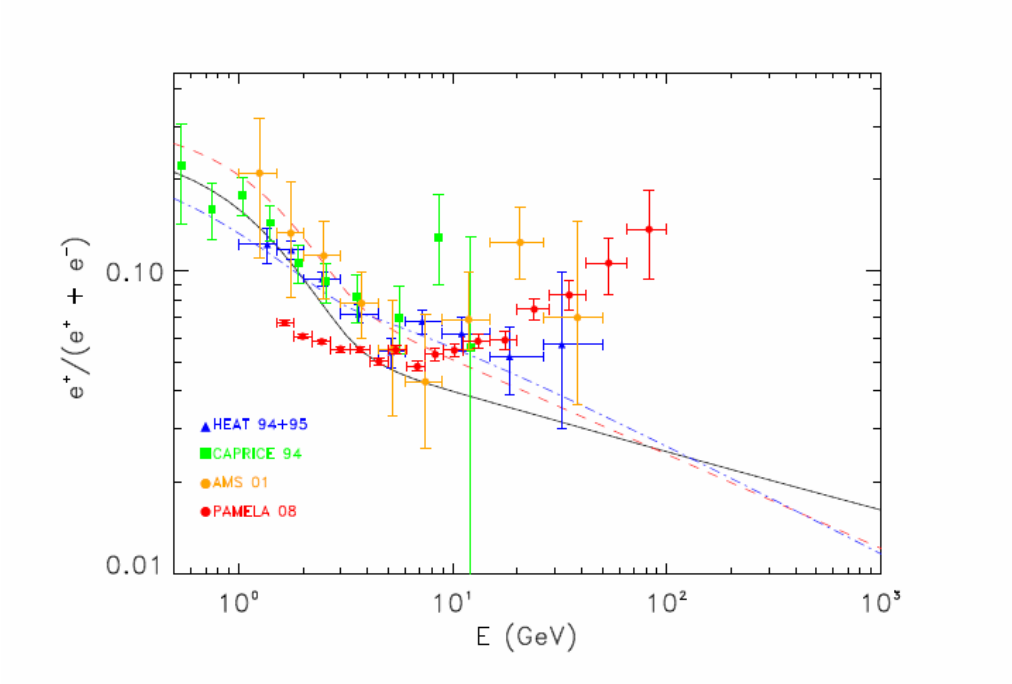
A.Ibarra,D.Tran(2008), K.Ishiwata, S.Matsumoto, T.Moroi(2008)
(Axino without R-parity: D.Hooper,L.Wang(2004))

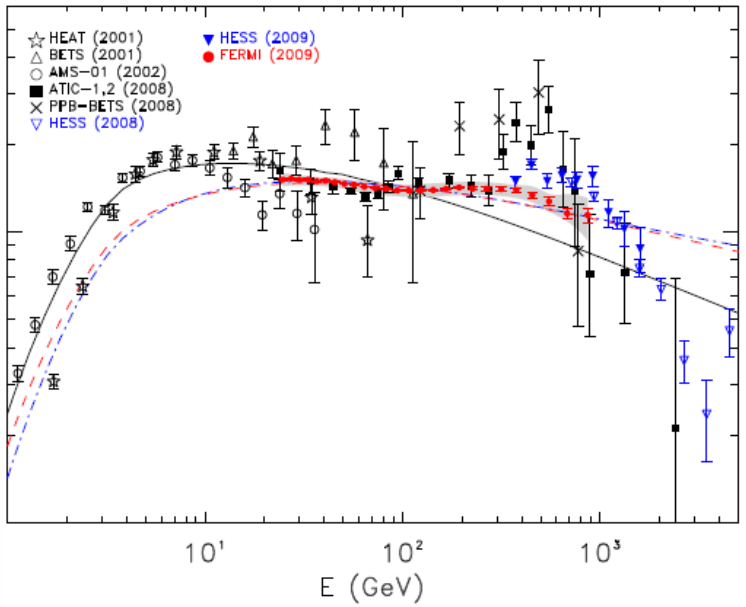
Hard positrons/electrons from two body decays

Antiprotons/Continuum photons from W/Z/higgs hadronizations

Cosmic ray observations now (PAMELA and Fermi LAT)

Observed new anomalies!! Indicating primary electrons/positrons sources





arXiv:0905.0636

Simple dark matter interperation
→ heavy dark matter > 2TeV ?

Gravitino(LSP) probe for very early universe!

Thermal gravitino overproductions vs thermal leptogenesis?

→Upper bound for gravitino mass
(assuming not thermalized after the reheating)

mG < 600GeV (Universal mass assumptions)

(W.Buchmuller, M.Endo, T.Shindou(2008))

mG < 2TeV (General MSSM spectrum)

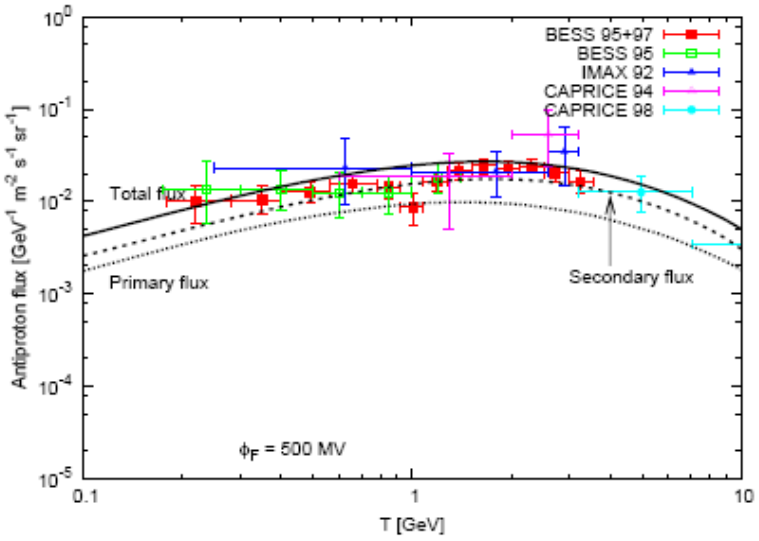
(S.Shirai, F.Takahashi,T.Yanagida(2008))

Still try careful examinations for mG<TeV….

Gravitino decays typically has hadronic decay modes:
What might happen to antiproton flux?

….currently no excess beyond the expected BG from astrophysical sources.

mG=200GeV, MED(=B/C best fit)
Astrophysical BG(Donato et al) is assumed



$d\phi/dEl_{source} \sim (\rho/\tau m)(dN/dE)$

W.Buchmuller, A.Ibarra, T.Shindou,F.Takayama,D.Tran(2009)

Cosmic ray details (antiproton vs photon)

Astrophysical uncertainties on new physics contributions

Size of diffusive zone: constrained by unstable isotopes

Two zone diffusion/convection model(Donato et al)

B/C(=insensitive to initial flux) allows degeneracy on antiproton flux from astrophysical sources localized on Galactic disk. (halo size and diffusion constant)

→Antiproton observation can not constrain the signal normalization for gamma ray

DM contributions break the degeneracy by new obs

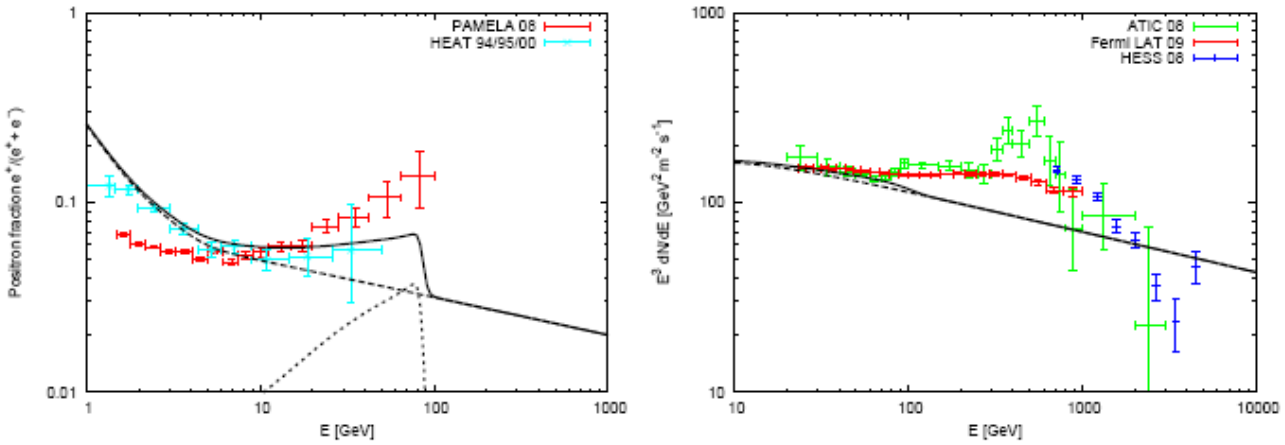
gamma ray ($E^2\, d\phi/dE \sim 1/\tau$)

vs antiprotons(flux=$d\phi/dE \sim L/(m\tau)$)

…source activity ~ L

Maximal positron excess and electron+positron flux
under antiproton constraint

mG=200GeV, MED model



MS Model0 is assumed as the BG

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The lack of primary electron(positron) flux can be explained by astrophysical sources?

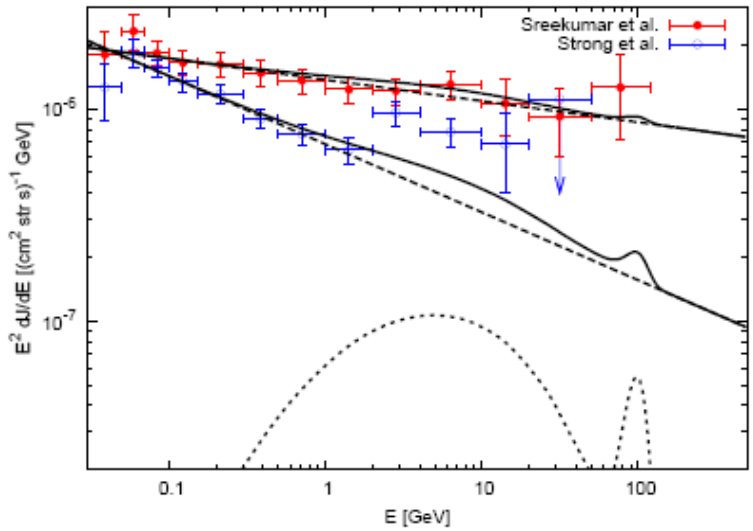
Future prospects

The null results on antiproton flux does not always exclude the possibility to observe dark matter signal in gamma ray

(a) Fermi/PAMELA era

mG=200GeV

Typically gravitino decay provides a line in the edge of the photon spectrum
→indicate the mass scale of gravitino if we could identify it.



(IC/FSR contributions is not included)

W.Buchmuller, A.Ibarra, T.Shindou,F.Takayama,D.Tran(2009)

In same propagation model,

L=4kpc→2kpc may allow factor 2 enhancement for gamma flux:

→γ–ray and antiproton observation constrain astrophysical uncertainties if we observe signals.

(b) LHC era

If decaying gravitino dark matter has weak scale mass,
It seems that the R-parity violating couplings is already highly constrained to be small values.
→We could expect metastable NLSP or stable NLSP inside collider experiments.

For lighter gravitino,
Gamma line may become the leading signature to constrain the R-parity violating couplings.

Summary

Recent progress of cosmic ray observations have allowed us to reach the better understanding of the astrophysical sources and may even constrain theoretical models of dark matter.

If DM is gravitino LSP with the prefered mass range by early universe discussions and they are decaying now, cosmic ray observations are saying something, e.g on the degree of R-parity violation and we may expect some signatures at near future colliders.

In general scenario of gravitino LSP(superWeakly interacting massive particle), the interplay between comology/astrophyscis and on-earth experiments like collider is important to ask whether the produced DM at collider is stable or not.