Indirect Searches for Gravitino Dark Matter

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Based on work in progress in collaboration with Laura Covi and Gilles Vertongen.

Motivation for Unstable Gravitino Dark Matter

- Supergravity predicts the gravitino as the spin-3/2 superpartner of the graviton
- Gravitinos are produced thermally after inflation:

$$\Omega_{3/2}h^2 \simeq 0.27 \left(\frac{T_R}{10^{10}\,\mathrm{GeV}}\right)\left(\frac{100\,\mathrm{GeV}}{m_{3/2}}\right)\left(\frac{m_{\tilde{g}}}{1\,\mathrm{TeV}}\right)^2$$

[Bolz *et al.* (2001)]

- Problem in models with neutralino dark matter:
  - Thermal leptogenesis requires high reheating temperature: $T_R \gtrsim 10^9$ GeV [Davidson *et al.* (2002)]
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Possible solution: *R* parity is not exactly conserved!

Gravitino Dark Matter with Bilinear R-Parity Violation

- Bilinear R-Parity Violation: $W_{\not{R}_p} = \mu_i H_u \tilde{\ell}_i, \quad -\mathcal{L}_{\not{R}_p}^{\text{soft}} = B_i H_u \tilde{\ell}_i + m_{H_d \ell_i}^2 H_d^* \tilde{\ell}_i + \text{h.c.}$
- Only lepton number violated $\Rightarrow$ Proton remains stable!
- Cosmological bounds on R-violating couplings
  - Lower bound: The NLSP must decay fast enough to evade BBN constraints
  - Upper bound: The lepton/baryon asymmetry must not be washed out
- Gravitino decay suppressed by Planck scale and small R-parity violation
  - The gravitino lifetime exceeds the age of the universe by many orders of magnitude
  - The unstable gravitino is a viable dark matter candidate
- Rich phenomenology instead of elusive gravitinos
  - A long-lived NLSP could be observed at the LHC $\longrightarrow$ see C. Weniger's talk
  - Gravitino decays lead to possibly observable signals at indirect detection experiments

Gravitino Dark Matter with Bilinear *R*-Parity Violation

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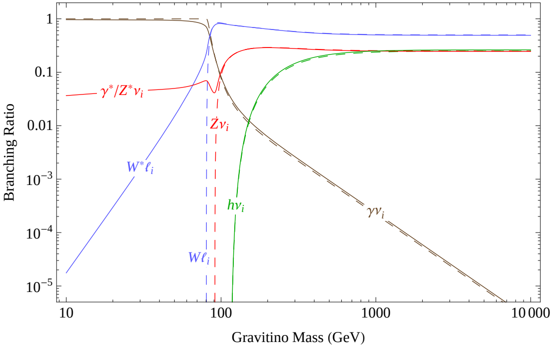
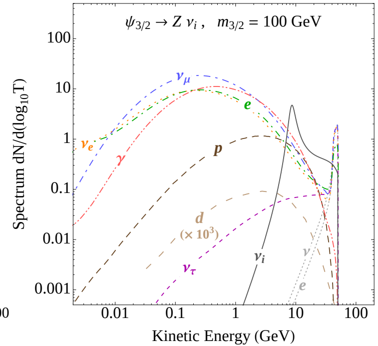
The gravitino is a well-motivated dark matter candidate that could be indirectly observed at colliders and in cosmic-ray spectra!

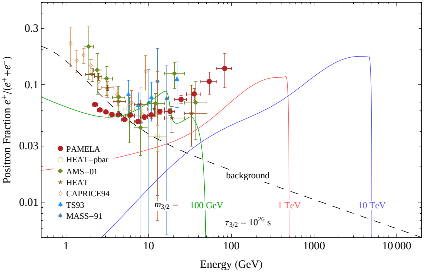
Gravitino Decay Channels

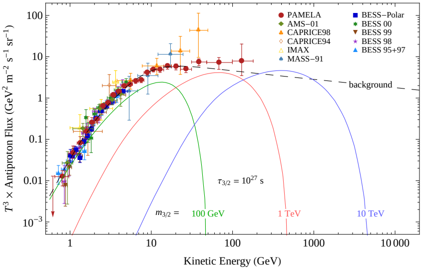
- Several contributing decay channels: $\psi_{3/2} \to \gamma\,\nu_i,\ Z^*\nu_i,\ h^*\nu_i,\ W^*\ell_i$
  - For $m_{3/2} < m_W$ three-body decays can play an important role [Choi *et al.* (2010)]
  - Ratio between $\gamma\,\nu_i$ and other channels is model-dependent





- Gravitino decays produce spectra of stable cosmic rays: $\gamma,\ e,\ p,\ \nu_{e/\mu/\tau},\ d$
  - Two-body decay spectra generated with PYTHIA
  - Deuteron coalescence treated on event-by-event basis


Positron Fraction $e^+/(e^+ + e^-)$
Energy (GeV)
PAMELA
HEAT−pbar
AMS−01
HEAT
CAPRICE94
TS93
MASS−91
background
$m_{3/2}$ =
100 GeV
1 TeV
10 TeV
$\tau_{3/2} = 10^{26}$ s


$T^3 \times$ Antiproton Flux (GeV^2 m^{-2} s^{-1} sr^{-1})
Kinetic Energy (GeV)
PAMELA
AMS−01
CAPRICE98
CAPRICE94
IMAX
MASS−91
BESS−Polar
BESS 00
BESS 99
BESS 98
BESS 95+97
background
$\tau_{3/2} = 10^{27}$ s
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100 GeV
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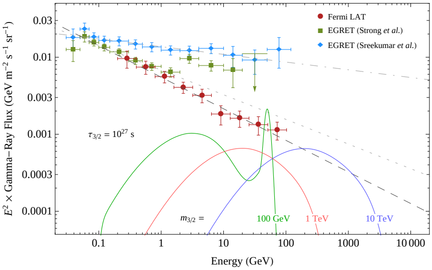
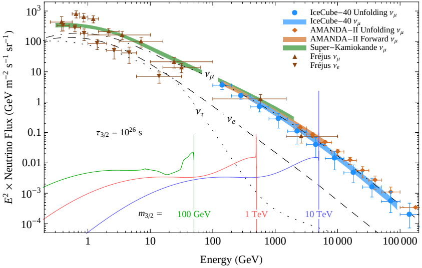

$E^2 \times$ Gamma-Ray Flux (GeV m^{-2} s^{-1} sr^{-1})
Energy (GeV)
Fermi LAT
EGRET (Strong *et al.*)
EGRET (Sreekumar *et al.*)
$\tau_{3/2} = 10^{27}$ s
$m_{3/2}$ =
100 GeV
1 TeV
10 TeV


$E^2 \times$ Neutrino Flux (GeV m^{-2} s^{-1} sr^{-1})
Energy (GeV)
IceCube−40 Unfolding ν_μ
IceCube−40 ν_μ
AMANDA−II Unfolding ν_μ
AMANDA−II Forward ν_μ
Super−Kamiokande ν_μ
Fréjus ν_μ
Fréjus ν_e
ν_μ
ν_τ
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$\tau_{3/2} = 10^{26}$ s
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100 GeV
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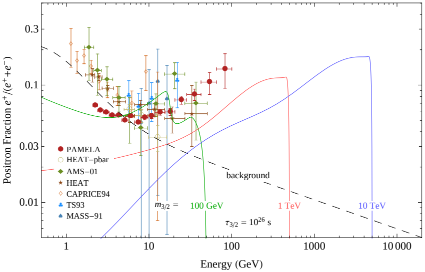
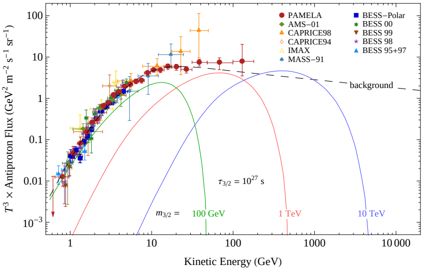
Gravitino Decay Signals in Cosmic-Ray Spectra: $\frac{e^+}{e^+ + e^-}$, $\bar{p}$, γ and ν





- Gravitino decay in principal could explain the rise in the positron fraction data
  - Explanation requires a gravitino lifetime of $\mathcal{O}(10^{26})$ s $\longrightarrow$ see A. Ibarra's talk
  - Depends on flavor structure of R-parity breaking (hard e^+ from $W\,e$, $W\mu$ needed)
  - Associated $\bar{p}$ from W, Z and h fragmentation in conflict with $\bar{p}$ data (not leptophilic)
    (Remind that $\bar{p}$ propagation introduces large uncertainties $\rightarrow$ see talk of P. Salati / A. Ibarra)

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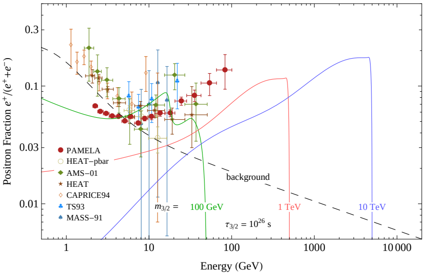

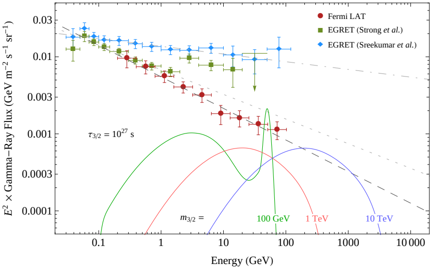

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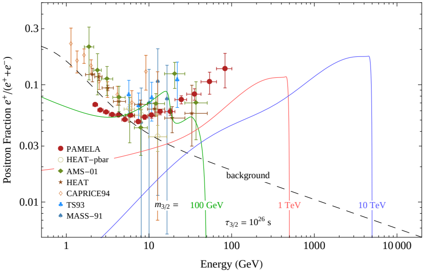

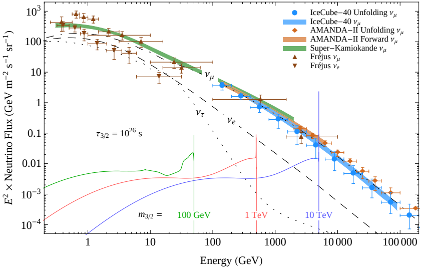

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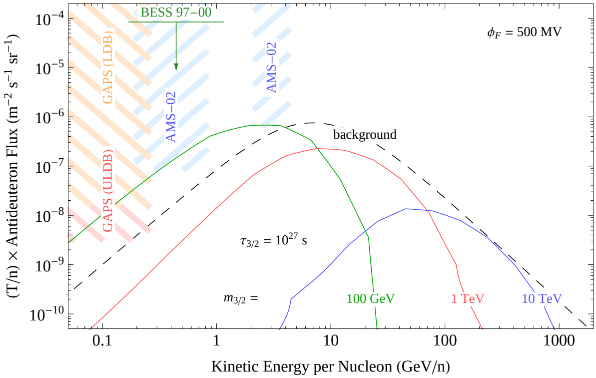
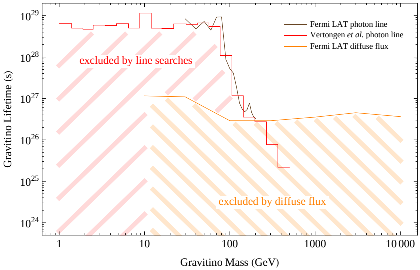
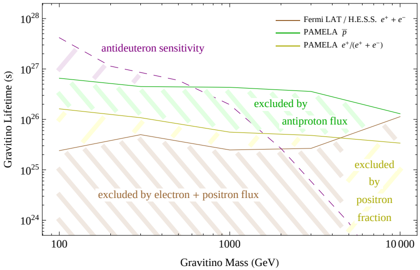
  - Associated gamma-ray flux in conflict with Fermi LAT data for isotropic diffuse flux
  - For large gravitino masses constraints from neutrino flux can become important
- Astrophysical sources like pulsars are required to explain the excess

Antideuteron Signals from Gravitino Decays

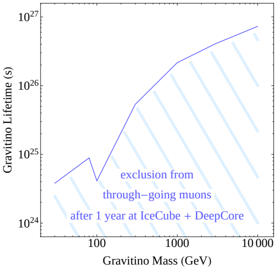
- Antideuterons are a valuable additional indirect detection channel
  - In particular sensitive to low gravitino masses due to small astrophysical background
  - AMS-02 and GAPS will be able to put strong constraints on light gravitino dark matter
  - Complementary to gamma rays, relevance depends on branching ratio for the photon line







- Estimate of bounds on gravitino lifetime
  - Additional uncertainties from charged CR propagation
  - Background subtraction could improve bounds
  - Photon line bounds can be very strong for low gravitino masses
    (see C. Weniger's talk for a discussion of γ constraints)
  - Antideuterons can give complementary limits at low gravitino masses
  - Neutrino bounds competitive for large gravitino masses



Conclusion

- Gravitino dark matter with broken *R* parity is well motivated as it leads to a cosmological scenario that is consistent with thermal leptogenesis and BBN
- The Gravitino lifetime is naturally in the range of indirect detection experiments and can be strongly constrained using a multi-messenger approach
- Gravitino dark matter cannot explain the PAMELA excess due to strong constraints from gamma rays and antiprotons
- Future antideuteron searches can provide strong constraints on light gravitinos, in particular if the gamma-ray line signal is suppressed
- Neutrino experiments like IceCube have the capability to provide competetive constraints on the gravitino lifetime, in particular at large masses

  New neutrino detection channels like showers and use of spectral information will allow to greatly improve the sensitivity of these experiments

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Thanks for your attention!