The positron excess and supersymmetric dark matter

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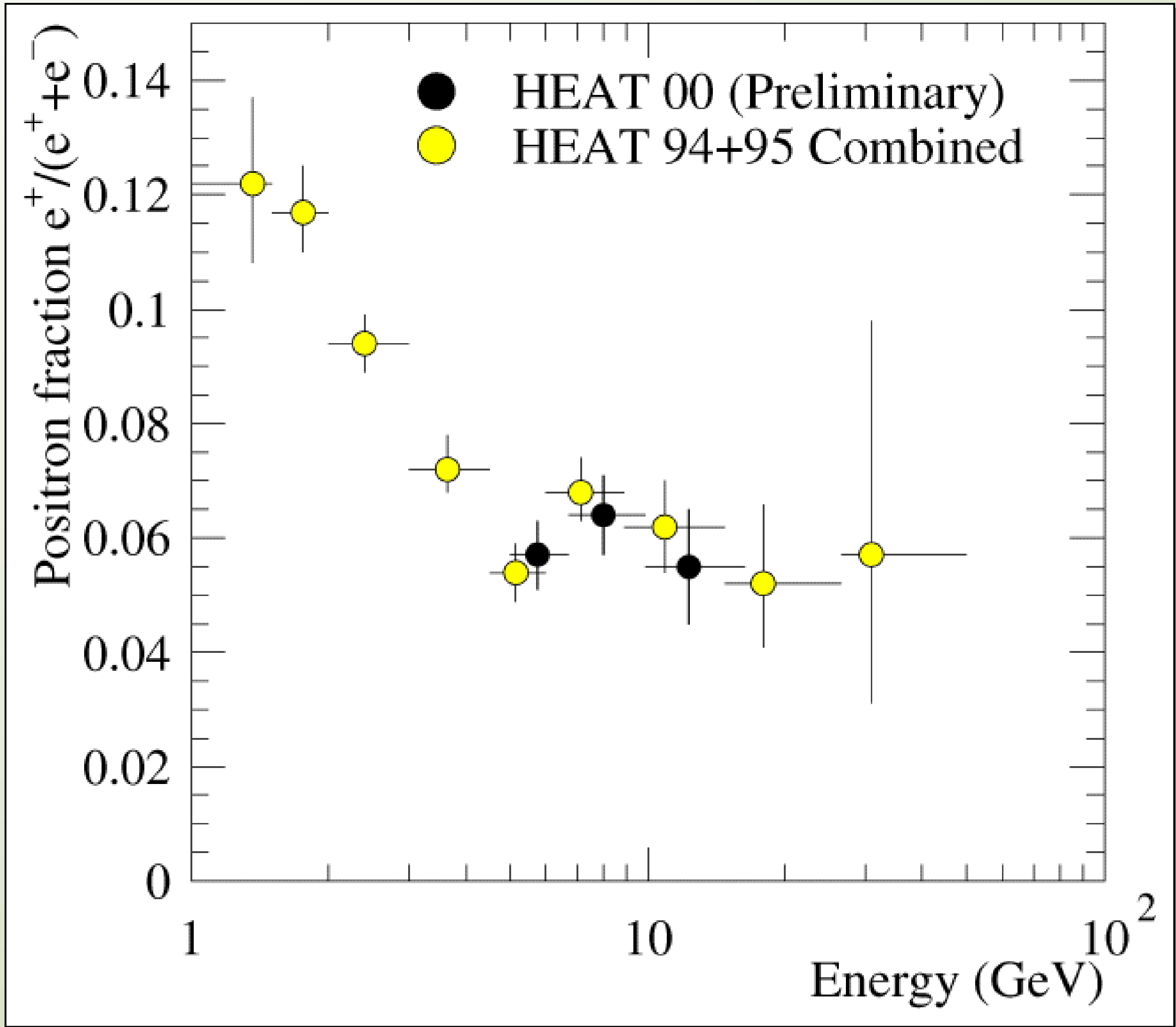
Outline

- The HEAT measurements
- Supersymmetric dark matter and their positron flux
- Conclusions

The HEAT measurements



The intriguing excess at ~8 GeV remains in the new data with a new experiment.

SUSY Dark matter modelling

- There are some recent attempts to explain the HEAT excess with supersymmetric dark matter:
  - Kane, Wang and Wells, hep-ph/0108138.
    Kane, Wang and Wang, hep-ph/0202156.

    $$\chi + \chi \rightarrow W^+ + W^-,\ \chi + \tilde{\nu} \rightarrow e^+ + W^-,\ \tilde{\nu} + \tilde{\nu} \rightarrow W^+ + W^-,\ \ldots$$

  - de Boer, Sander, Horn and Kazakov, astro-ph/0207557

    $$\chi + \chi \rightarrow W^+ + W^-,\ \ldots$$

    See talk tomorrow!

  - Baltz, Edsjö, Freese, Gondolo, PRD 65 (2002) 063511.

    $$\chi + \chi \rightarrow W^+ + W^-,\ \ldots$$

The MSSM – parameters

μ	-	Higgsino mass parameter
M_2	-	Gaugino mass parameter
m_A	-	mass of CP-odd Higgs boson
$\tan\beta$	-	ratio of Higgs vacuum expectation values
m_0	-	scalar mass parameter
A_b	-	trilinear coupling, bottom sector
A_t	-	trilinear coupling, top sector

Parameter	μ	M_2	*tan* β	m_A	m_0	A_b/m_0	A_t/m_0
Unit	***GeV***	***GeV***	1	***GeV***	***GeV***	***1***	***1***
Min	-50000	-50000	1	0	100	-3	-3
Max	+50000	+50000	60	10000	30000	3	3

The MSSM – general

The Lightest Supersymmetric Particle (LSP)

Usually the neutralino. If R-parity is conserved, it is stable.

The Neutralino – χ

$$\tilde{\chi}_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W}^3 + N_{13}\tilde{H}_1^0 + N_{14}\tilde{H}_2^0$$

Gaugino fraction

$$Z_g = |N_{11}|^2 + |N_{12}|^2$$

1. Select MSSM parameters
2. Calculate masses, etc
3. Check accelerator constraints
4. Calculate relic density
5. $0.05 < \Omega_\chi h^2 < 0.25$?
6. Calculate fluxes, rates,...

Calculation done with

Dark SUSY

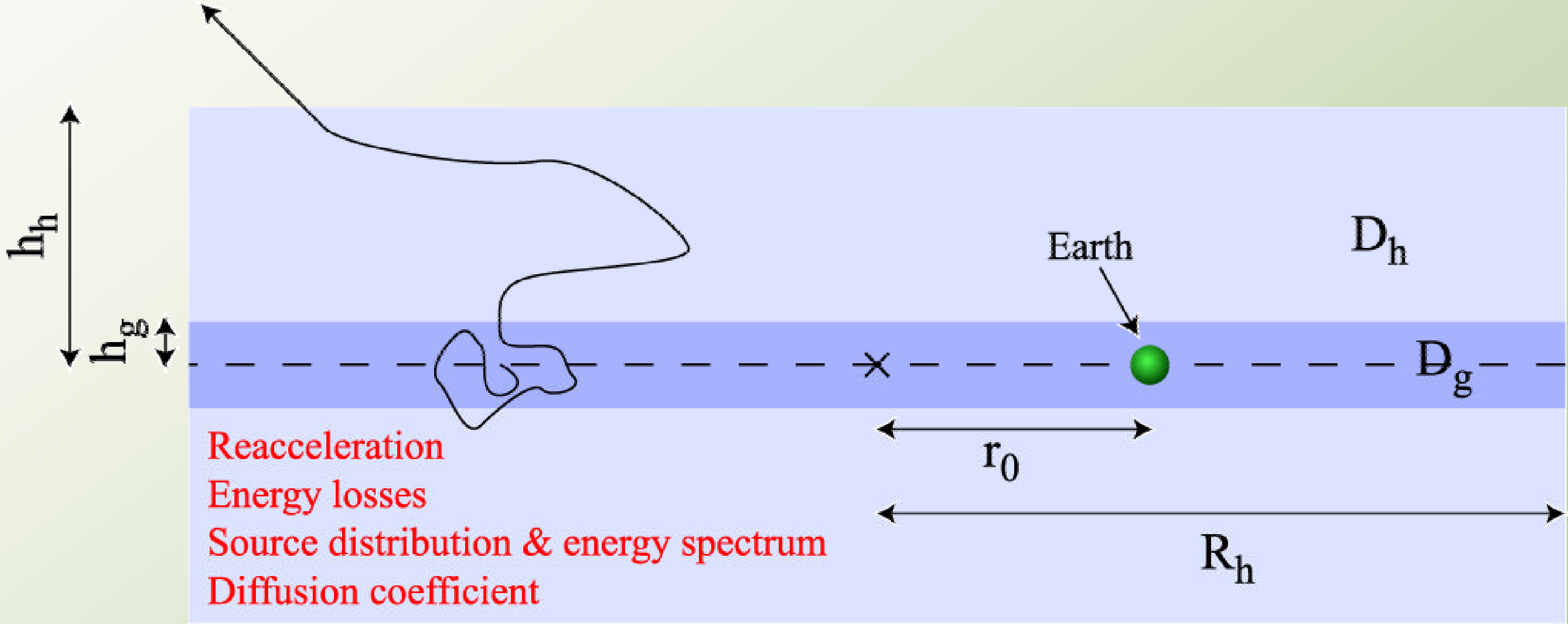
http://www.physto.se/~edsjo/darksusy/

WIMP search strategies

- Direct detection
- Indirect detection:
  - neutrinos from the Earth/Sun
  - antiprotons from the galactic halo
  - positrons from the galactic halo
  - gamma rays from the galactic halo
  - gamma rays from external galaxies/halos
  - synchrotron radiation from the galactic center / galaxy clusters

When fitting the positron flux, we have to check that the other searches are not violated!

Diffusion model of the Milky Way



$h_g \approx 0.1$ kpc
$h_h \approx 3–20$ kpc
$r_0 \approx 8.5$ kpc
$R_h \approx 20$ kpc

$D_l \approx D_l^0(1+R/R_0)^{0.6}$
$D^0 \approx 6\times10^{27}$ cm^2 s^{-1}
$R \approx p/|Z|$
$R_0 \approx 3$ GV

Positron signal from neutralinos

Positron source function

$$Q_{e^+}(T,\vec{x}) = \frac{1}{2}(\sigma_{ann} v)\left(\frac{\rho_\chi(\vec{x})}{m_\chi}\right)^2 \sum_f B_f \frac{dN_f}{dT}$$

Put into the diffusion equation taking the galaxy model into account.

$$\Phi_{e^+}^{\text{interstellar}}(T_{e^+})$$

The positrons meet the solar wind. Take this modulation into account.

$$\Phi_{e^+}^{\text{Earth}}(T_{e^+})$$

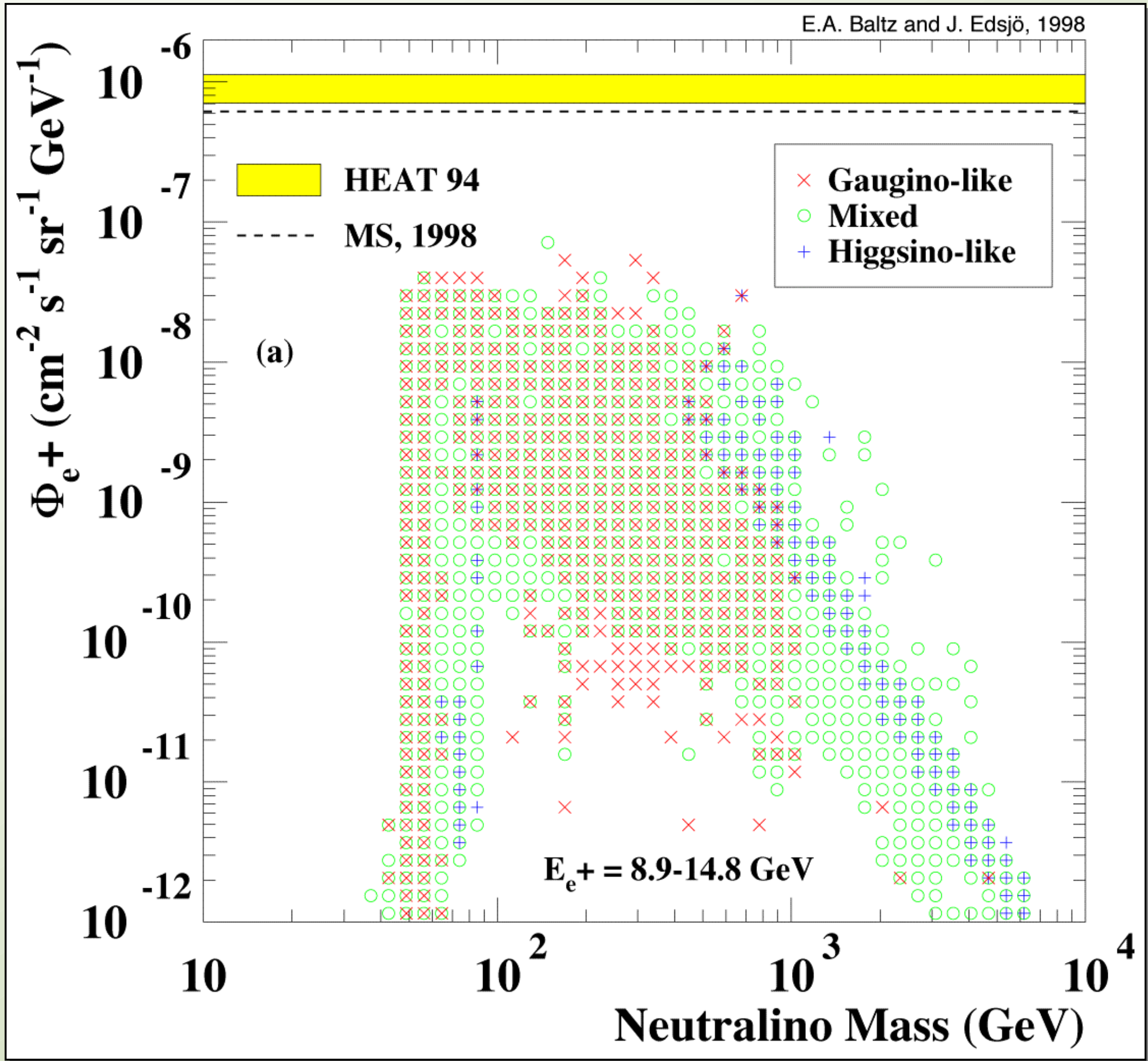
Look at the positron fraction, $e^+/(e^+ + e^-)$ to minimize modulation effects.

Positron fluxes from neutralinos

Compared to antiprotons,

- energy losses are much more important
- essentially only local halo properties are important
- higher energies due to more prompt annihilation channels (ZZ, W^+W^-, etc)
- propagation uncertainties are higher
- solar modulation uncertainties are higher

Signal fluxes

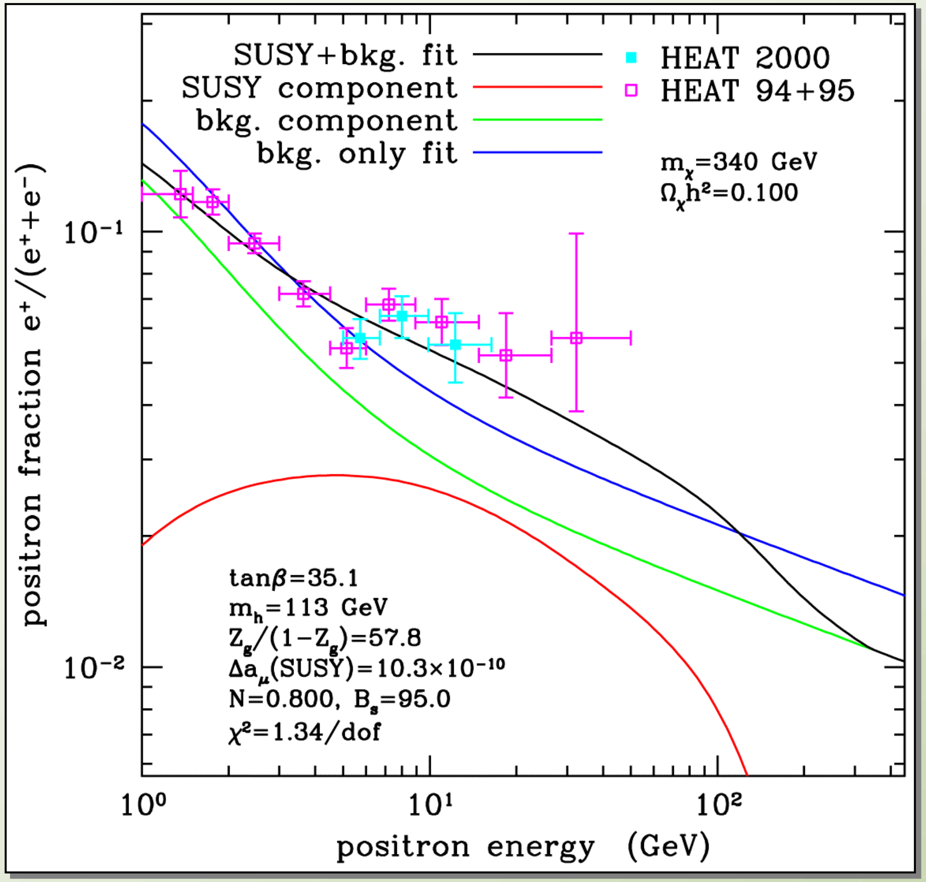


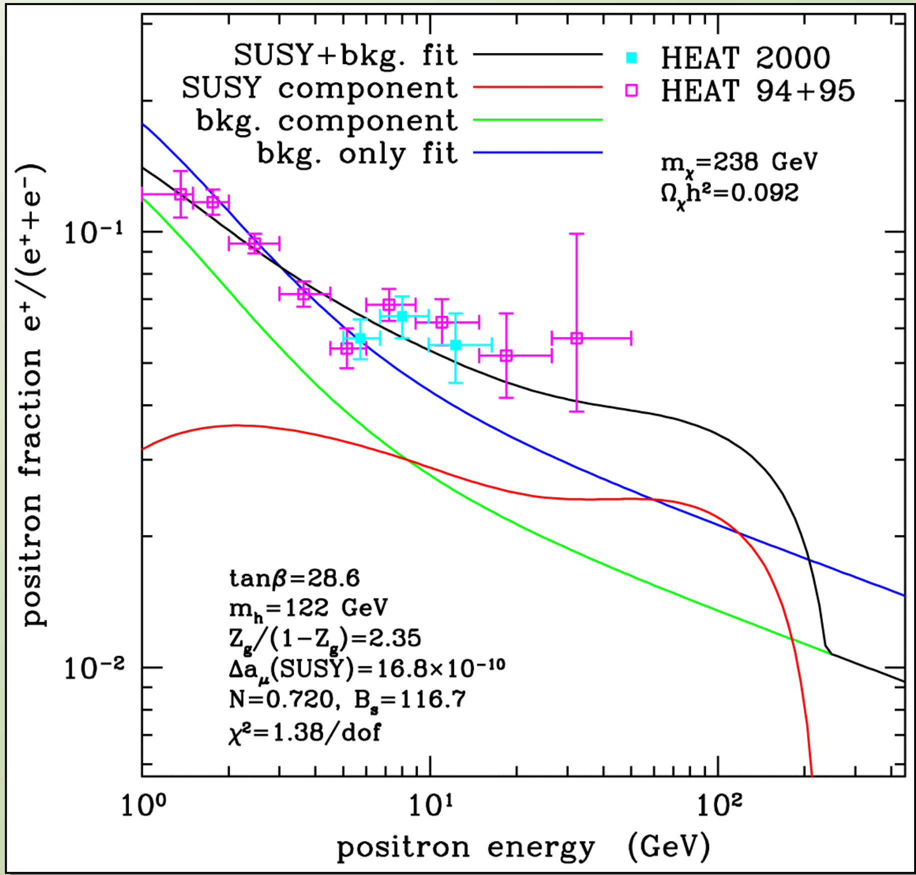
Compared to antiprotons, the fluxes are typically lower (except at high masses), but... the positron spectra can have features that are detectable.

Boosting scheme

- The fluxes are too low, so we arbitrarily boost them with $\mathbf{B_s}$ (due e.g. to clumpiness).
- We also let the background normalization, **N**, be free to within a factor of 2.
- Fit $\mathbf{B_s}$ and **N** and make sure not to violate other fluxes, specifically producing too many antiprotons.
- For the antiprotons, the flux is boosted by a factor ~0.75 k B_s where k reflects the maximum uncertainty we have in the antiproton flux. (k=0.2 – 5) Compare with BESS.
- We get B_s in the range from ~50 up to 10^{10}. Restrict to the lower range, $B_s<1000$.
- Only reasonable relic densities: $0.05 < \Omega_\chi h^2 < 0.25$

Best fit spectra



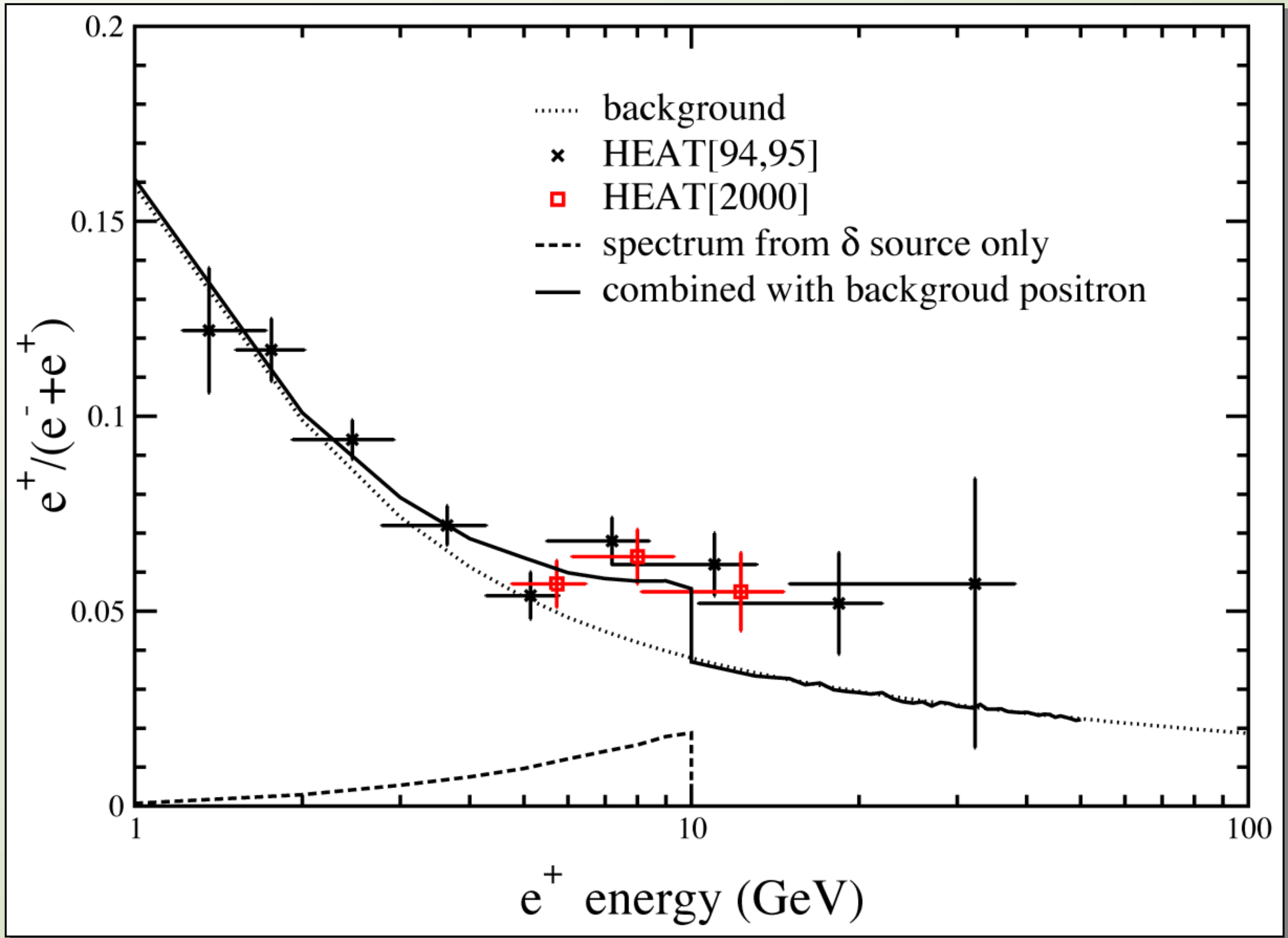


The fits are better including a signal (χ^2/d.o.f. = 1.34 and 1.38 to be compared with 2.33 for the background only),

but the feature at ~8 GeV is not reproduced.

What about a monochromatic signal?

Figure from Kane, Wang and Wang, hep-ph/0202156.



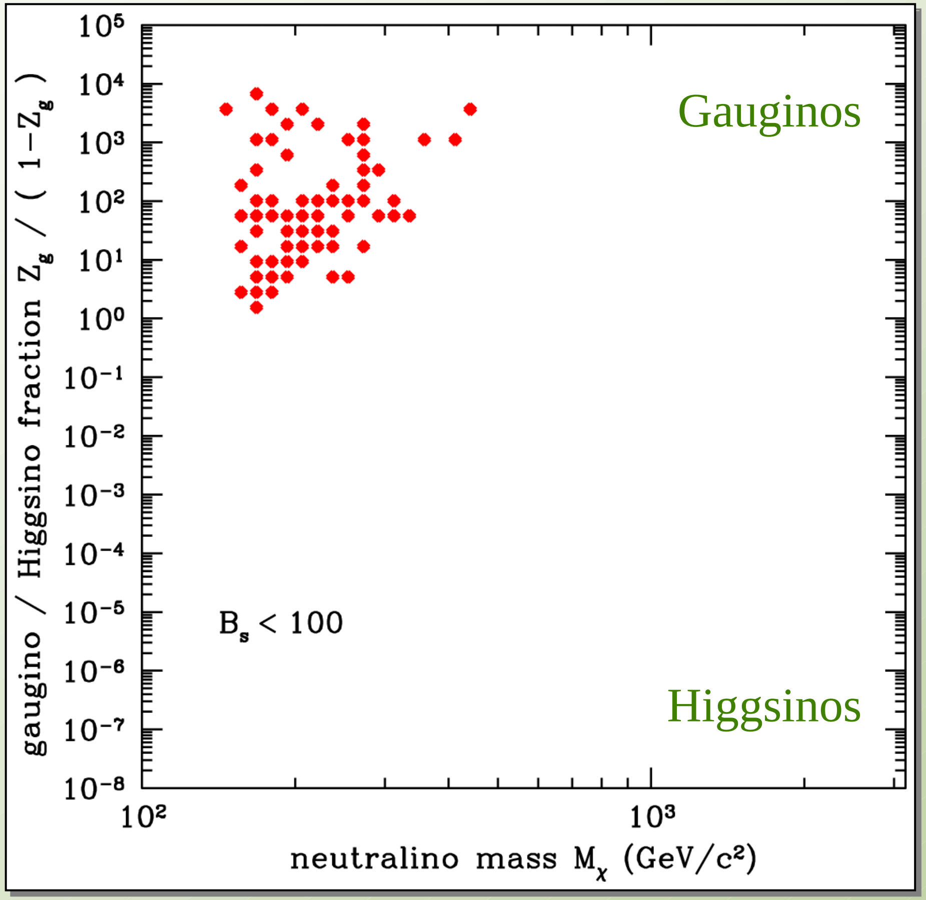
- Due to energy losses, the monochromatic line is smeared and doesn't fit the data very well either.
- Can be produced via

$$\chi + \tilde{\nu} \rightarrow e^{+} + W^{-}$$

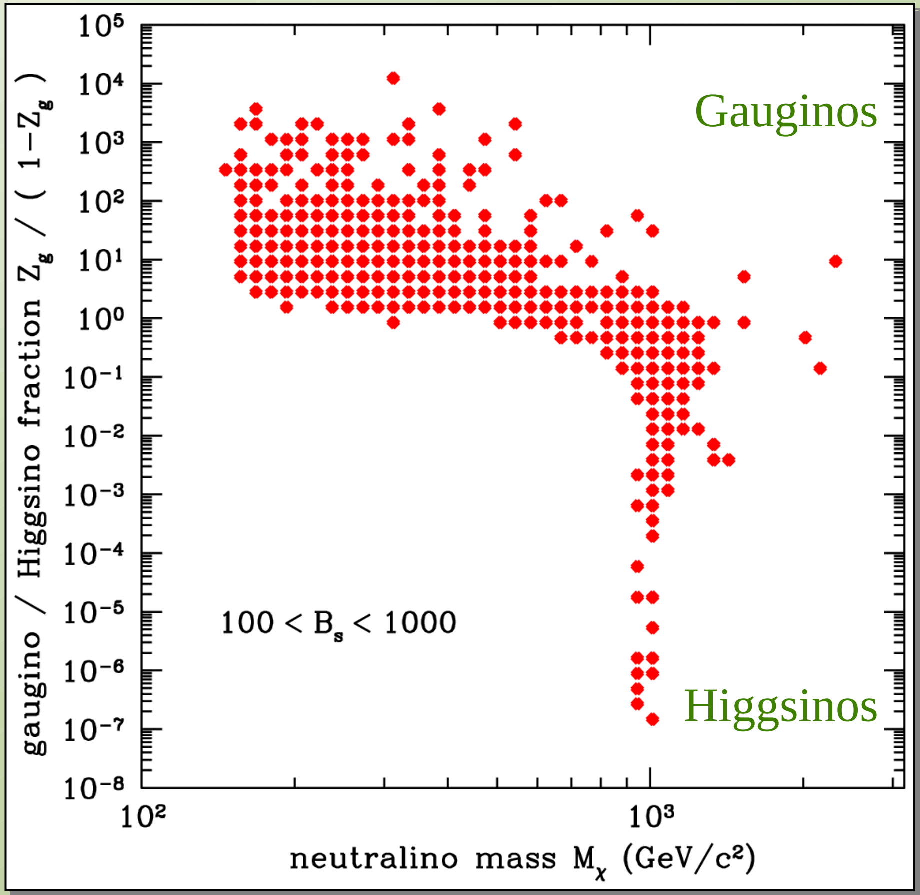
but this is an extremely fine-tuned model. Sneutrinos are also excluded by direct detection...

Boost factors and composition

Small boosts factors

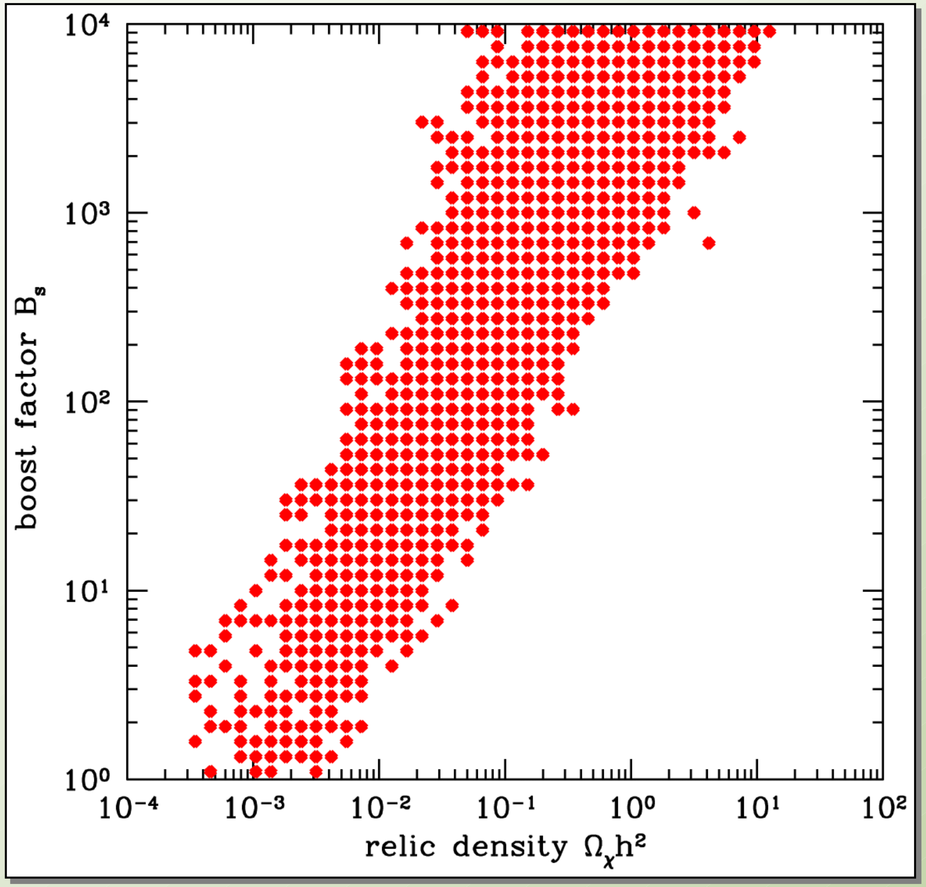


Large boost factors

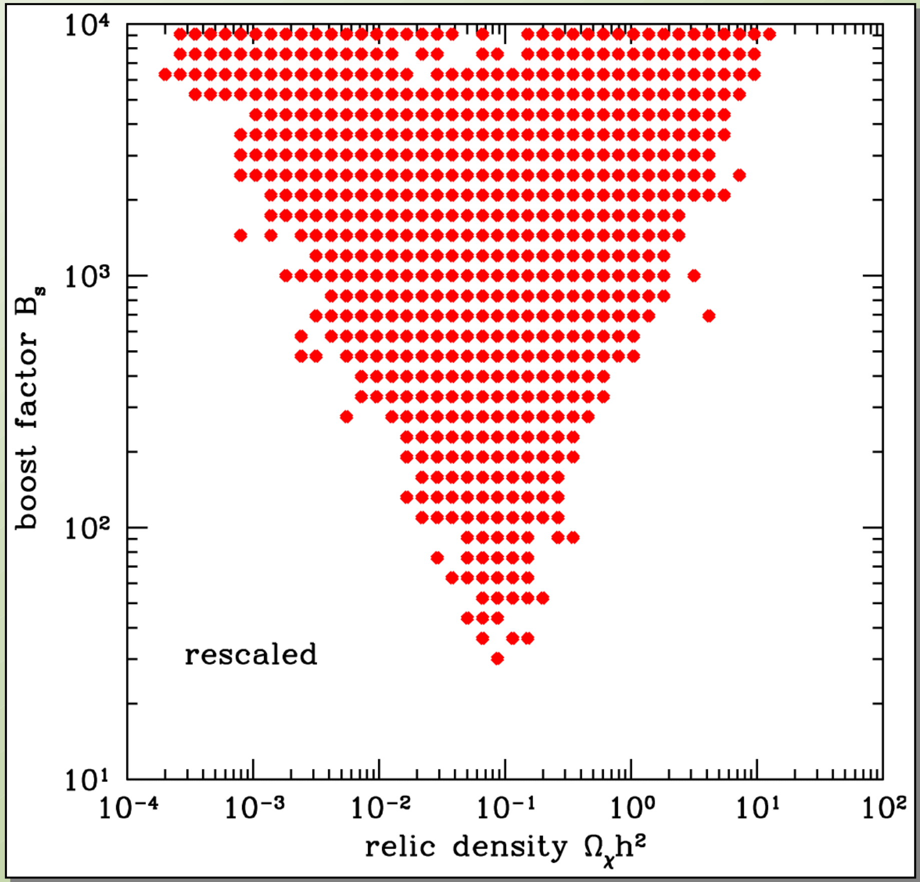


Boost factors and Ω_χ

No rescaling

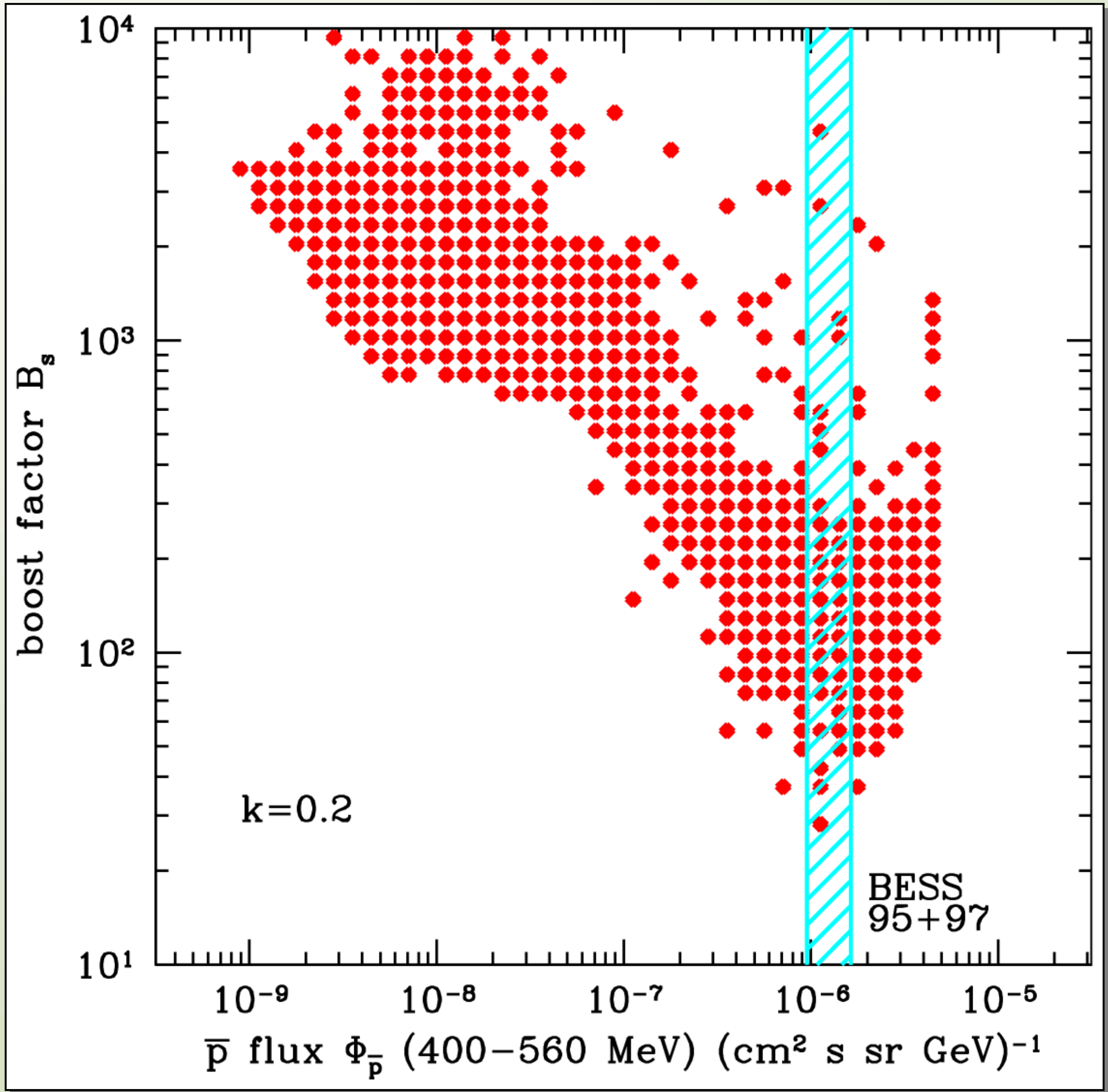


With rescaling



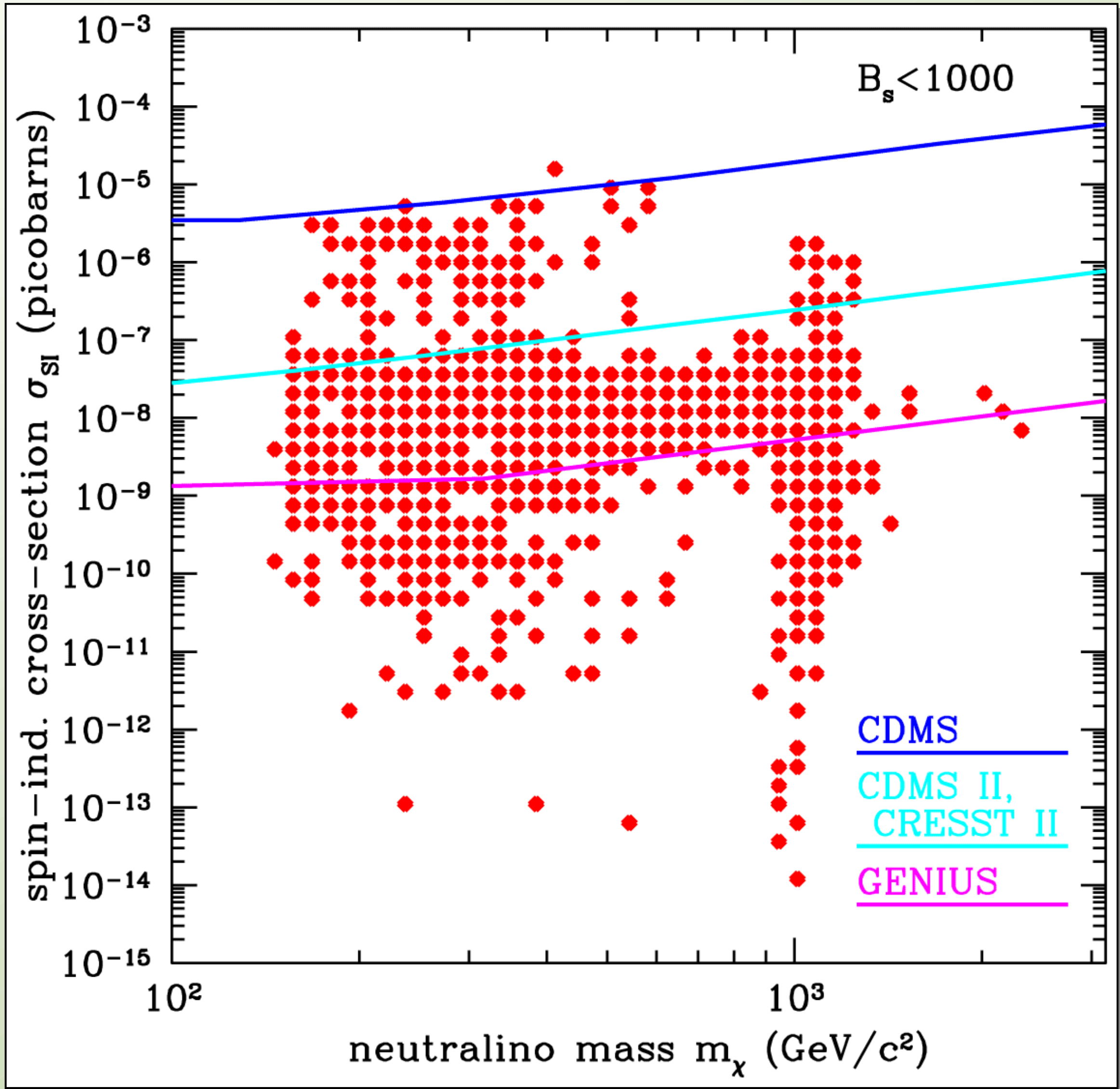
Accept large boost factors, or resort to non-thermal production schemes.

Comparison with antiproton fluxes



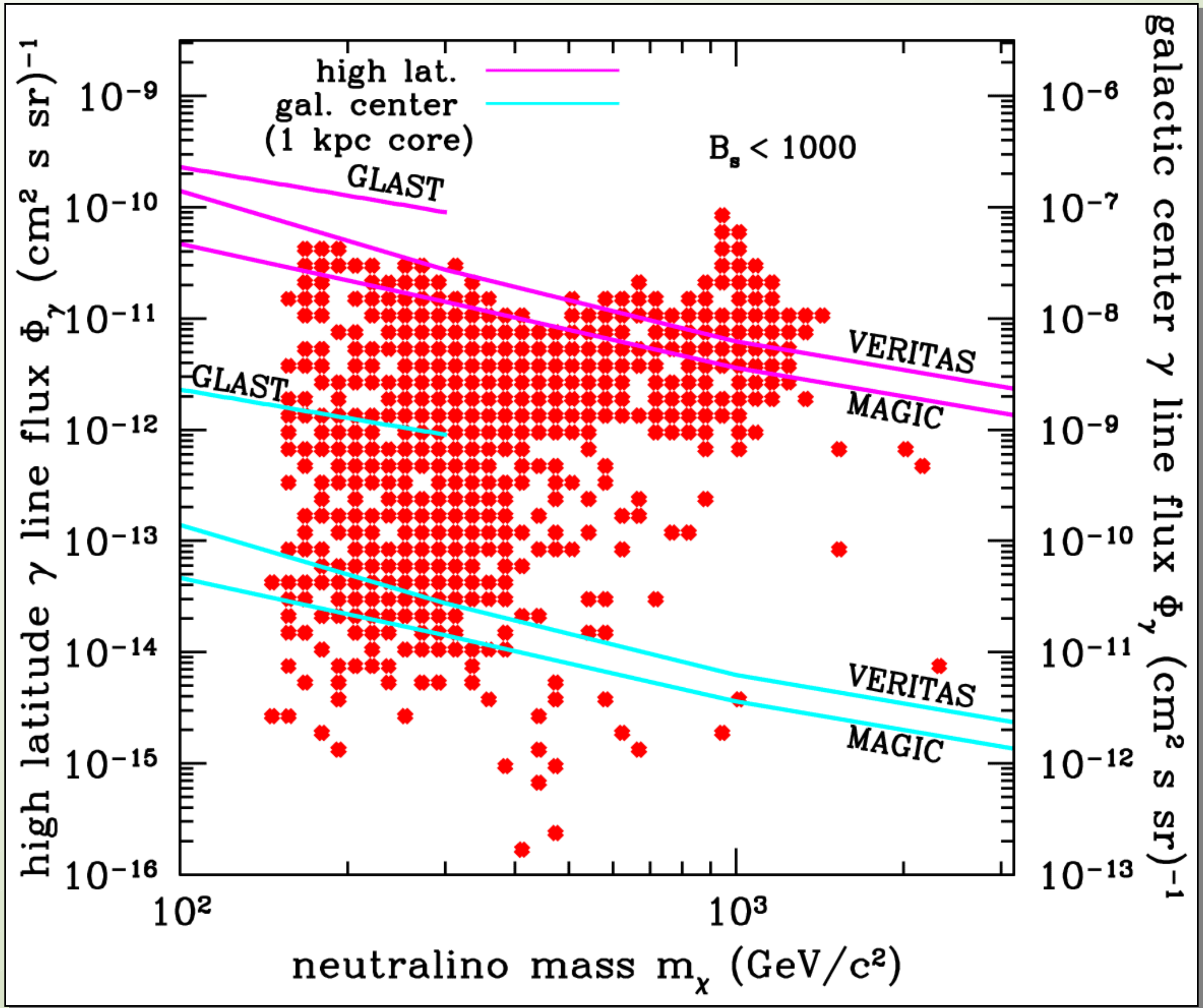
When boosting the positron flux, it is very easy to produce too many antiprotons!

Comparison with direct detection



Only models with signal fits that are better than background only are shown.

Comparison with gamma lines



Only models with signal fits that are better than background only are shown.

Conclusions

- With standard MSSM and astrophysical assumptions, the positron fluxes are typically too low.
- With clumpiness, the signals can be boosted.
- HEAT sees an intriguing bump at ~8 GeV. With a signal from neutralinos, the fits are better, ***but*** the bump can not be fully reproduced, not even with a monochromatic source of positrons.
- For models with good fits, other signals are typically also high:
  - antiproton fluxes
  - direct detection
  - gamma lines
- I wouldn't bet my life savings on super-symmetric dark matter as the explanation of the positron excess...