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Non - thermal Dark Matter

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LSP wino dark matter, satellite data, string theory, moduli and non-thermal cosmological history, and LHC

Gordy Kane

Trieste, June 2009

*based on talks given at dark matter workshop Institute for Advanced Study, April 2009; Pamela workshop, Rome, May 2009; Fermi/GLAST meeting RICAP, Frascati, May 2009; SUSY 2009, Boston, June 2009; String Phenomenology June 2009 Warsaw and several papers

- Long ago recognized that one way to “see” dark matter was via products of annihilation of pairs of DM particles in the galaxy
- ***Traditionally the lightest superpartner, LSP, a very good DM candidate***
- Annihilate into everything, but positrons, antiprotons, gammas should be easier to see over backgrounds so look for those

Recently reported possible satellite signals and relevant data:

PAMELA, Fermi/GLAST, etc

Dark matter! Not only learn what DM is – could also be the discovery of supersymmetry (if indeed LSP) – may also point toward underlying theory – probes cosmological history of universe!

Worth lot of effort to untangle the situation, test interpretations – does an LSP give a satisfactory description of the data? Then formulate tests to confirm it. LHC is the crucial test!

OUTLINE OF TALK

Are we observing DM in cosmic rays?
YES

- ❑ PAMELA data $\leftrightarrow$ light wino LSP works well
  - -- issues to check
  - -- wino plus astrophysics description of satellite data

- ❑ Dark matter relic density from non-thermal-equilibrium cosmological history of the universe – e.g. LSPs and entropy arise from moduli decay – but still "wimp miracle"!

- ❑ LHC tests and implications – focus on one model as example

- ❑ Concluding remarks

Why a new paper every day?
-- they assume thermal history
-- misunderstanding of antiprotons
-- assume single source

WINO LSP VERY WELL MOTIVATED FOR DARK MATTER

- theoretically

$$\boxed{W^+, W^0, W^- \rightarrow \tilde{W}^+, \tilde{W}^0, \tilde{W}^-}$$

Wino LSP

-- $\sim$ two decades

-- anomaly mediated supersymmetry breaking (Randall, Sundrum…Moroi, Randall)

Predicted PAMELA signal, 1999

-- "split" supersymmetry (Arkani-Hamed, Dimopoulos, …)

-- Z' mediation (Wang, Langacker, Yavin, Paz, Verlinde …)

-- M theory compactified on G_2 manifold (Acharya, Kane, …)

-- MSSM scan – (Hewett, Rizzo et al)

- *Phenomenologically --Wino* LSP DM annihilation provides the most positrons (σxBR), most energetic positrons, compared to other forms of LSP

My perspective today:

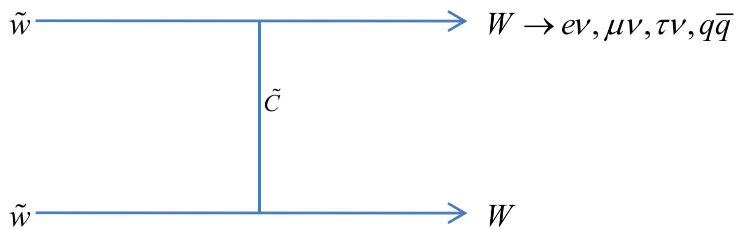
-- does a light wino LSP ($\sim$ 200 GeV) plus astrophysics provide a good description of PAMELA, Fermi data and constraints?

-- no discussions of other interpretations

Next consider several issues briefly, then the data

CAN A LIGHT WINO LSP DESCRIBE THE PAMELA DATA?

- Grajek, Kane, Phalen, Pierce, Watson 0812.4555, plus Ran Lu, Cheng Peng recently
- GK, Ran Lu, Scott Watson arXiv:0906.4765



Rate? – relic density too small with thermal equilibrium cosmology
-- wino annihilates well into positrons – much better than binos, better than higgsinos – so hopeful

[“thermal” → LSPs today present from Big Bang minus those that annihilated -- no additional ones e.g. from moduli decay -- no additional entropy]

- ***But in comprehensive theories, e.g. Planck scale string constructions that have dark matter, EW symmetry breaking, TeV physics, stabilized moduli, consistency with nucleosynthesis and other data, etc, non-thermal cosmological history is probably the default***

- ***We normalize to local relic density (use 0.3 GeV/cm^3)*** – This is the right procedure if LSPs of non-thermal origin, e.g. moduli decay

  → NO "BOOST FACTORS" NEEDED TO REPRODUCE PAMELA SIGNAL

- **Antiprotons** – Naively expect signal here if see positron signal, but not apparent in PAMELA data – however:

  - antiprotons from quark fragmentation soft – lose energy poorly so soft antiprotons get to detector – signal present to low energies ($\sim$ GeV) – signal, secondaries have similar spectrum so normalization main difference

  - present in old data, so old data was background + "signal"

  - but old data was fitted as if just background, result used as background in recent analyses

  - consistent treatment of data and background → signal *was* seen in old data!

  - no need for "leptophilic" models – indeed, care needed, cannot treat antiprotons and positrons independently

- Gammas? Fermi/Glast data? $e^+ + e^-$ not from wino

- Synchrotron radiation, recombination etc – OK

- Also, for DM annihilation, energy dependent small “boost factors” are better motivated than none – actually inevitable

  Lavalle, Salati, Brun, Donato, Fornengo, Taillet et al 0809.5268 etc

  [“boost factor” is not good terminology here since average not increased]

OTHER ISSUES

- Profile of galaxy DM – use NFW everywhere – results a little better if profile a little softer, and that is probably preferred by astrophysics

  -- relevant for antiprotons and gammas, not much for positrons

- Run Galprop, vary 8 parameters and others, all relevant – ***not yet scan or fit*** since computing time long, few hundred simulations so far – treat signal and background in same way!!!

- M_{wino} = 180-200 GeV so far – ***only parameter of underlying physics in PAMELA region***
- Region below $\sim$ 10 GeV poorly described – little wino DM signal there, only relevant to be sure no systematic problem – assume solar modulation, experts working on it
- Direct detection very small for wino, very sensitive to higgsino, bino mix

High energy astrophysics e^- , e^+ component:

Fermi sees energetic $e^+ + e^-$ up to a TeV – obviously an LSP of mass $\sim$ 200 GeV cannot generate those – but conventional astrophysics is expected to

Assume for higher energy component form suggested by interstellar medium electrons accelerated by supernova remnants and shock waves, or pulsar spectra, (follow Zhang and Cheng)

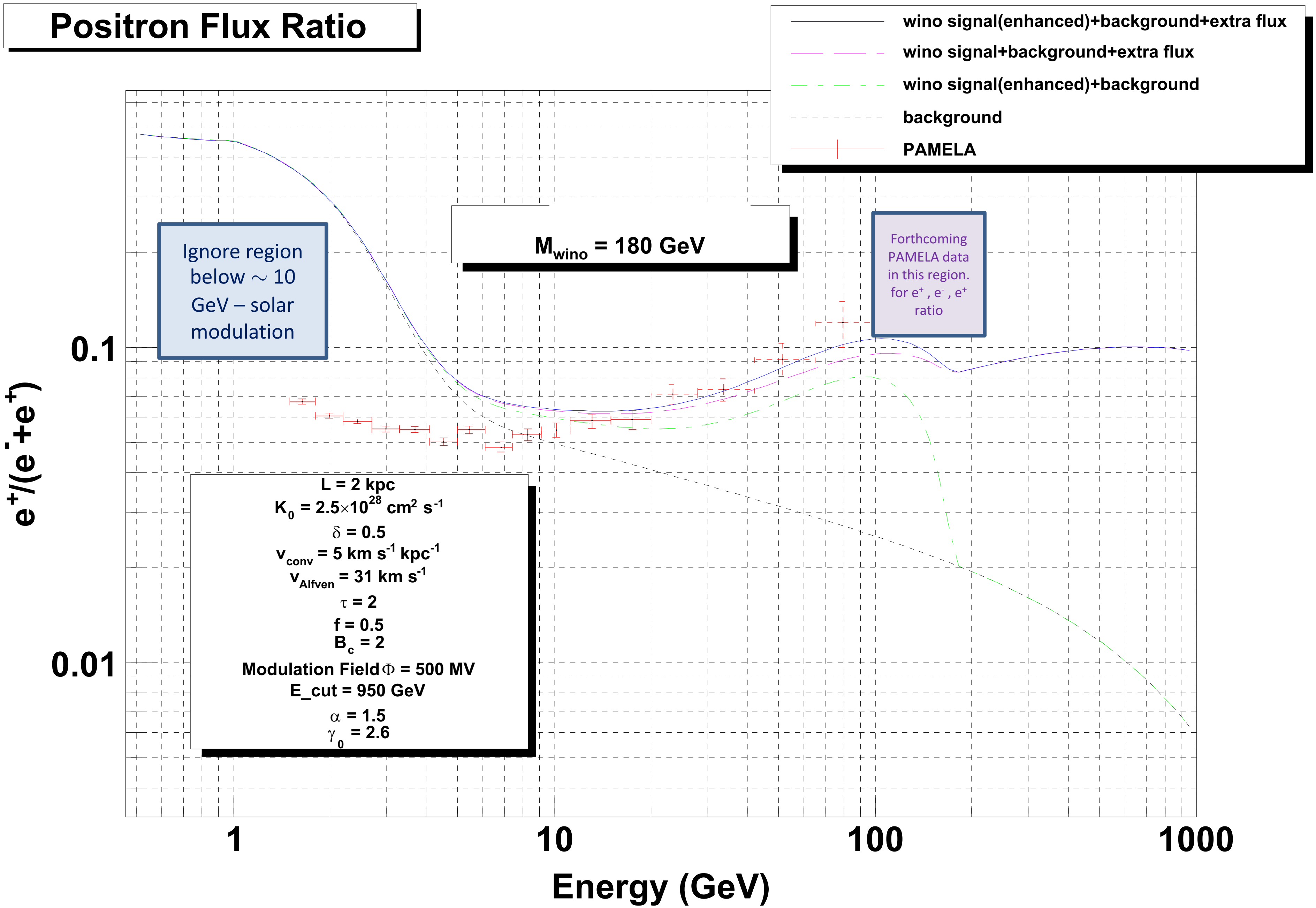
$$\rho(r) = N(r/r_\odot)\exp(-1.8(r-r_\odot)/r_\odot)\exp(-z/0.2kpc)$$

$$dN_{e^\pm}/dE = N' E^{-1.5}\exp(-E/950GeV)$$

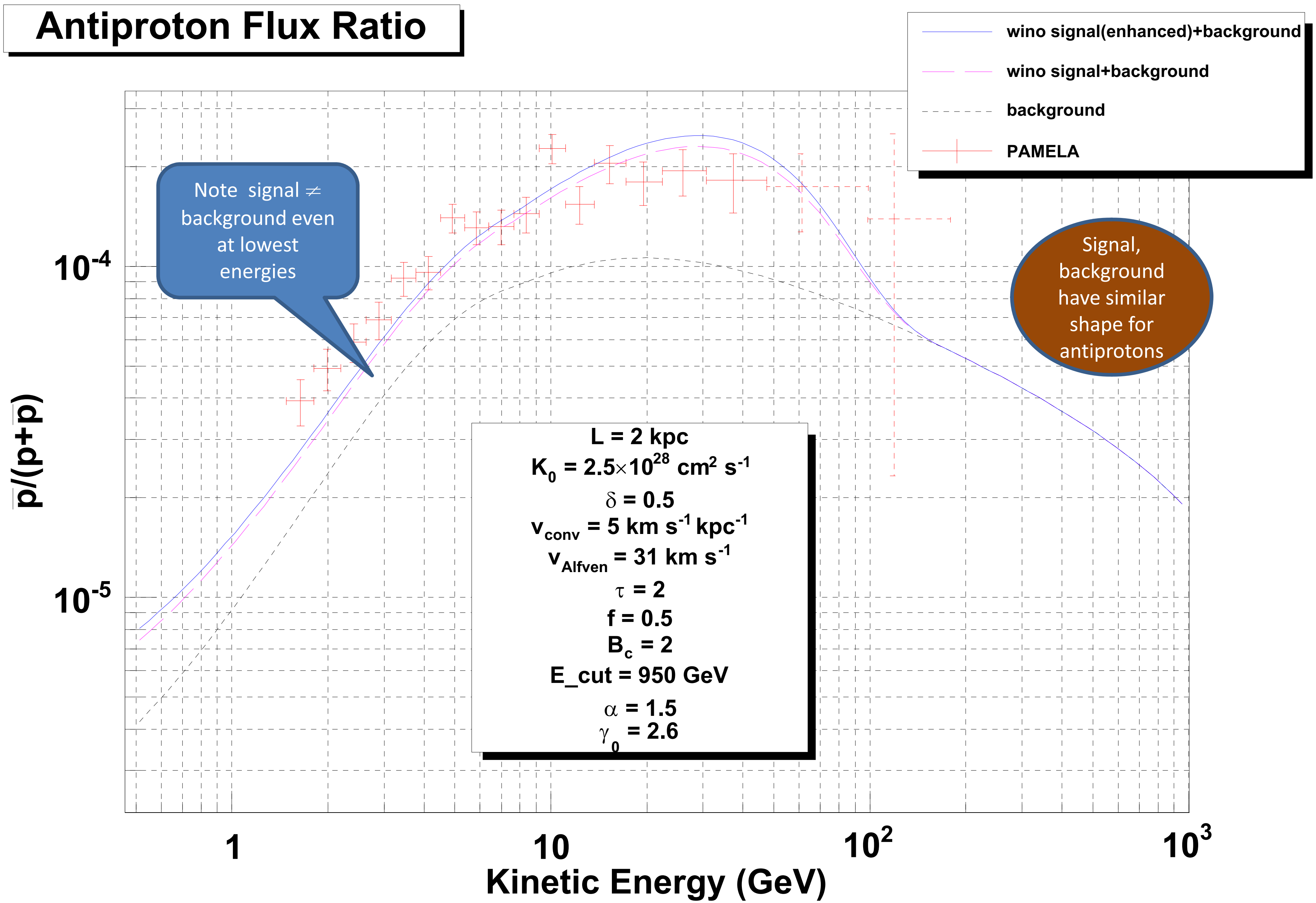
And assume $e^+/e^- = 1/6$

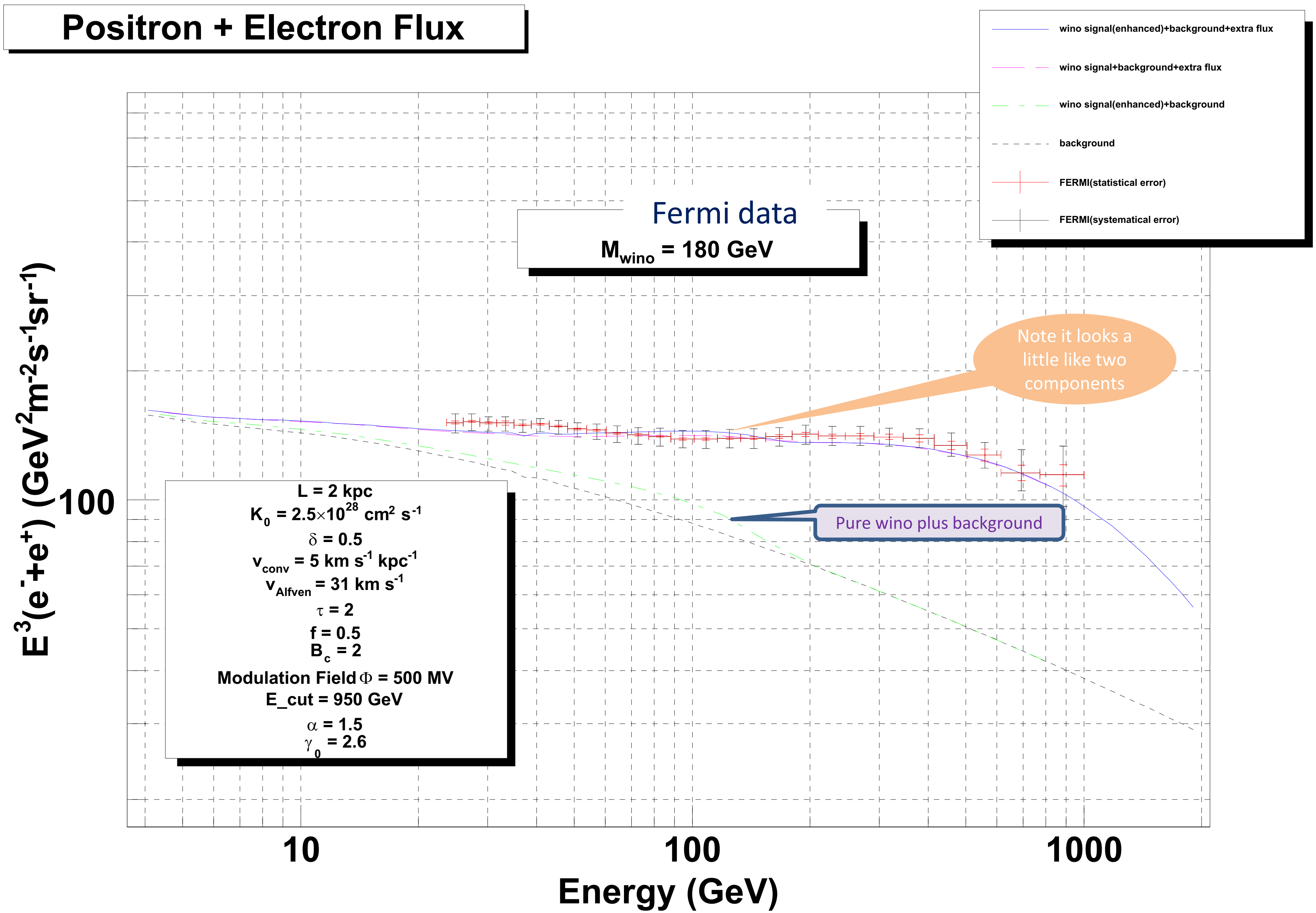
And normalize to Fermi data

Now show data and descriptions and predictions for one consistent set of propagation and injection parameters – M_{wino} =180 GeV

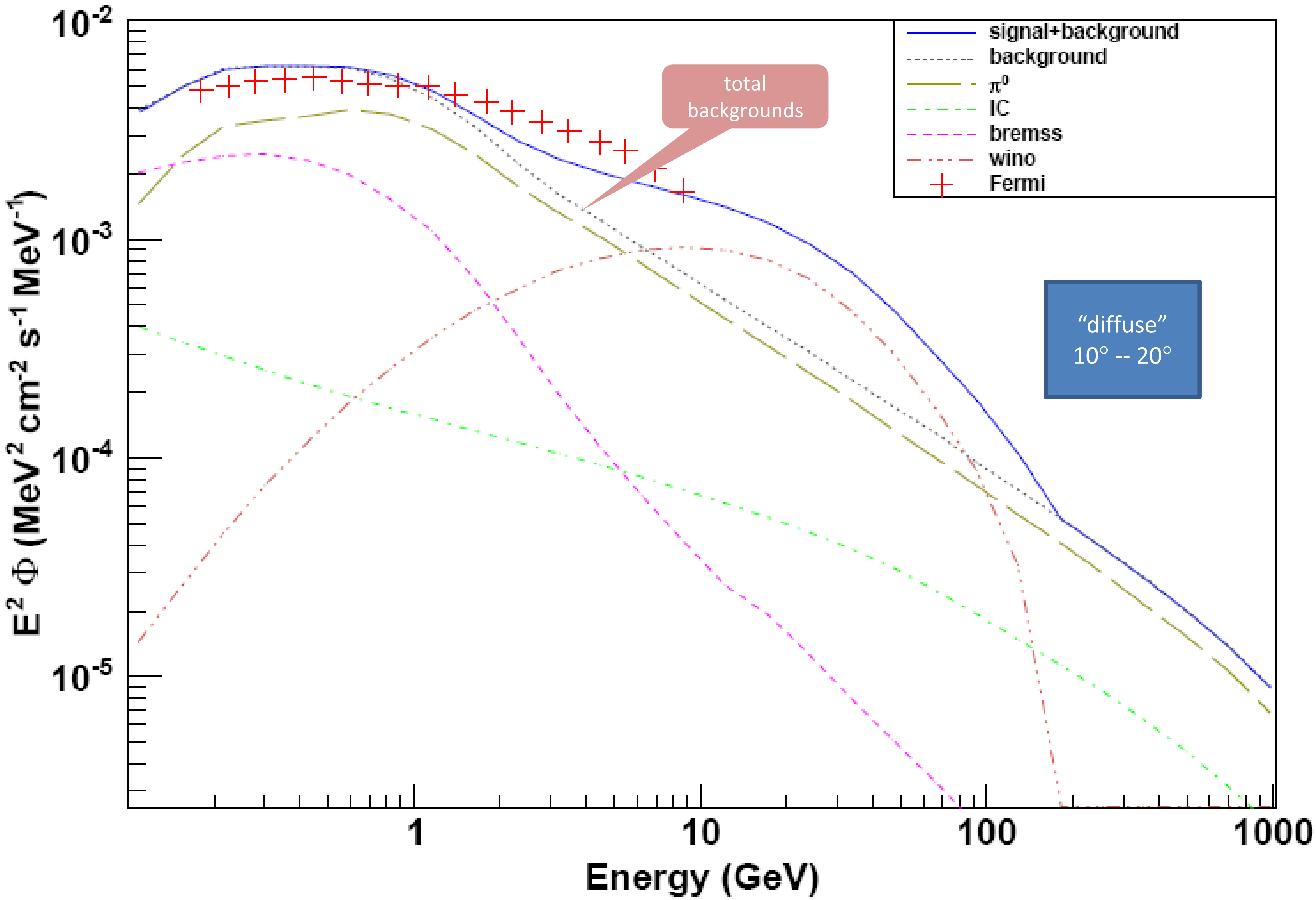


Positron Flux Ratio
wino signal(enhanced)+background+extra flux
wino signal+background+extra flux
wino signal(enhanced)+background
background
PAMELA
Ignore region below ~ 10 GeV – solar modulation
M_{wino} = 180 GeV
Forthcoming PAMELA data in this region. for e^+, e^-, e^+ ratio
L = 2 kpc
$K_0 = 2.5\times10^{28}$ cm^2 s^{-1}
δ = 0.5
v_{conv} = 5 km s^{-1} kpc^{-1}
v_{Alfven} = 31 km s^{-1}
τ = 2
f = 0.5
B_c = 2
Modulation Field Φ = 500 MV
E_cut = 950 GeV
α = 1.5
γ_0 = 2.6
0.1
0.01
$e^+/(e^-+e^+)$
1
10
100
1000
Energy (GeV)

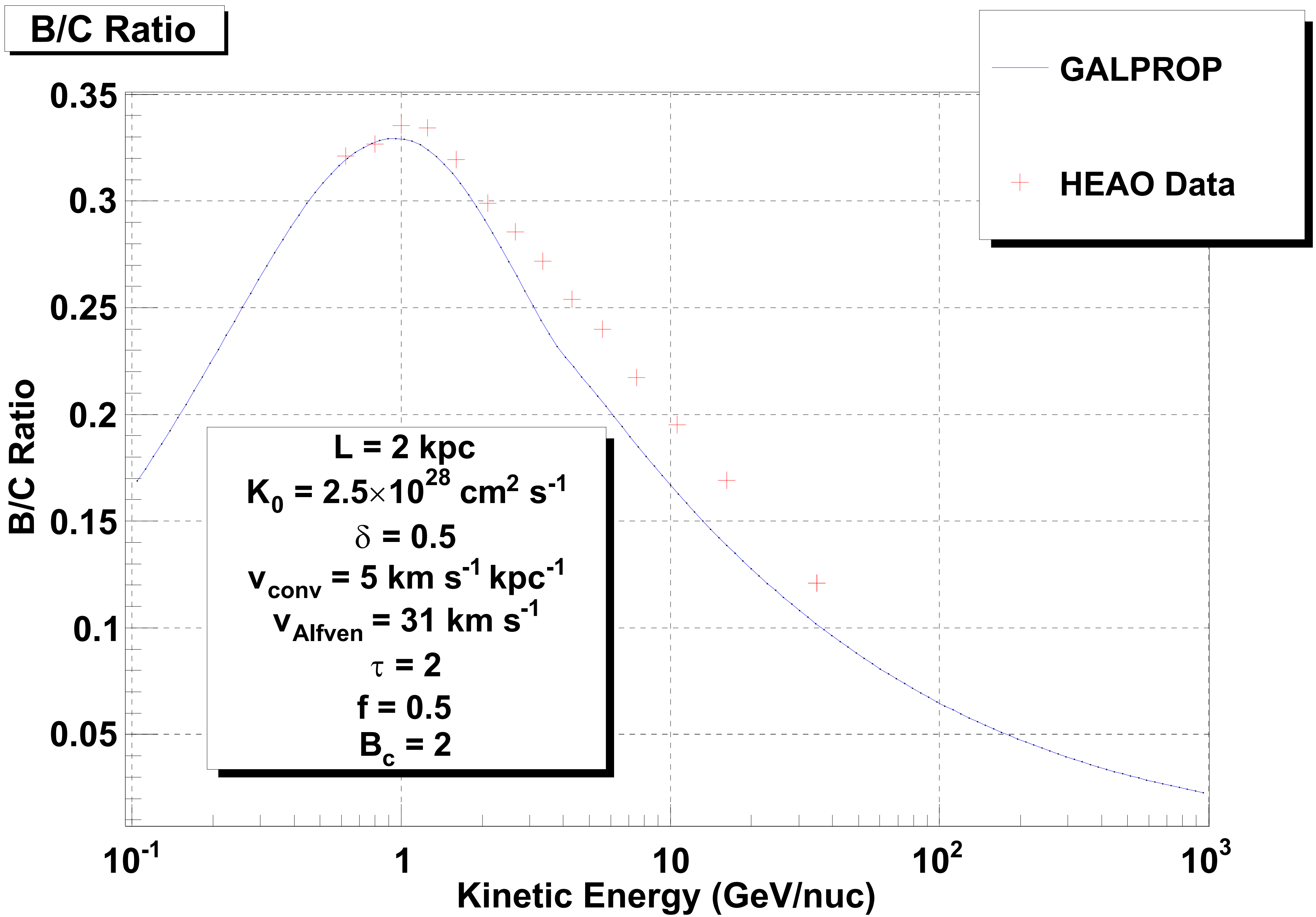

Antiproton Flux Ratio
wino signal(enhanced)+background
wino signal+background
background
PAMELA
Note signal ≠ background even at lowest energies
Signal, background have similar shape for antiprotons
L = 2 kpc
$K_0 = 2.5 \times 10^{28}$ cm^2 s^{-1}
$\delta = 0.5$
v_{conv} = 5 km s^{-1} kpc^{-1}
v_{Alfven} = 31 km s^{-1}
$\tau = 2$
f = 0.5
$B_c = 2$
E_cut = 950 GeV
$\alpha = 1.5$
$\gamma_0 = 2.6$
10^{-4}
10^{-5}
$\bar{p}/(p+\bar{p})$
1
10
10^2
10^3
Kinetic Energy (GeV)



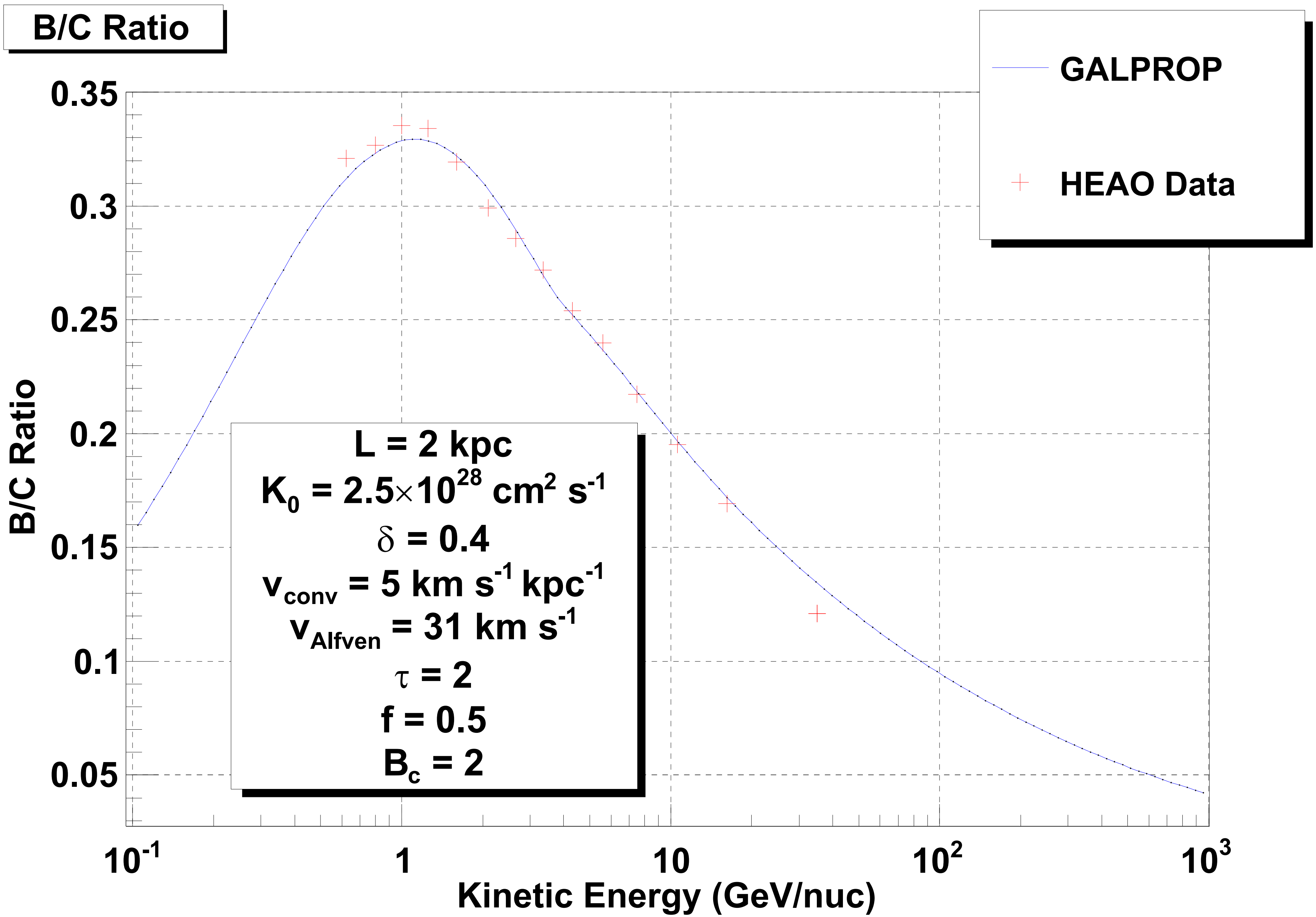
Positron + Electron Flux
wino signal(enhanced)+background+extra flux
wino signal+background+extra flux
wino signal(enhanced)+background
background
FERMI(statistical error)
FERMI(systematical error)
Fermi data
M_{wino} = 180 GeV
Note it looks a little like two components
Pure wino plus background
L = 2 kpc
$K_0 = 2.5\times10^{28}$ cm^2 s^{-1}
δ = 0.5
v_{conv} = 5 km s^{-1} kpc^{-1}
v_{Alfven} = 31 km s^{-1}
τ = 2
f = 0.5
B_c = 2
Modulation Field Φ = 500 MV
E_cut = 950 GeV
α = 1.5
γ_0 = 2.6
$E^3(e^-+e^+)$ (GeV^{2}m^{-2}s^{-1}sr^{-1})
100
10
100
1000
Energy (GeV)



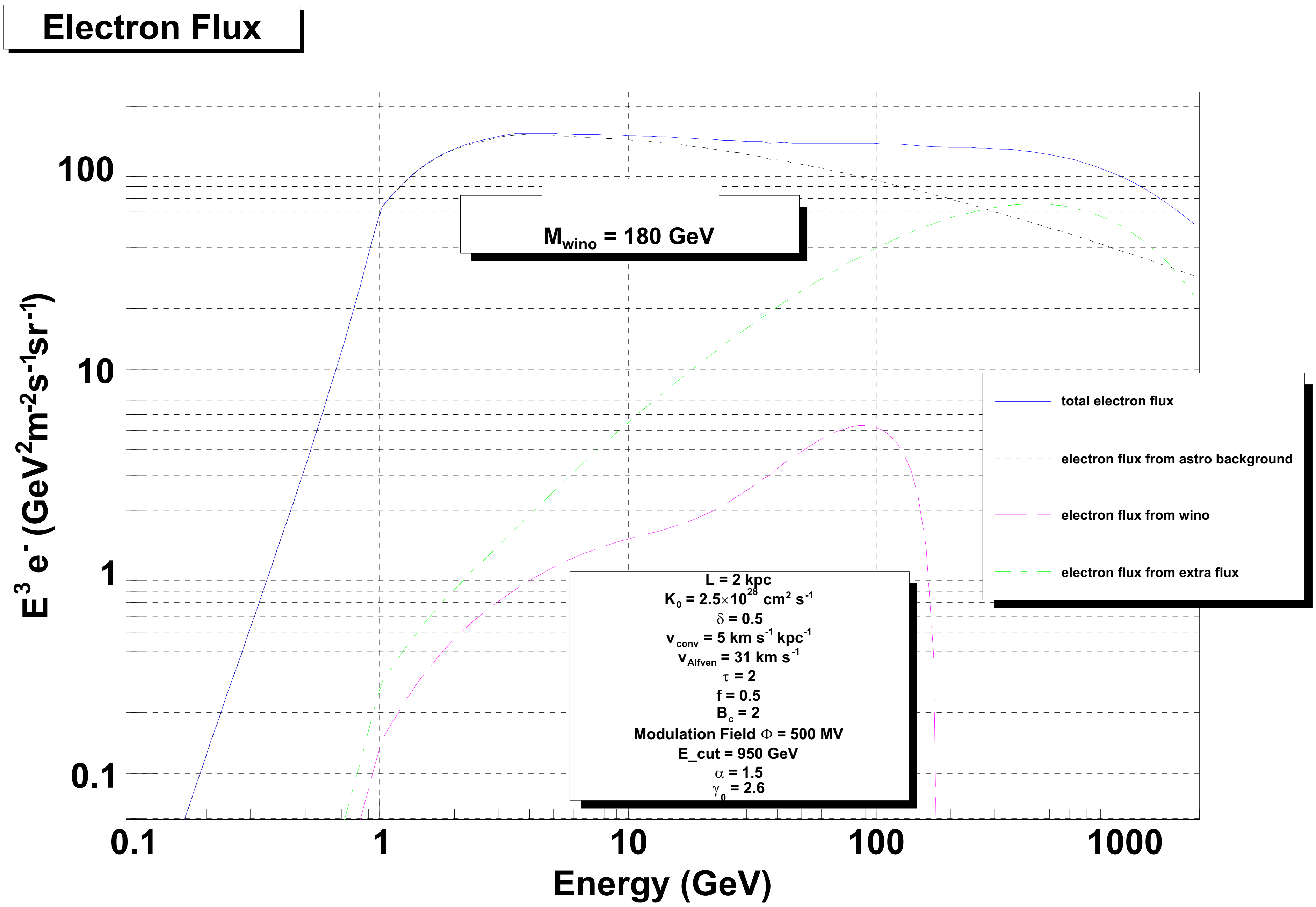
10^{-2}
10^{-3}
10^{-4}
10^{-5}
E^2 Φ (MeV^2 cm^{-2} s^{-1} MeV^{-1})
1
10
100
1000
Energy (GeV)
signal+background
background
π^0
IC
bremss
wino
Fermi
total backgrounds
"diffuse" 10° -- 20°



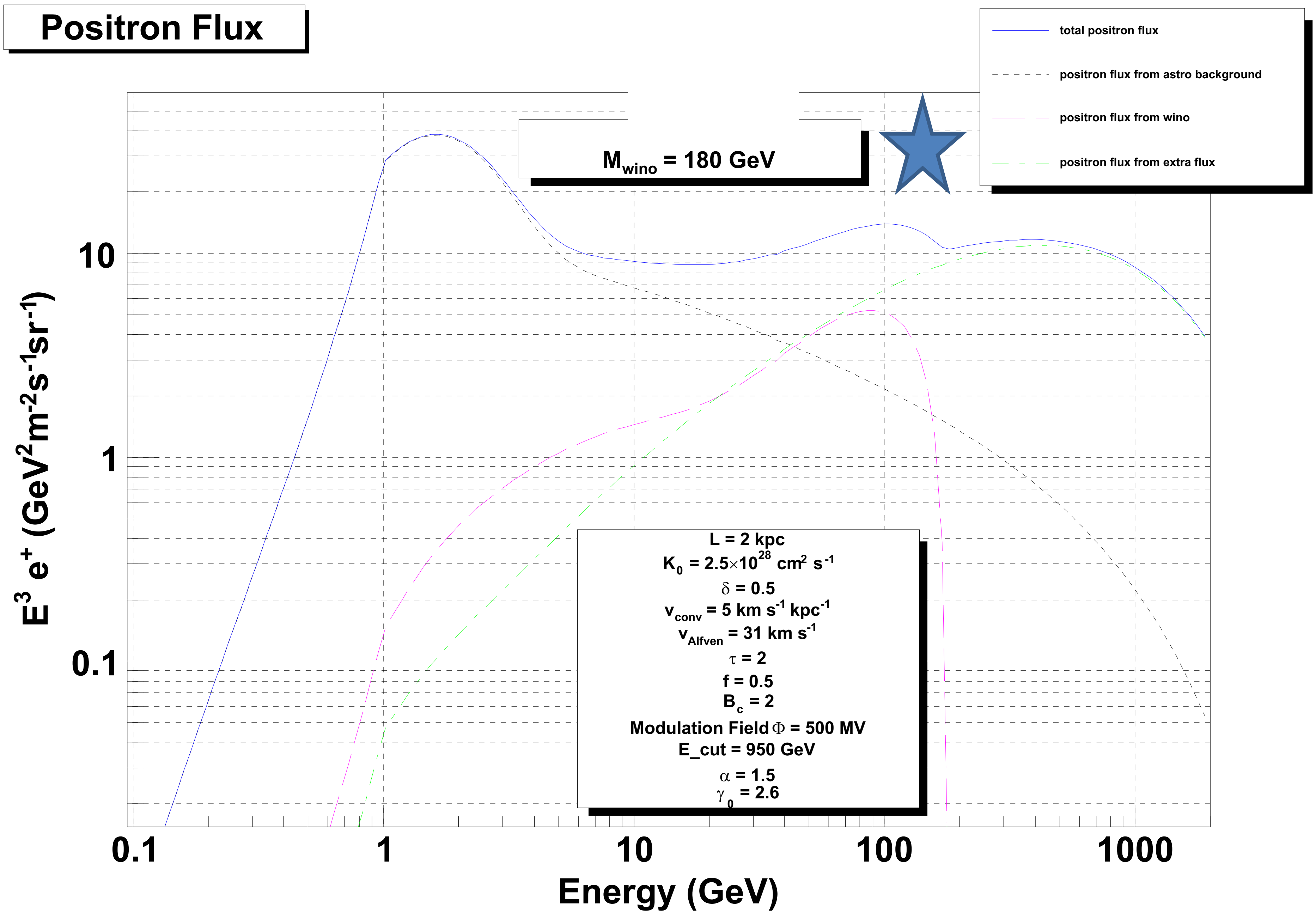
B/C Ratio
GALPROP
HEAO Data
B/C Ratio
0.35
0.3
0.25
0.2
0.15
0.1
0.05
10^{-1}
1
10
10^{2}
10^{3}
Kinetic Energy (GeV/nuc)
L = 2 kpc
$K_0 = 2.5\times10^{28}$ cm^2 s^{-1}
$\delta = 0.5$
$v_{conv} = 5$ km s^{-1} kpc^{-1}
$v_{Alfven} = 31$ km s^{-1}
$\tau = 2$
f = 0.5
$B_c = 2$



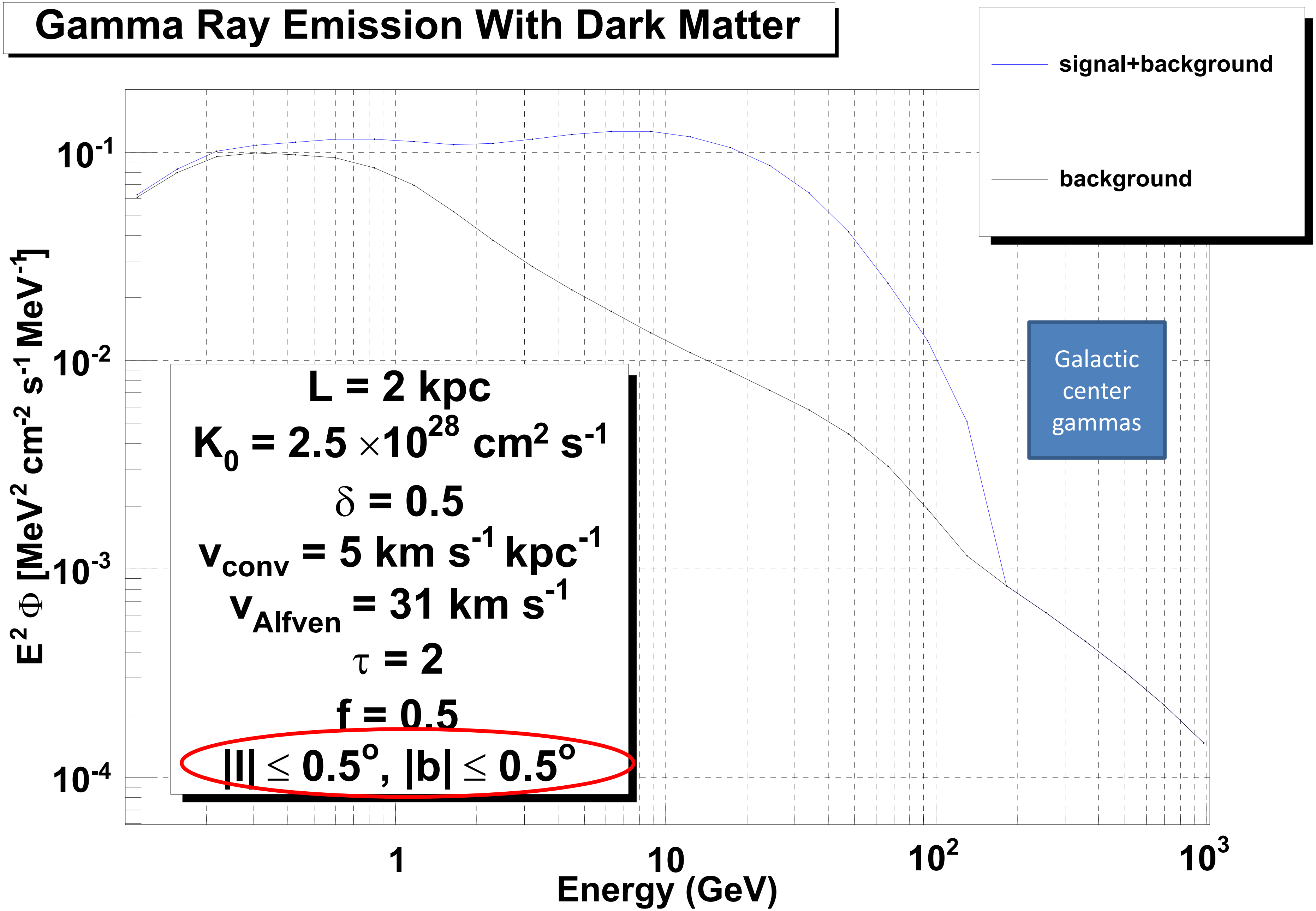
B/C Ratio
GALPROP
HEAO Data
0.35
0.3
0.25
0.2
0.15
0.1
0.05
B/C Ratio
L = 2 kpc
$K_0 = 2.5\times10^{28}$ cm^2 s^{-1}
$\delta = 0.4$
v_{conv} = 5 km s^{-1} kpc^{-1}
v_{Alfven} = 31 km s^{-1}
$\tau = 2$
f = 0.5
$B_c = 2$
10^{-1}
1
10
10^2
10^3
Kinetic Energy (GeV/nuc)

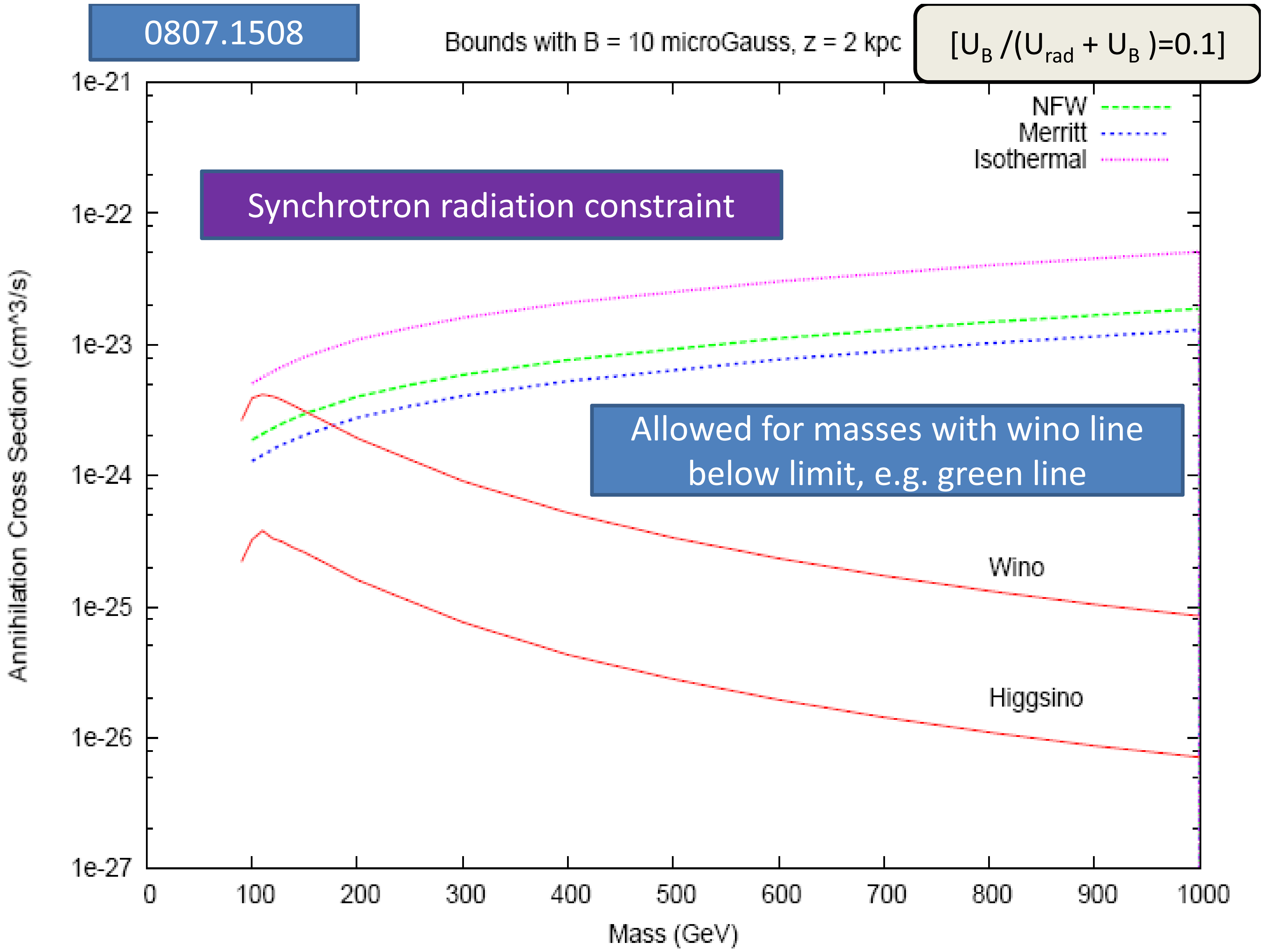


Electron Flux
M_{wino} = 180 GeV
total electron flux
electron flux from astro background
electron flux from wino
electron flux from extra flux
L = 2 kpc
$K_0 = 2.5\times10^{28}$ cm^2 s^{-1}
δ = 0.5
v_{conv} = 5 km s^{-1} kpc^{-1}
v_{Alfven} = 31 km s^{-1}
τ = 2
f = 0.5
B_c = 2
Modulation Field Φ = 500 MV
E_cut = 950 GeV
α = 1.5
γ_0 = 2.6
100
10
1
0.1
0.1
1
10
100
1000
Energy (GeV)
E^3 e^- (GeV^{2}m^{-2}s^{-1}sr^{-1})



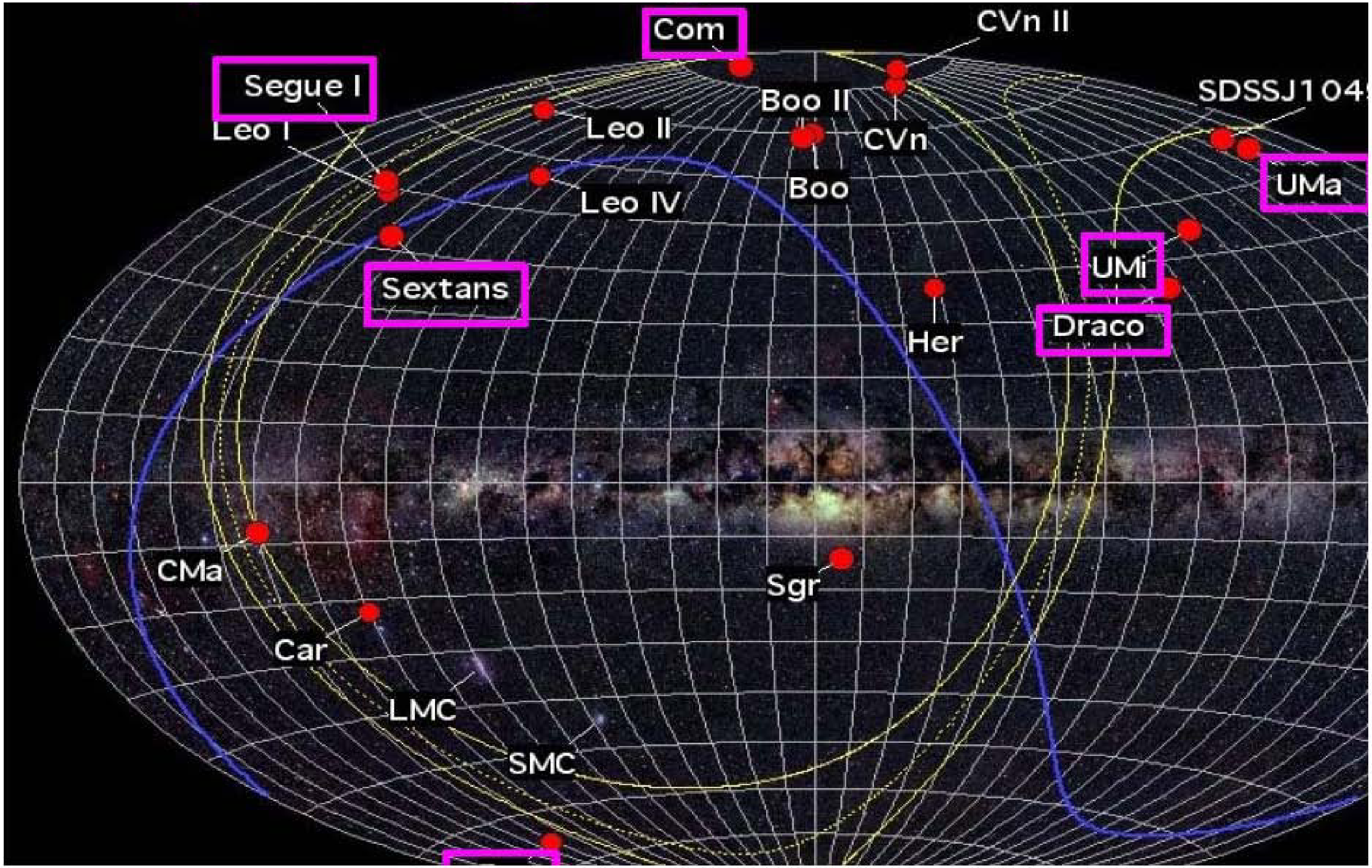
Positron Flux
total positron flux
positron flux from astro background
positron flux from wino
positron flux from extra flux
M_wino = 180 GeV
L = 2 kpc
K_0 = 2.5×10^28 cm^2 s^-1
δ = 0.5
v_conv = 5 km s^-1 kpc^-1
v_Alfven = 31 km s^-1
τ = 2
f = 0.5
B_c = 2
Modulation Field Φ = 500 MV
E_cut = 950 GeV
α = 1.5
γ_0 = 2.6
E^3 e^+ (GeV^2m^-2s^-1sr^-1)
10
1
0.1
0.1
1
10
100
1000
Energy (GeV)


Gamma Ray Emission With Dark Matter
signal+background
background
Galactic center gammas
L = 2 kpc
$K_0 = 2.5 \times 10^{28}$ cm^2 s^{-1}
$\delta = 0.5$
$v_{conv} = 5$ km s^{-1} kpc^{-1}
$v_{Alfven} = 31$ km s^{-1}
$\tau = 2$
f = 0.5
$|l| \le 0.5°$, $|b| \le 0.5°$
$E^2\,\Phi$ [MeV^2 cm^{-2} s^{-1} MeV^{-1}]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
1
10
10^2
10^3
Energy (GeV)



0807.1508
Bounds with B = 10 microGauss, z = 2 kpc
[U_B /(U_rad + U_B)=0.1]
Synchrotron radiation constraint
Allowed for masses with wino line below limit, e.g. green line
NFW
Merritt
Isothermal
Wino
Higgsino
Annihilation Cross Section (cm^3/s)
Mass (GeV)
1e-21
1e-22
1e-23
1e-24
1e-25
1e-26
1e-27
0
100
200
300
400
500
600
700
800
900
1000

Dwarf spheroidal galaxies (dSph) promising targets for DM detection



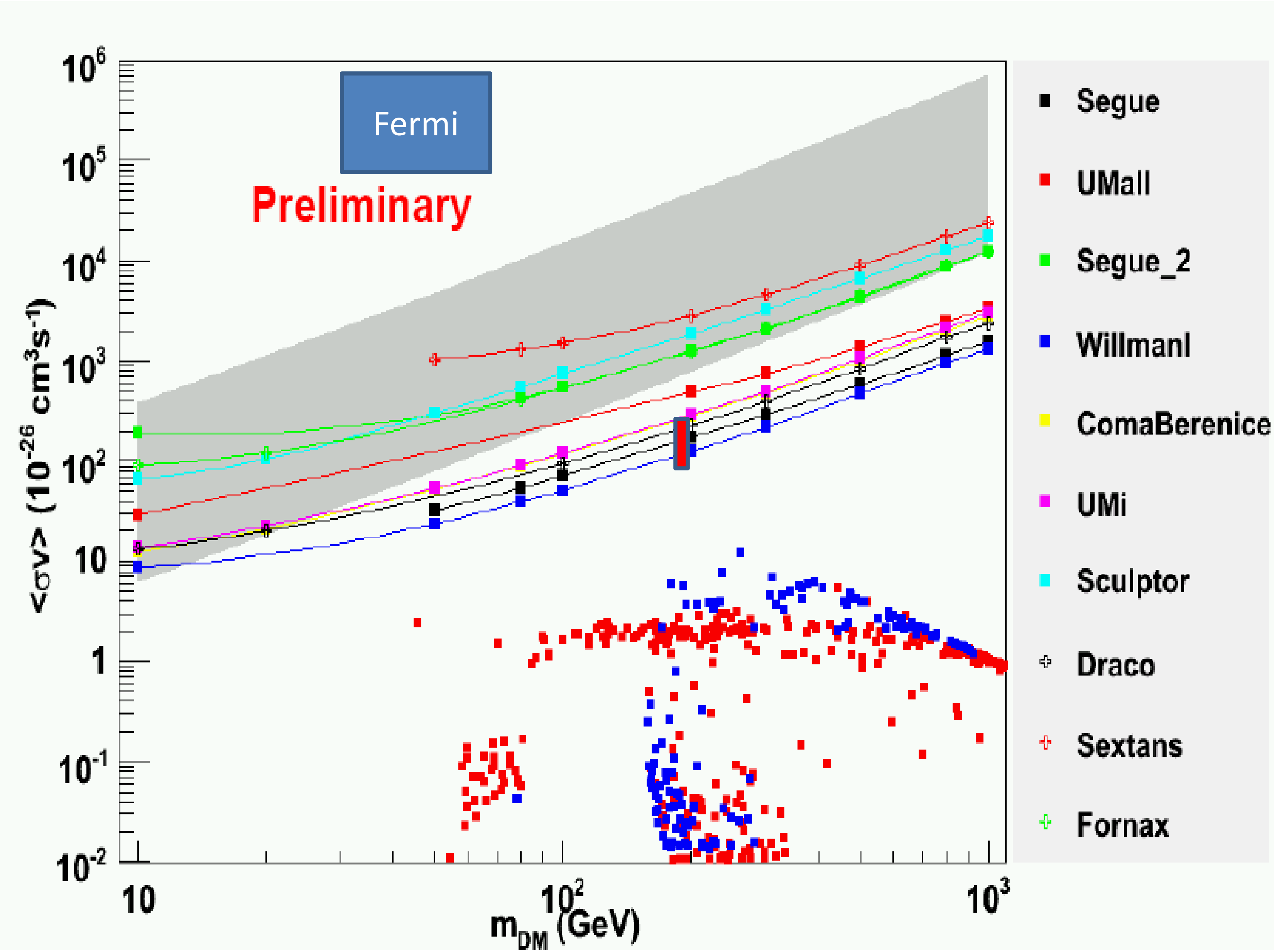
Formula for gamma ray flux from annihilating dark matter in a dark matter halo is

$$\frac{dN_\gamma}{dAdt} = \frac{1}{8\pi}\mathcal{L}_{\rm ann}\frac{\langle\sigma v\rangle}{m_\varkappa^2}\int_{E_{\rm th}}^{E_{\rm max}}\frac{dN_\gamma}{dE_\gamma}dE_\gamma$$

where

$$\begin{aligned}
\langle\sigma v\rangle &= 2.08\times 10^{-24}\,cm^3\,s^{-1} \\
m_\varkappa &= 197\,\mathrm{GeV} \\
\int_{E_{\rm th}}^{E_{\rm max}}\frac{dN_\gamma}{dE_\gamma}dE_\gamma &= 4.18 \\
\mathcal{L}_{\rm ann} &= \int_0^{\Delta\Omega}\left\{\int_{LOS}\rho^2(r)\,ds\right\}d\Omega
\end{aligned}$$

Dwarf	$\mathcal{L}_{\rm ann}(\log_{10}[\mathrm{GeV}\,c^{-4}\,cm^{-5}])$	Flux $\Phi(cm^{-2}s^{-1})(E_{\rm th}=5\,\mathrm{GeV})$
Sagittarius	19.35 ± 1.66	$1.99\times 10^{-10}(4.36\times 10^{-12},\ 9.10\times 10^{-9})$
Draco	18.63 ± 0.60	$3.79\times 10^{-11}(9.53\times 10^{-12},\ 1.51\times 10^{-10})$
Ursa Minor	18.79 ± 1.26	$5.48\times 10^{-11}(3.01\times 10^{-12},\ 9.98\times 10^{-10})$
Willman 1	19.55 ± 0.98	$3.16\times 10^{-10}(3.30\times 10^{-11},\ 3.01\times 10^{-9})$
Segue 1	20.17 ± 1.44	$1.32\times 10^{-9}(4.78\times 10^{-11},\ 3.62\times 10^{-8})$



Fermi
Preliminary
$<\sigma v> (10^{-26}\ cm^3 s^{-1})$
m_{DM} (GeV)
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10
10^2
10^3
Segue
UMall
Segue_2
WillmanI
ComaBerenice
UMi
Sculptor
Draco
Sextans
Fornax

Summary of tests:

1. Turnover or flattening of the positron ratio and the positron absolute flux with increasing energy. (Figure 1, 8)

2. The rise in the positron ratio is not due to a decrease in the electron flux, which will not decrease faster in the region from 10 - 200 GeV. (Figure 7).

3. The $\bar{p}$ rate will turn over with increasing energy. (Figure 2, 9).

4. There will be an observable excess in the region below 200 GeV in the diffusive gamma spectrum, by a factor o order 3 – 4 from wino annihilation (Figure 5) (Lower limit)

5. There will be an increase in gammas from the galactic center below 200 GeV from wino annihilation, almost ar order of magnitude (Figure 6) (Lower limit)

6. Effects on synchrotron radiation (WMAP haze)[43, 44] and recombination[45–47] need further detailed study Wino annihilation is consistent with the current experimental constraints[47–49], though barely if all thei assumptions are accepted. This may mean the wino annihilation is an explanation. Planck data will provide a significant test here.

7. Effects from wino annihilation for dwarf galaxies are probably observable (Table II)

And LHC!

THUS a wino LSP with mass $\sim$ 180 GeV is a promising candidate to describe PAMELA data including constraints, and Fermi data with additional component beyond $\sim$ 100 GeV

IMPROVED EXPERIMENTAL TESTS COMING

VERY SOON

- PAMELA higher energy positrons 100-200 GeV – must see “turnover” (or flattening if one bin) if wino LSP (M$\sim$180-200 GeV)
- PAMELA higher energy electrons – important to separate e^+ from e^-
- Fermi/GLAST – diffuse, galactic center gammas, Dwarf galaxies

SOON

- LHC
- AMS-02

Trying to describe the satellite data with dark matter – two approaches:

(a) thermal cosmological history, ***AND*** describe all data with one component $\rightarrow M_{LSP} > 2$ TeV

-- stable, $<\sigma v> \approx 3\text{x}10^{-26}$ cm^3 s^{-1} to get observed relic density

$\rightarrow$need large enhancement or "boost factor"

-- decaying DM, lifetime $\sim 10^{26}$ second

Many interesting models

Typically positron ratio rises significantly above 100 GeV!

(b) non-thermal cosmological history

-- $<\sigma v> \approx 3\text{x}10^{-24}$ cm^3 s^{-1} for wino LSP, M$\sim$ 200

-- normalize to observed relic density, no "boost factor" needed

-- about right relic density in moduli decay example

MUST HAVE NON-THERMAL COSMOLOGY TO GET RELIC DENSITY IF WINO LSP – PROBLEM? GOOD!

[wino annihilation cross section 2.5x10^{-24} cm^3 s^{-1} but thermal history implies cross section about 100x smaller]

-- Non-thermal cosmology – generic in any string theory with stabilized moduli, TeV scale, EWSB, nucleosynthesis? – (Acharya, GK, Piyush Kumar, Scott Watson in preparation)

-- similarly for supersymmetric flat directions, Q-balls (Fujii Hamaguchi), kination (Salati …, Chung, Everett…), cosmic strings (Zhang, Gondolo, Brandenberger …)

-- *model of moduli decay Moroi-Randall ph/9906527*

-- existence proof: M-theory compactified on G_2 manifold → wino LSP, relic density about right from first principles -- 0804.0863 (Acharya, Kane, Kumar, Shao, Watson) has detailed calculations for moduli masses and widths, thermal DM diluted by entropy from moduli decay → DM from moduli decay – no moduli or gravitino problems

NON-THERMAL WIMP MIRACLE, RELIC DENSITY (M-theory → G_2)

- Consider theories with stabilized moduli and weak scale, wino LSP
- Moduli decay is Planck, helicity suppressed → long lifetime ~ 10^{-3} sec
- They dominate universe before decay (after freezeout) before BBN
- Decays produce many LSPs, entropy, dilute thermal LSPs
- LSPs annihilate

$$\dot{n}_{LSP} + 3Hn_{LSP} = -\langle \sigma \mathrm{v} \rangle n_{LSP}^2$$

so LSPs will annihilate down to

$$3H / \langle \sigma \mathrm{v} \rangle$$

"Non-thermal wimp miracle"

but now at decay temperature rather than at freezeout temperature

- Assuming large initial abundance and large annihilation cross section, results independent of initial abundance – in G_2

$$\Omega_{LSP} h^2 \approx \frac{1}{10} \frac{165 MeV}{T_{\mathrm{mod}}^{rh}} \frac{m_{LSP}}{200 GeV} \frac{3x10^{-7} GeV^{-2}}{\langle \sigma \mathrm{v} \rangle}$$

$$T_{\mathrm{mod}}^{rh} \approx 30 MeV, T_{\varphi}^{rh} \approx 100 MeV$$

Relic density increases by ratio of reheat temp at decay to that at freezeout

Consistent well-motivated picture

- PAMELA positrons $\leftrightarrow$ wino LSP
- Large wimp $\sigma v \sim 3\text{x}10^{-24}\ \text{cm}^3\text{sec}^{-1}$
- DM non-thermal in origin
- Moduli dominate universe after inflation, matter dominated
- Gravity mediated ~~susy~~
- $M_{3/2} \sim$ 10-100 TeV $\sim$ moduli masses
- Moduli decay before BBN
- Spectrum:

  -- scalars $\sim M_{3/2}$

  -- higgsinos from Giudice-Masiero term $\sim M_{3/2}$

  -- gauginos including LSP, light (< TeV) – tree level $\sim$ anomaly contribution

    [field whose F-term dominates ~~susy~~ is not the field whose vev gives the gauge coupling – maybe consequence of approximate R symmetry]

G_2 – MSSM is a concrete example of a UV completion of these generic arguments!

Dark matter at LHC

Is what is seen at LHC same as in indirect data?

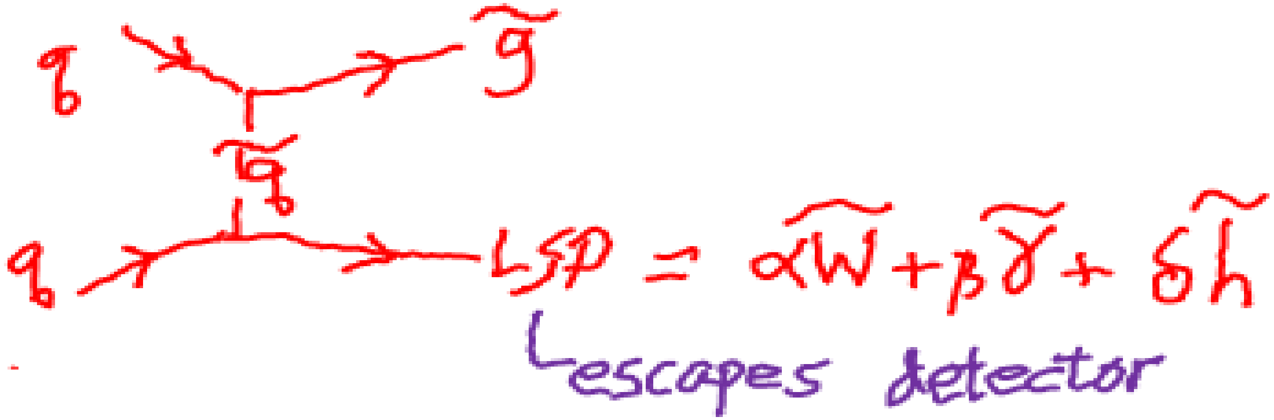
Test wino hypothesis

Get more info to calculate the relic density – with non-thermal history!

LHC will tell us much about DM in addition to missing energy events!

Can study composition of LSP by studying different processes at LHC – each LSP type couples differently to other stuff

e.g. higgsinos couple to quark-squark proportional to quark mass, so suppressed, while wino couples to left handed quarks but not right handed



Not discovery channels – but after gluino and squark masses and BR known, probably observable

For G2-MSSM squarks heavy so predict no signal here, but see winos in gluino decay

LHC phenomenology of light wino LSP well known

Early $\sim$ 1999, 2000

- Moroi-Randall
- Feng Moroi Randall Strassler
- Ghergetta, Giudice, Wells

Recent

- Moroi, Yanagida et al ph/0610277
- Acharya et al 0801.0478

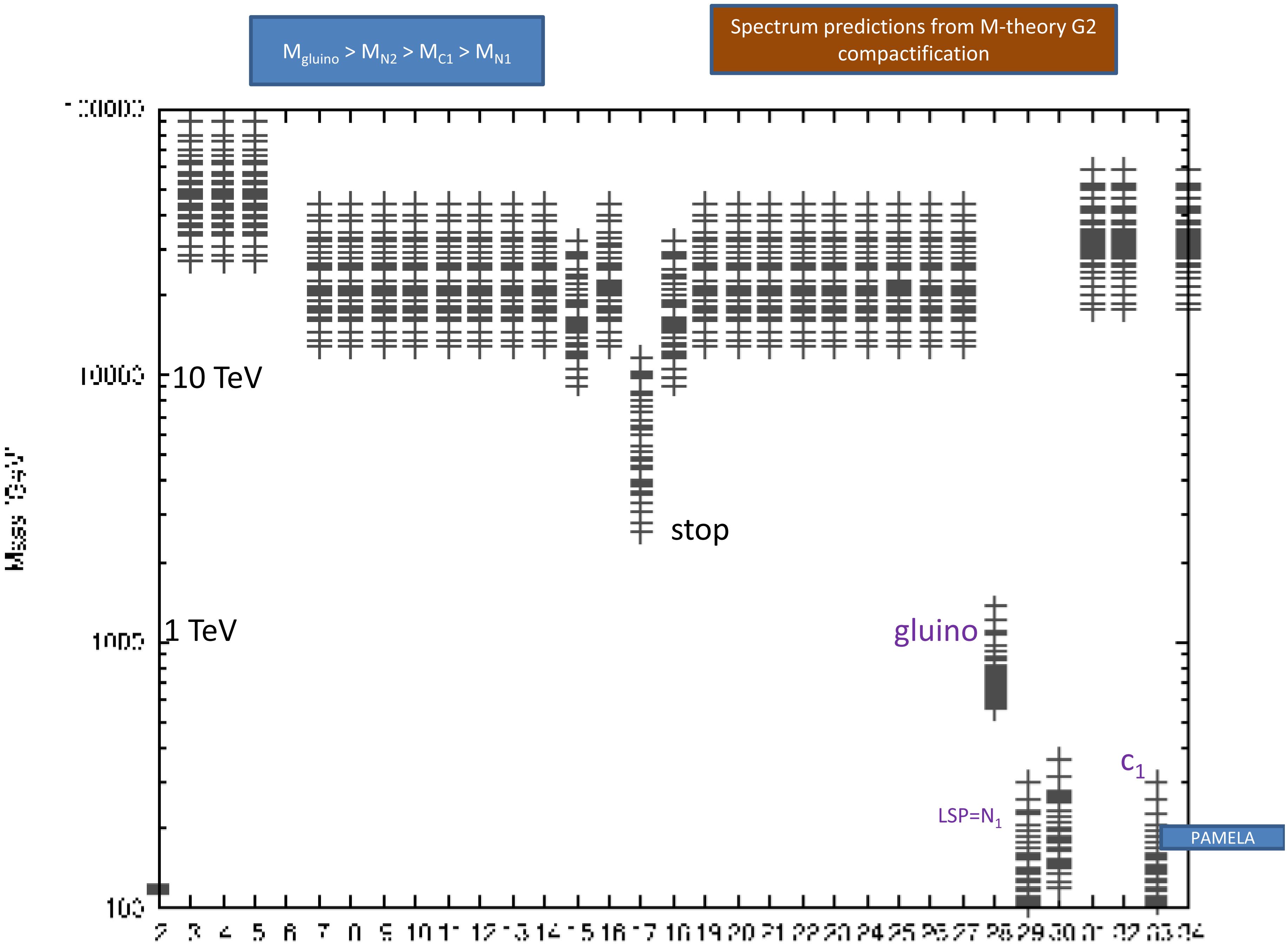
Today -- focus on an example, motivated by taking seriously PAMELA data and underlying theory consistent with that

– assume PAMELA → wino LSP is indeed DM

-- assume M-theory compactified on G_2 manifold is underlying theory since it gives such an LSP

[Acharya, Bobkov, Kane, Kumar, Shao 0801.0478]

-- pick particular spectrum from allowed ranges for the G_2 case



$M_{gluino} > M_{N2} > M_{C1} > M_{N1}$
Spectrum predictions from M-theory G2 compactification
10 TeV
1 TeV
stop
gluino
LSP=N_1
C_1
PAMELA

Spectrum and notation:

Gluino G, mass 900 GeV

Chargino C1, mass 173 GeV

LSP N1, mass 173 GeV

2nd neutralino N2, mass 253 GeV

Stop ~ 8700 GeV, mainly RH

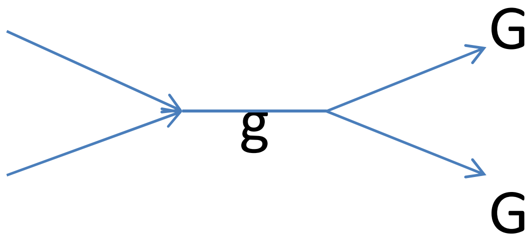
Higgs boson= 120 GeV

(gravitino ~ 35 TeV)

C1 ~ wino, N1 ~ wino, N2 ~ bino

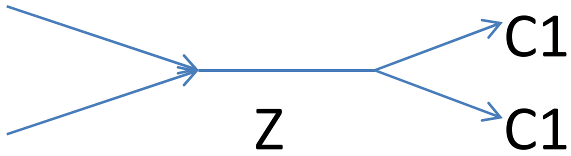
Production cross sections (14 TeV):

Dominant:



$\sigma \sim 1/2$ pb

Also



$\sigma \sim 1/2$ pb

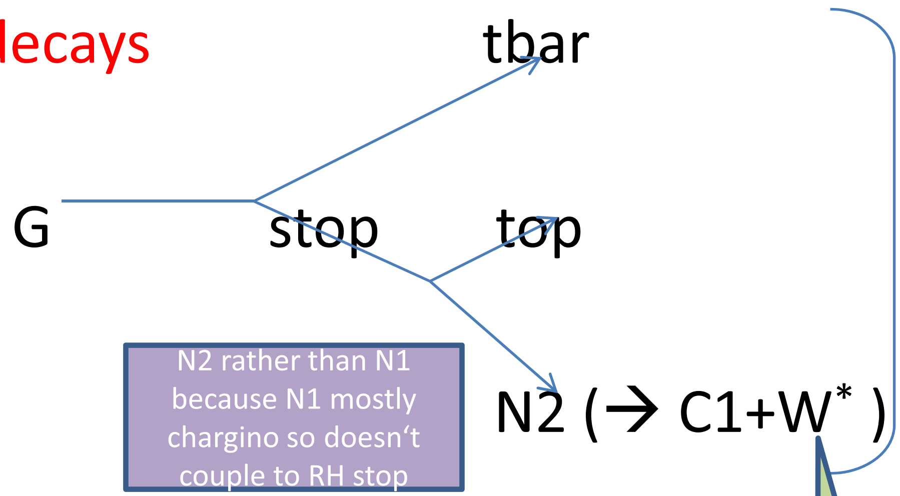
C1 and N1 are essentially degenerate, so C1 decays soft, so C1 + N1 channel has large cross section but nearly unobservable

C1 → N1 + W*,   W*→eν, $\mu\nu$, quarks

C1 + N2 and N1 + N2 small since C1 – W – bino coupling small

C1 + G, N1 + G, N2 + G all small since need squark exchange

Gluino decays



2 b's, 3 W's for each gluino!

lifetime ~ 10^{-19} sec

$M_{N2} - M_{C1}$ = 80 GeV for this model so essentially real W

MODE	BR
G→t tbar N2	~ ½
→t bbar C1	~ ¼
→b bbar N1	~ ¼
→g N1+N2	~ 1%

Chargino, LSP nearly degenerate, so hard to see – missing energy from “escaping” chargino, LSP

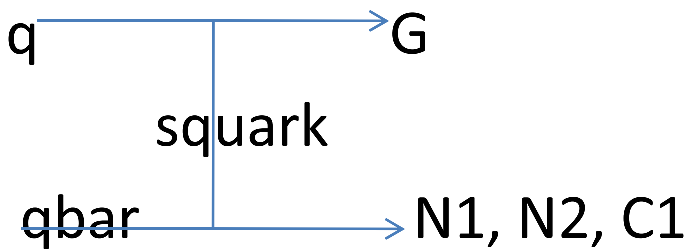
- mass difference $\sim$ 200 MeV(!), so decay has 1-2 soft pions

- find via gluino trigger

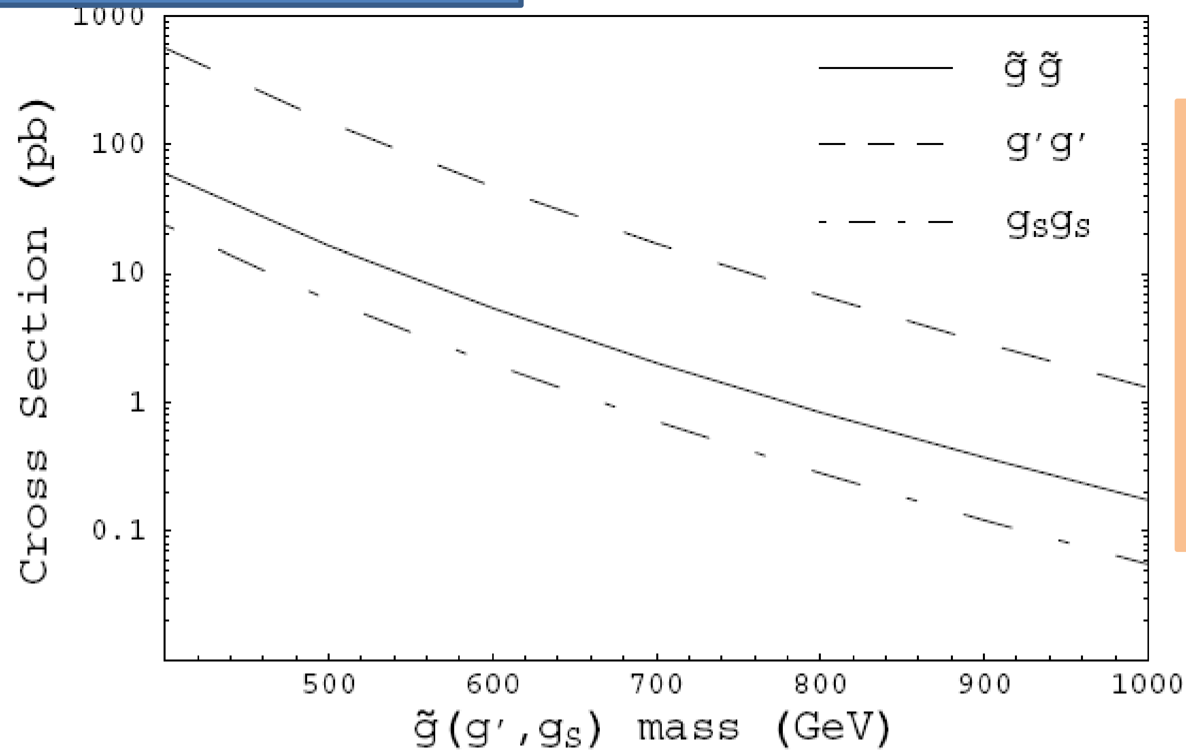
- probably can use vertex detector on events with gluino production to see N2, C1

General features of signatures:

- lots of leptons but always with jets – no “trileptons”
- ALL prompt leptons are from W decay! → no flavor correlations for leptons
- Leptons from gluino production so no charge asymmetries (compared to squarks…)
- Assuming the model is right, distributions can measure three mass differences, G-N2, G-N1, G → can solve for three masses
- N2 –> C1 + W^* but not C1 + Z^*
- Should not see squarks, or virtual squarks such as



Early gluino spin measurement at LHC
GK, Petrov, Shao, Wang 0805.1397
see also Datta, Kane, Tohariaph/0510204



Once there is a signal, use cross section to measure gluino spin and confirm indeed seeing superpartner

FIG. 2: A plot of the cross sections for gluino pair production (solid line), spin-1 gluon partner g' pair production (dashed line) and spin-0 gluon partner g_S pair production (dot-dashed line) at LHC. In the calculation, extra color triplets (e.g. $\tilde{q}$ or q') are taken to be 5 TeV.

4-top counting and reconstruction analysis

[Acharya, Grajek, Kane, Kuflik, Suruliz, Wang arXiv:0901.3367]

- Early discovery of signal beyond the SM easy with 4 b's and 6 W's per event, just counting
- SM fakes unlikely when include many jets, some leptons, large missing energy
- Same sign dilepton channel very good
- Reconstruction of tops hard, but relative decay BR of tt, tb, bb states useful
- Get information on gluino mass and cross section

IF THE PAMELA EXCESS IS INDEED DUE TO A LIGHT WINO LSP THE IMPLICATIONS ARE REMARKABLE

- Would have learned that the dark matter, about a fifth of the universe, is (mainly) the W superpartner, and its approximate mass

- Discovery of supersymmetry!

  -- guarantees can study superpartners at LHC

- Would have learned that the universe had a non-thermal cosmological history, one we can probe

- Suggests moduli dominated “UV completion” –> string theory!

  -- M-Theory “G_2 – MSSM” construction a concrete example

TESTS SOON!

Energy-dependent and particle-dependent annihilation enhancements from density fluctuations – necessarily present

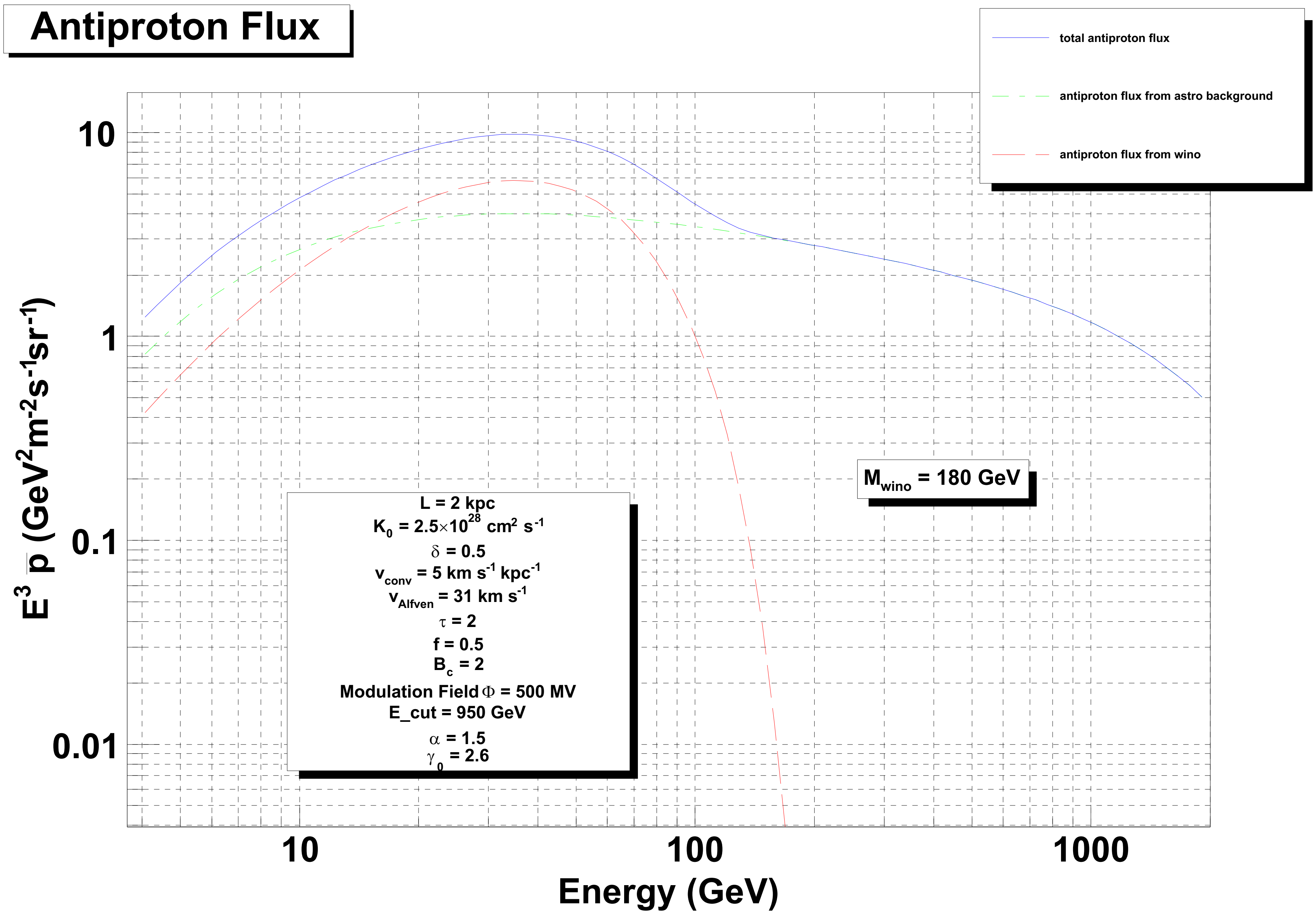
- Galaxies are built from little galaxies – density fluctuations inevitable
- Keep average local density, but $<n^2> \neq <n>^2$ and annihilations $\sim n^2$
- Positrons lose energy rapidly so mainly come from nearer us
- Antiprotons lose energy poorly, come from farther away
- Different distances feel profile differently, different amount of clumps

On the antimatter signatures of the cosmological dark matter subhalos. Julien Lavalle . Dec 2008. **arXiv:0812.3576** [astro-ph]

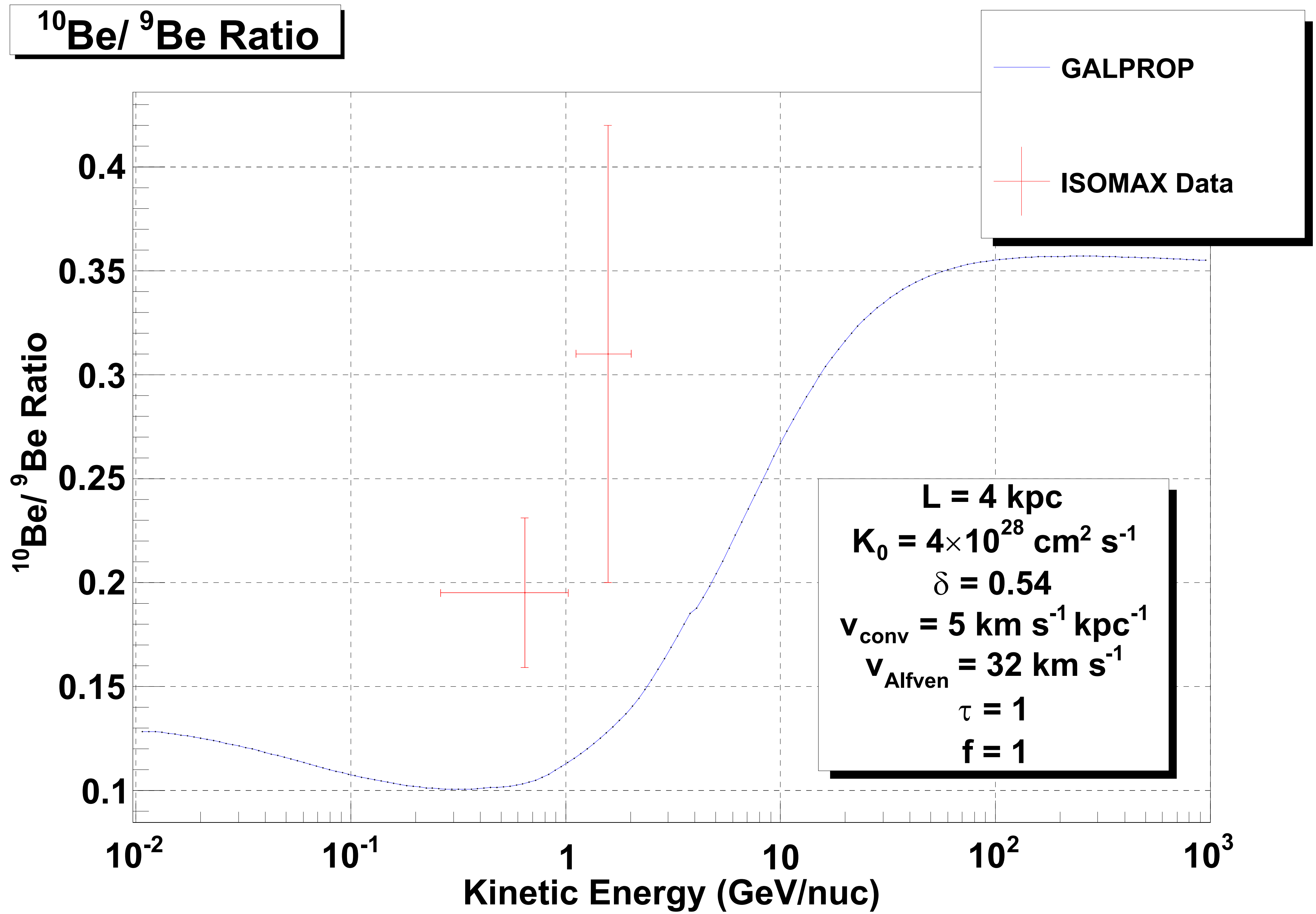
Galactic secondary positron flux at the Earth T. Delahaye, F. Donato, N. Fornengo, J. Lavalle, R. Lineros, P. Salati, R. Taillet **arXiv:0809.5268** [astro-ph]

Antimatter cosmic rays from dark matter annihilation: First results from an N-body experiment. J. Lavalle, E. Nezri, E. Athanassoula, F.-S. Ling , R. Teyssier **Phys.Rev.D78:103526,2008. arXiv:0808.0332** [astro-ph]

Clumpiness of dark matter and positron annihilation signal: computing the odds of the galactic lottery. Julien Lavalle, Jonathan Pochon , Pierre Salati, Richard Taillet. **astro-ph/0603796**



Antiproton Flux
total antiproton flux
antiproton flux from astro background
antiproton flux from wino
L = 2 kpc
K0 = 2.5×10^28 cm^2 s^-1
δ = 0.5
v_conv = 5 km s^-1 kpc^-1
v_Alfven = 31 km s^-1
τ = 2
f = 0.5
B_c = 2
Modulation Field Φ = 500 MV
E_cut = 950 GeV
α = 1.5
γ_0 = 2.6
M_wino = 180 GeV
10
1
0.1
0.01
10
100
1000
Energy (GeV)
E^3 p̄ (GeV^2m^-2s^-1sr^-1)



^{10}Be/ ^{9}Be Ratio
GALPROP
ISOMAX Data
0.4
0.35
0.3
0.25
0.2
0.15
0.1
^{10}Be/ ^{9}Be Ratio
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
Kinetic Energy (GeV/nuc)
L = 4 kpc
K_0 = 4×10^{28} cm^2 s^{-1}
δ = 0.54
v_{conv} = 5 km s^{-1} kpc^{-1}
v_{Alfven} = 32 km s^{-1}
τ = 1
f = 1