Does a non-thermal wino LSP plus astrophysics describe the PAMELA and Fermi data?

Gordy Kane

SLAC, July 2009

Start with assumptions, theory issues – then show data, predictions

Based on arXiv: kane, Ran Lu, Scott Watson arXiv: 0906.4765

Two physically different approaches to the origin of the dark matter relic density, even assuming wimps – *every analysis picks one of these*

- "Thermal" cosmological history – at the BB, SM particles and superpartners created – since then no additional particles created and no entropy added – *poorly motivated, but widely used*

  --Leads to "thermal wimp miracle"

$$n_{wimp} = H(\,freezeout\ \text{temp} \approx \text{few GeV}) \Big/ \langle \sigma \upsilon \rangle_{wimp}$$

$$n_{wimp} = n_{wmap} \rightarrow \langle \sigma \upsilon \rangle_{wimp} \approx 3 \times 10^{-26}\, cm^3\, \text{sec}^{-1}$$

$$\rightarrow wimp \approx bino$$

--Bino annihilates via heavy squark exchange or neutral Z to quarks and leptons, helicity suppressed, so small rate to positrons (and softer ones), so poor description of PAMELA positron excess

❑ "non-thermal" cosmological history

-- real theories have many ways to get entropy, other particles that decay to LSP – non-thermal well motivated

-- generic in broader theories, string theories, maybe inevitable

-- leads to "non-thermal wimp miracle"

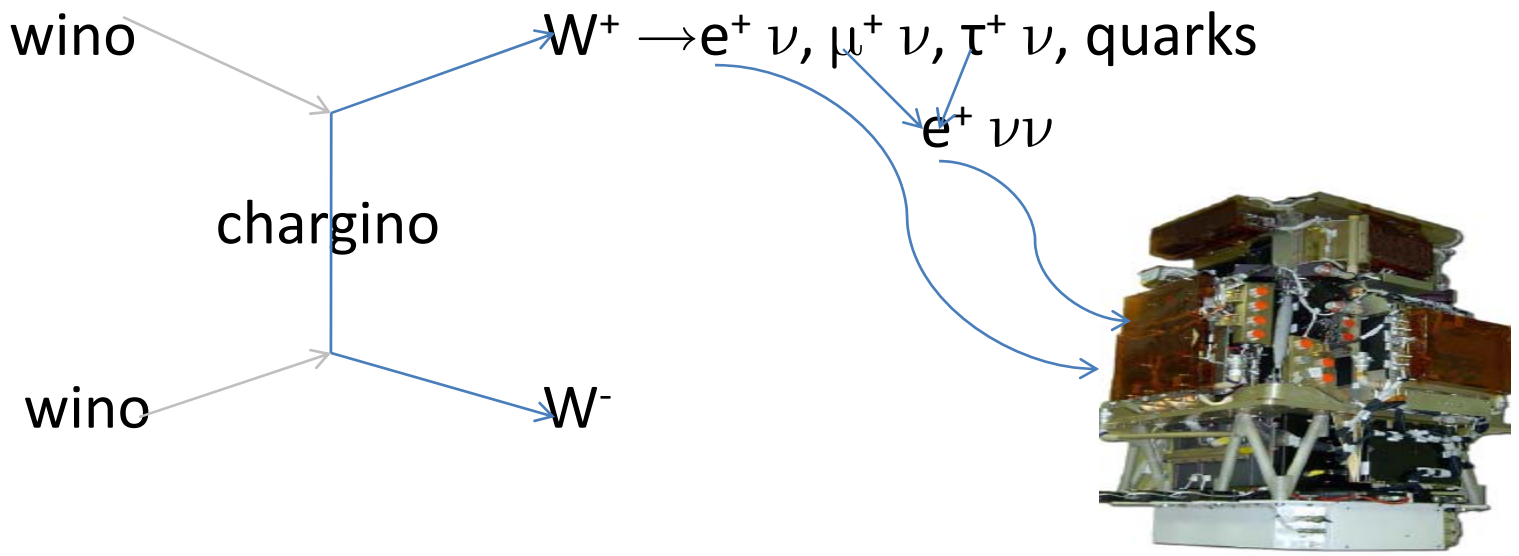
$$n_{wimp} = H(\text{reheating temp} \approx \text{few MeV}) \Big/ \langle \sigma \upsilon \rangle_{wimp}$$

$$n_{wimp} = n_{wmap} \rightarrow \langle \sigma \upsilon \rangle_{wimp} \approx 3 \times 10^{-24} cm^3 \sec^{-1}$$

$$\rightarrow wimp \approx wino$$

-- wino annihilates well via chargino exchange to W's, which have large BR to energetic e^+ , so good description of PAMELA excess

-- wino LSP also well motivated theoretically, in MSSM, anomaly mediated ~~SUSY~~, M-theory on G_2 manifold (moduli decay generates entropy, winos) [Acharya, Bobkov, Kane, Kumar, Shao, Watson 0804.0863]



- for a given wino mass, positron and quark (antiproton) injection has no parameters

My perspective today:

-- does a light wino LSP ($\sim$ 180 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

❑Relic density

➢Non-thermal histories can get the relic density right – for phenomenology the right procedure is to normalize to the local relic density (we use 0.3 GeV/cm^3)

→ NO “BOOST FACTORS” NEEDED TO REPRODUCE PAMELA SIGNAL FOR WINO LSP

❑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 (∼ GeV) → signal, secondaries have similar spectrum so normalization main difference

• so if DM annihilates into quarks, old data actually background + "signal"

• but old data was defined to be background, fitted to analytic formula, and result used as background in recent analyses

• for any model, need consistent treatment of data and background, propagate both with same parameters → for wino LSP signal *was* seen in old data!

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

❑ 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

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

Fermi sees energetic $e^+ + e^-$ up to a TeV – obviously an LSP of mass $\sim$ 180 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)

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

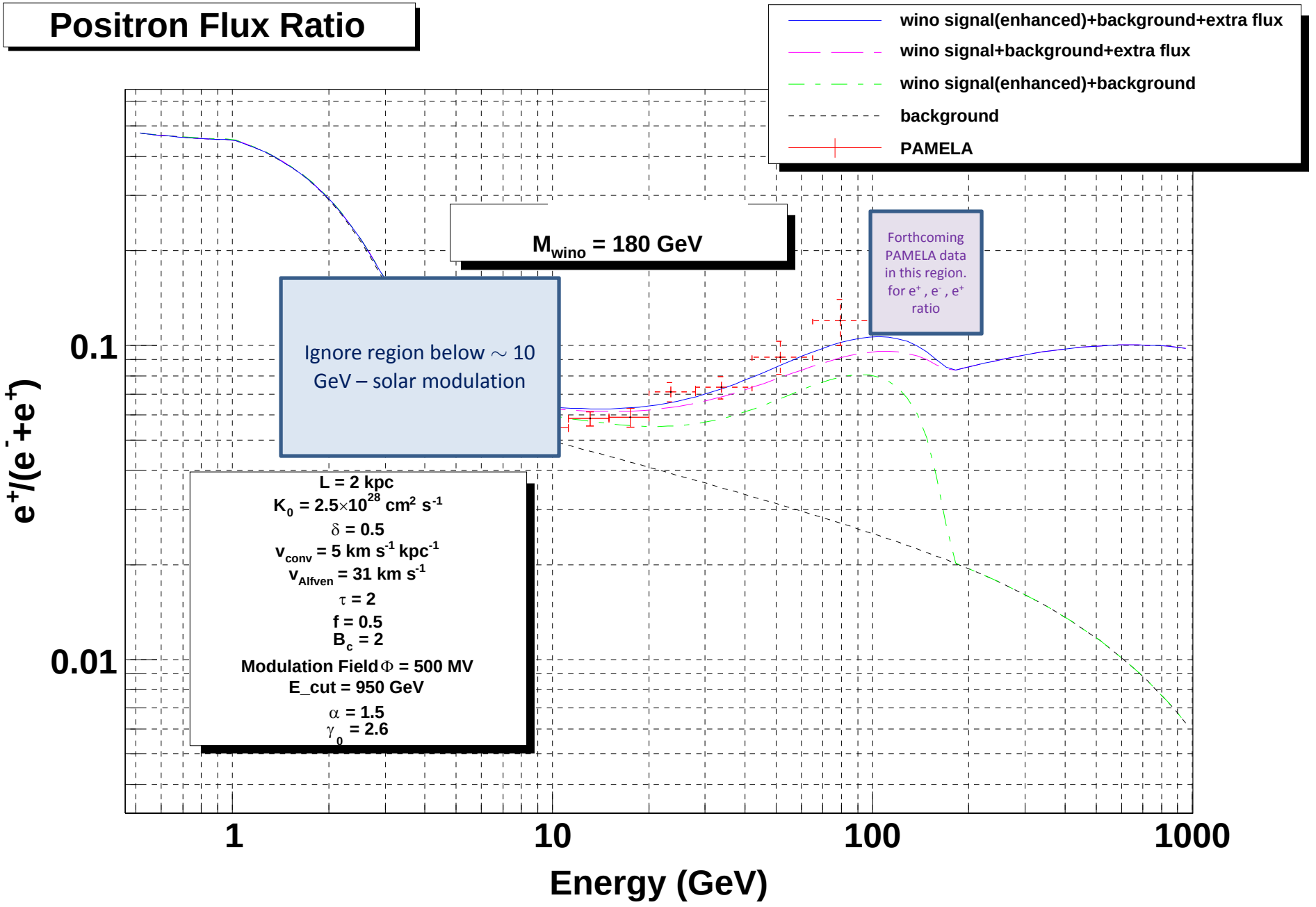
$$dN_{e^{\pm}} / dE = N' E^{-1.5} \exp(-E / 950GeV)$$

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

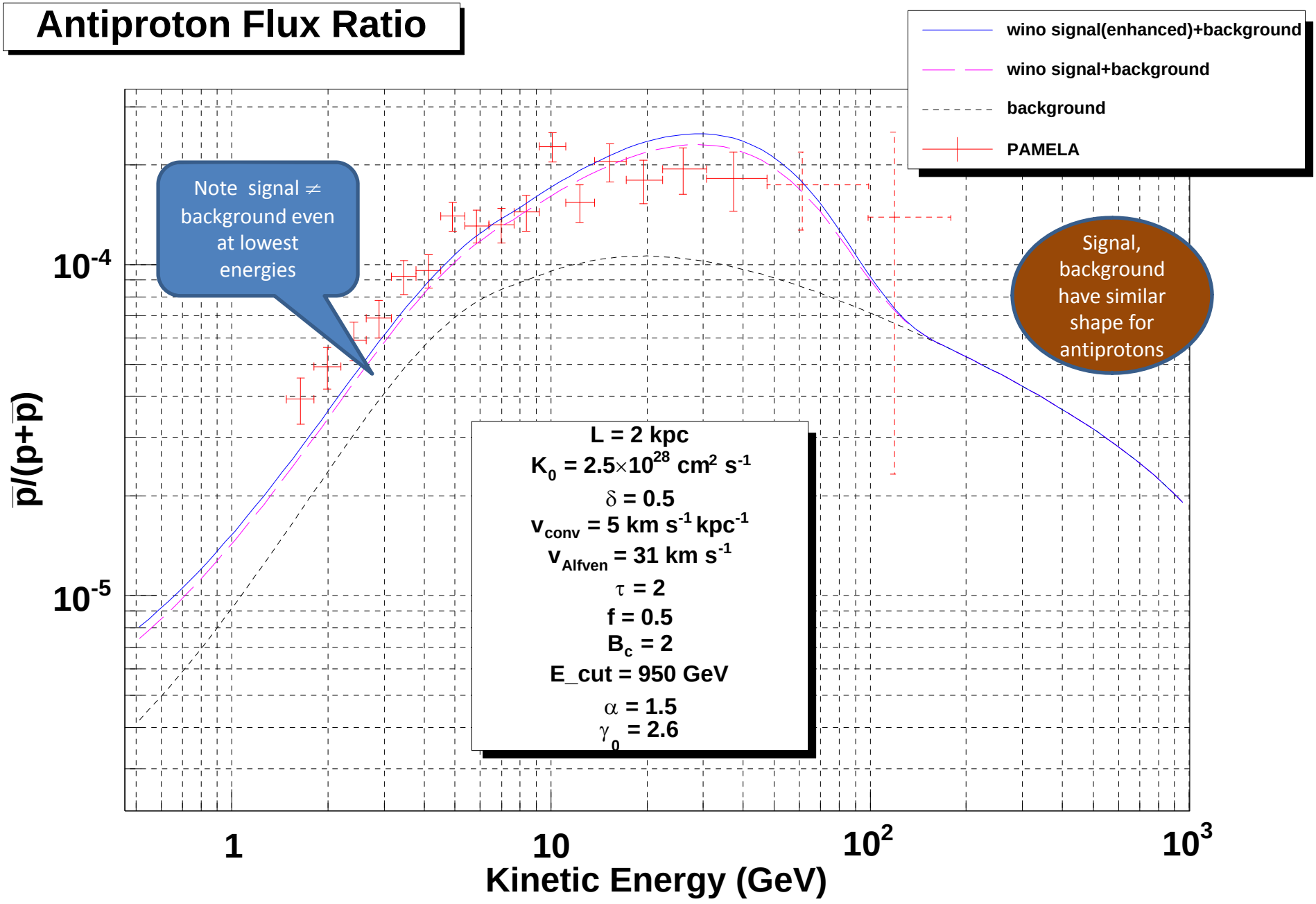
And normalize to Fermi data

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

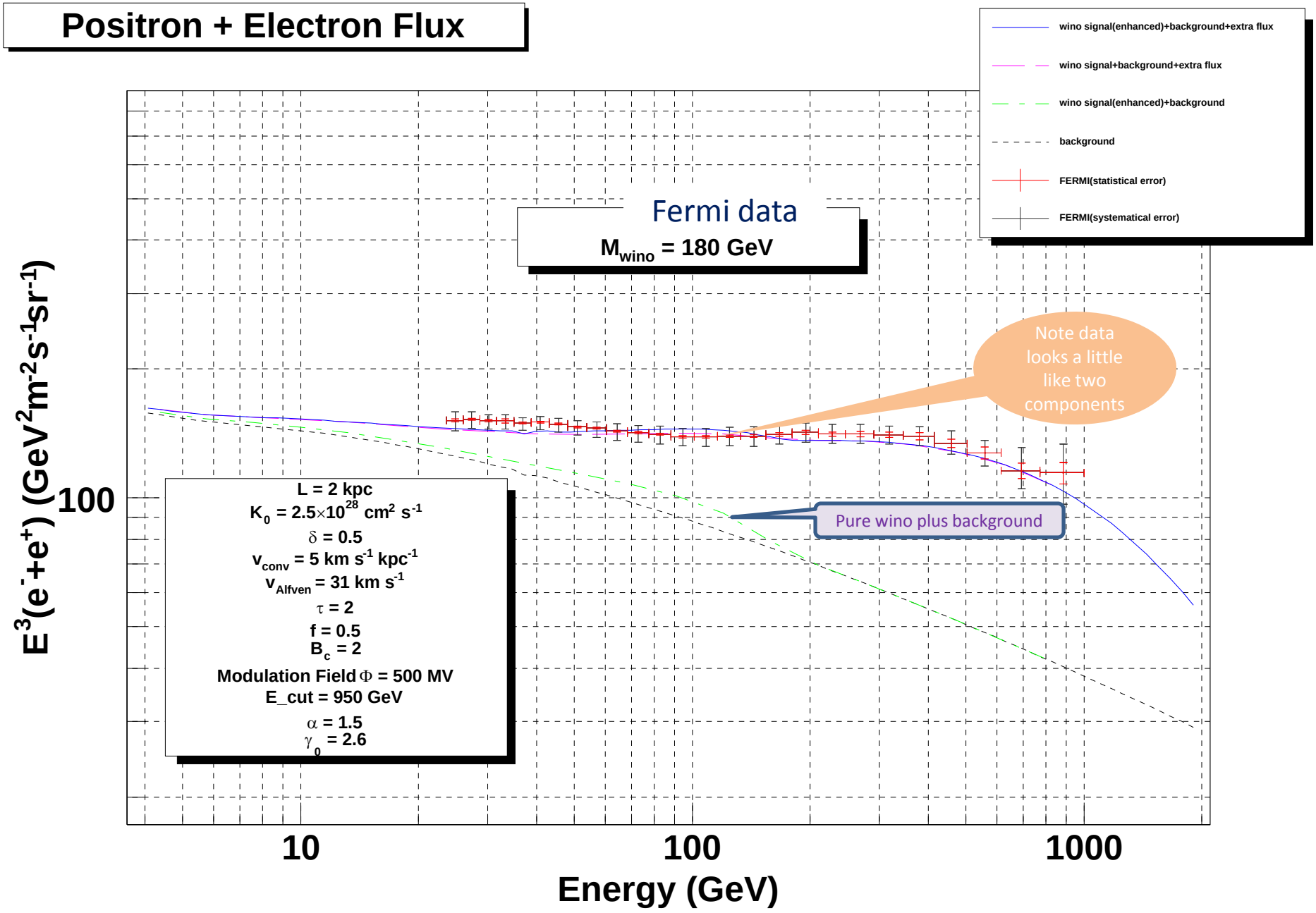
Positron Flux Ratio

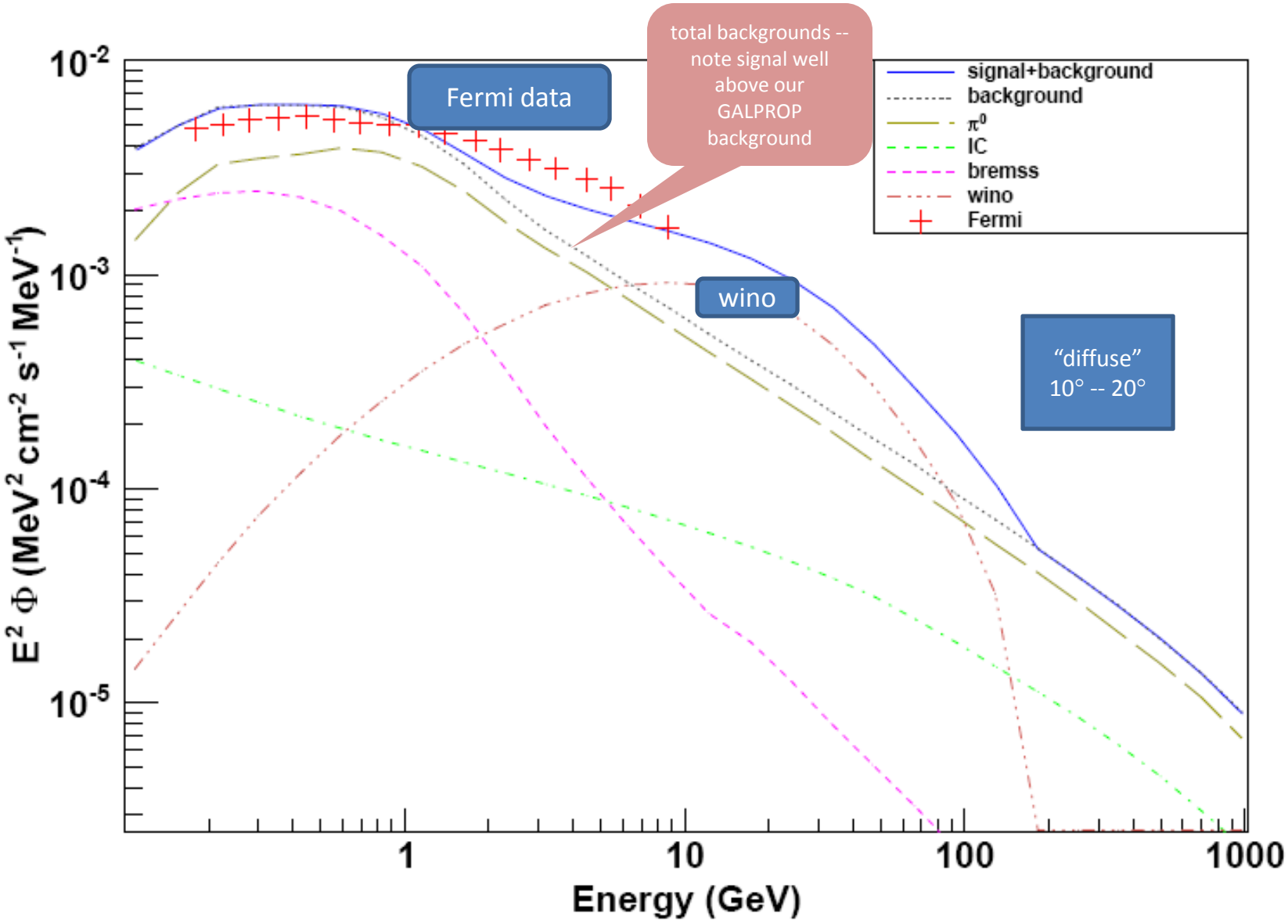


Antiproton Flux Ratio

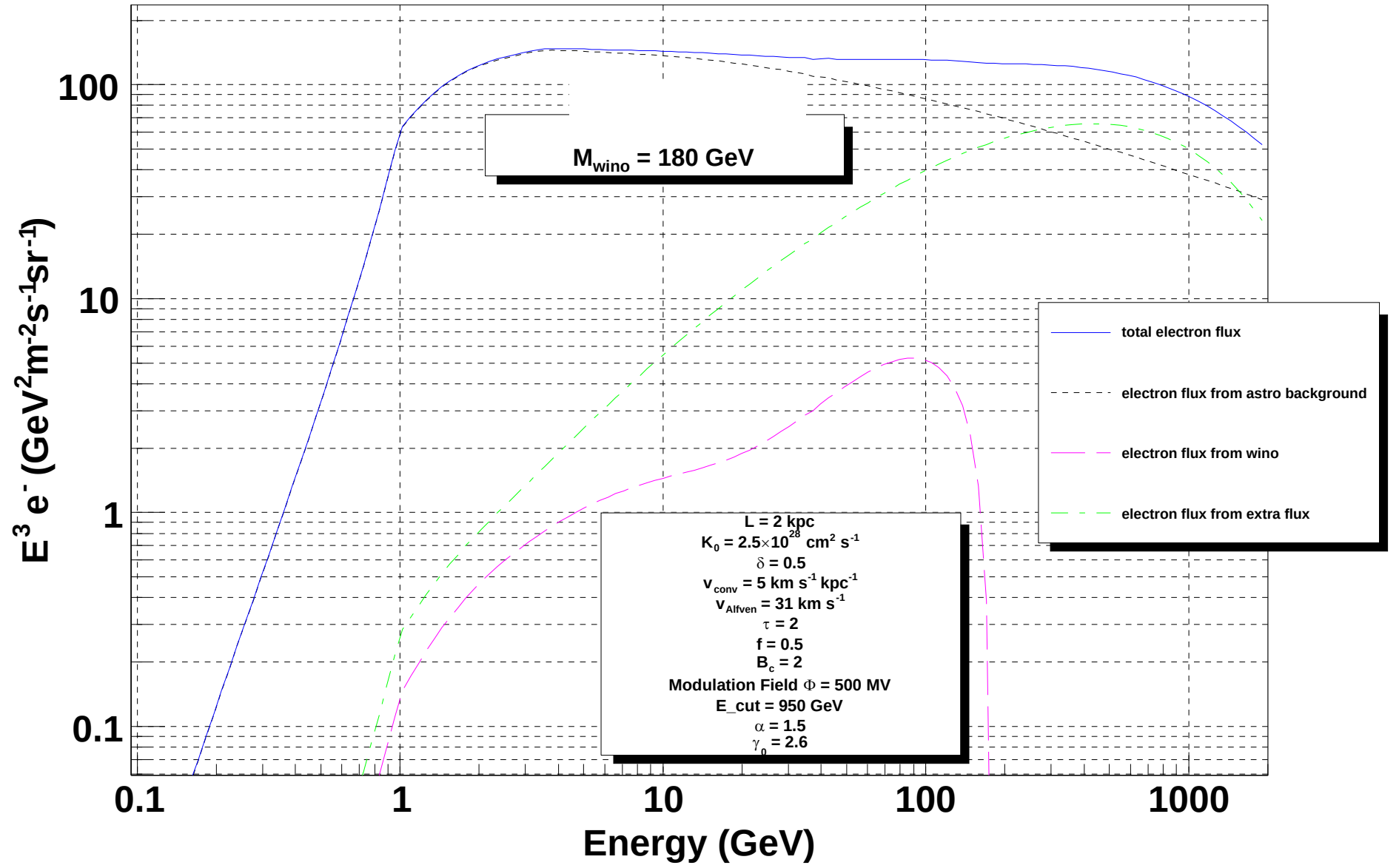


Positron + Electron Flux

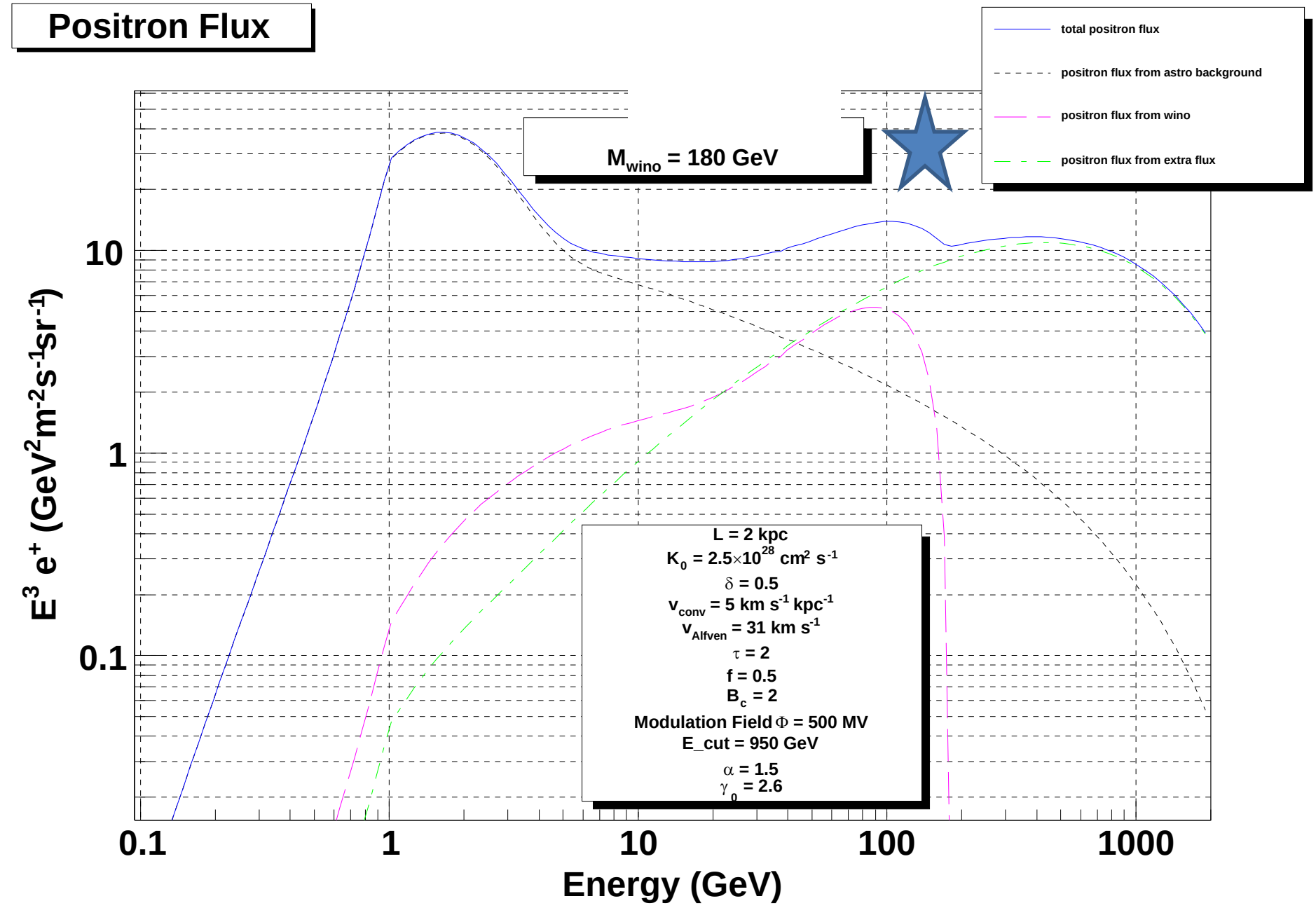



total backgrounds -- note signal well above our GALPROP background
Fermi data
wino
"diffuse" 10° -- 20°
signal+background
background
π^0
IC
bremss
wino
Fermi
10^{-2}
10^{-3}
10^{-4}
10^{-5}
$E^2\,\Phi$ (MeV^2 cm^{-2} s^{-1} MeV^{-1})
1
10
100
1000
Energy (GeV)

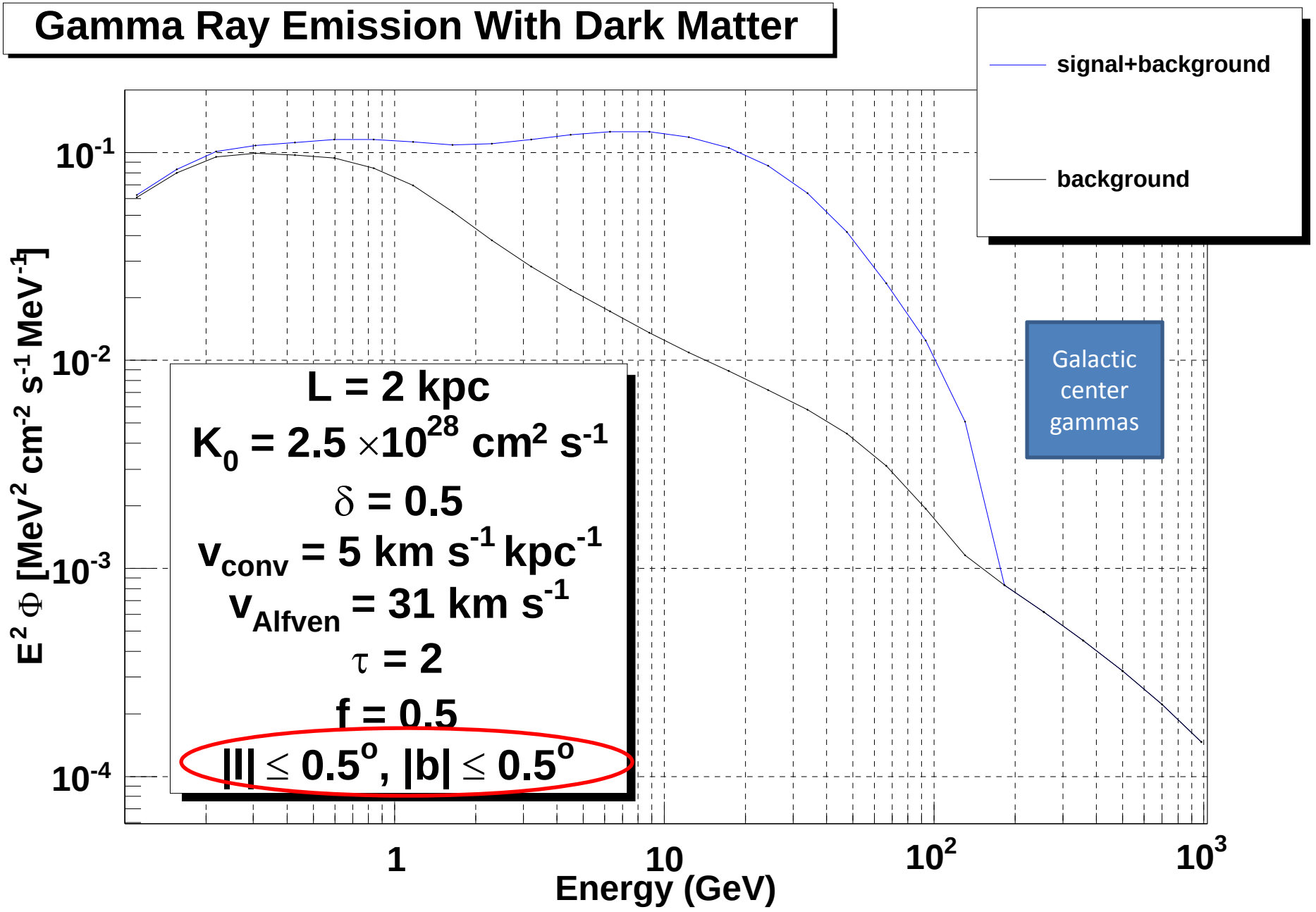
Electron Flux



Positron Flux



Gamma Ray Emission With Dark Matter



Flux from 180 GeV wino annihilation in a dark matter halo
(Essig, Sehgal, Strigari 0709.1510)

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

$$\mathcal{L}_{\rm ann} = \int_0^{\Delta\Omega}\left\{\int_{LOS}\rho^2(r)ds\right\}d\Omega$$

$$\langle\sigma v\rangle = 2.50\times10^{-24}\,{\rm cm^3 s^{-1}}$$

$$\int_{E_{\rm th}}^{E_{\rm max}}\frac{dN_\gamma}{dE_\gamma}dE_\gamma = 27.14$$

Dwarf Galaxy	Flux (E>100 MeV, 10^{-9} cm^{-2} sec^{-1})
Segue 1	0.5 – 350
Willman 1	0.3 – 30
Sagittarius	0.04 – 88
Ursa Minor	0.03 – 9.6
Draco	0.09 – 1.5

Summary of tests that wino LSP is good candidate for DM:

- Turnover in positron flux, ratio
- Rise in positron ratio not due to decrease in electron flux
- Antiproton ratio turnover
- Factor of few excess in diffuse gamma's below 200 GeV (compared to our GalProp background)
- Order of magnitude increase in galactic center gamma's below 200 GeV (compared to our GalProp background)
- Observable DM gammas from dwarf galaxies
- WMAP haze, recombination etc checked, maybe observable effects (Planck)

Note that for wino LSP annihilating DM signal already seen in positrons, antiprotons (down to low energies), and diffuse gammas, with our GalProp backgrounds

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!

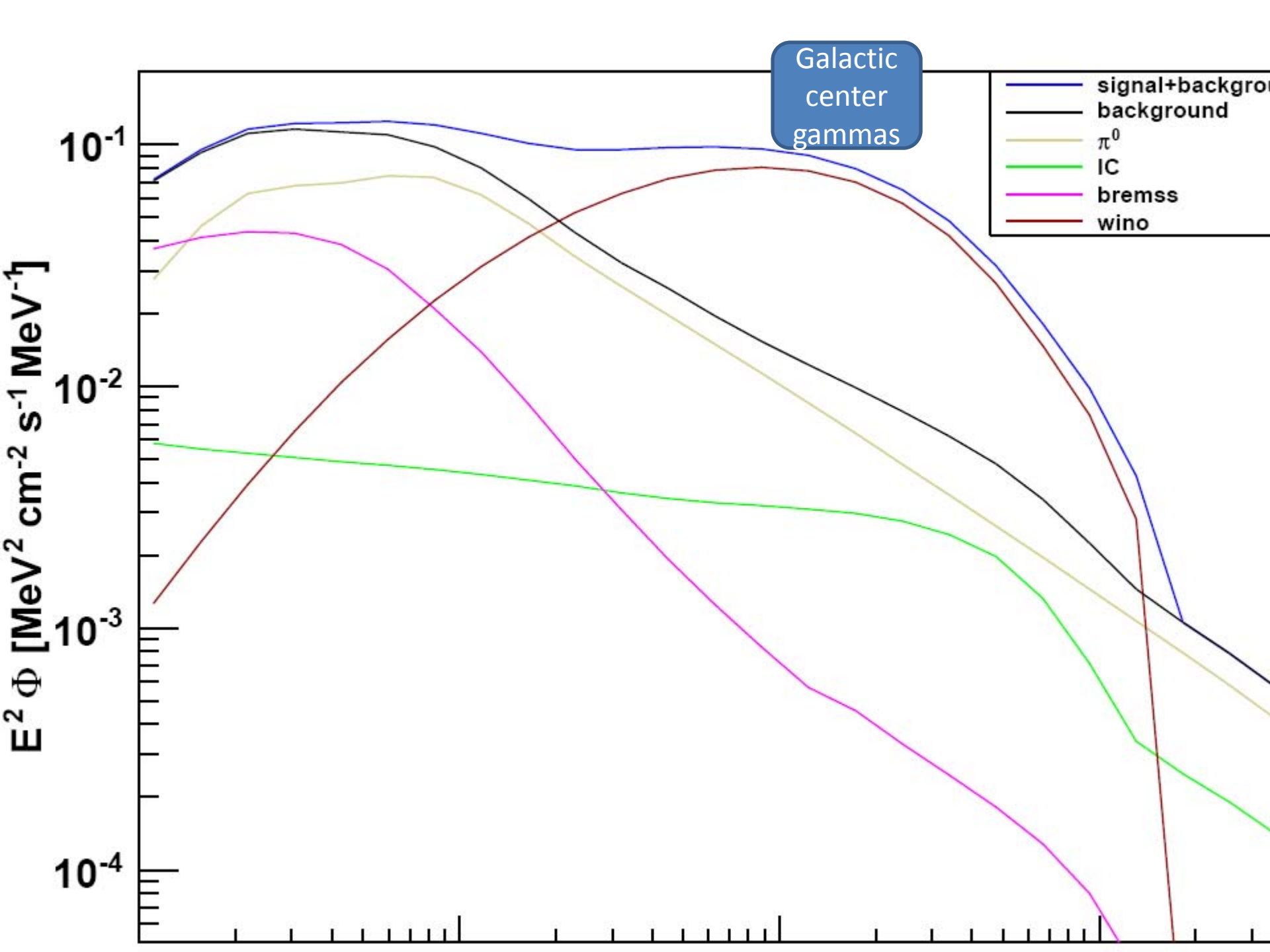
  -- guarantees can study superpartners at LHC

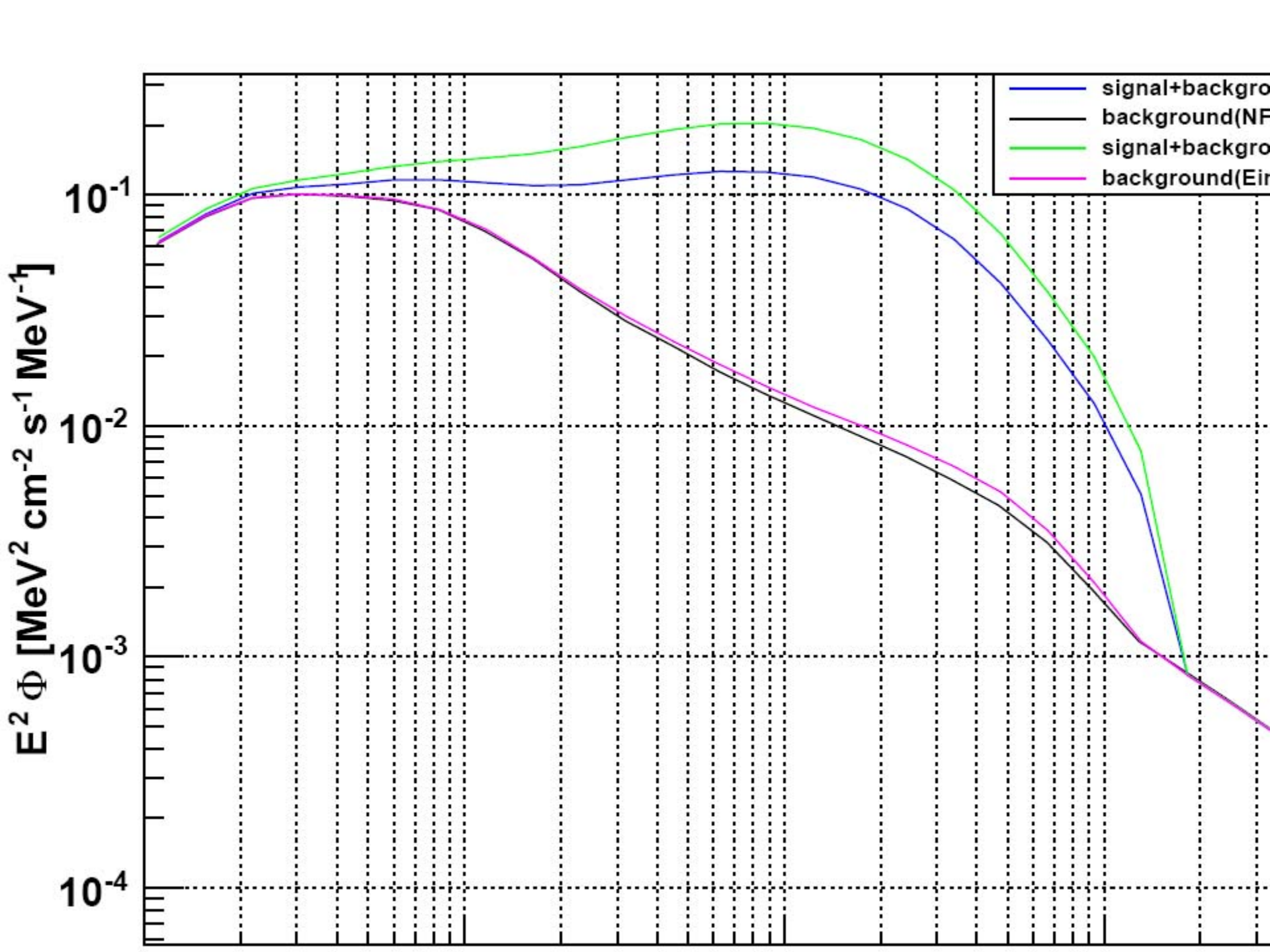
- Would have learned that the universe had a non-thermal cosmological history, one we can probe

[Suggests moduli dominated "UV completion" –> string theory!

-- M-Theory "G_2 – MSSM" construction a concrete example]

TESTS SOON!


Galactic center gammas
signal+backgro
background
π^0
IC
bremss
wino
$E^2 \Phi$ [MeV^2 cm^{-2} s^{-1} MeV^{-1}]
10^{-1}
10^{-2}
10^{-3}
10^{-4}


signal+backgro
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10^{-1}
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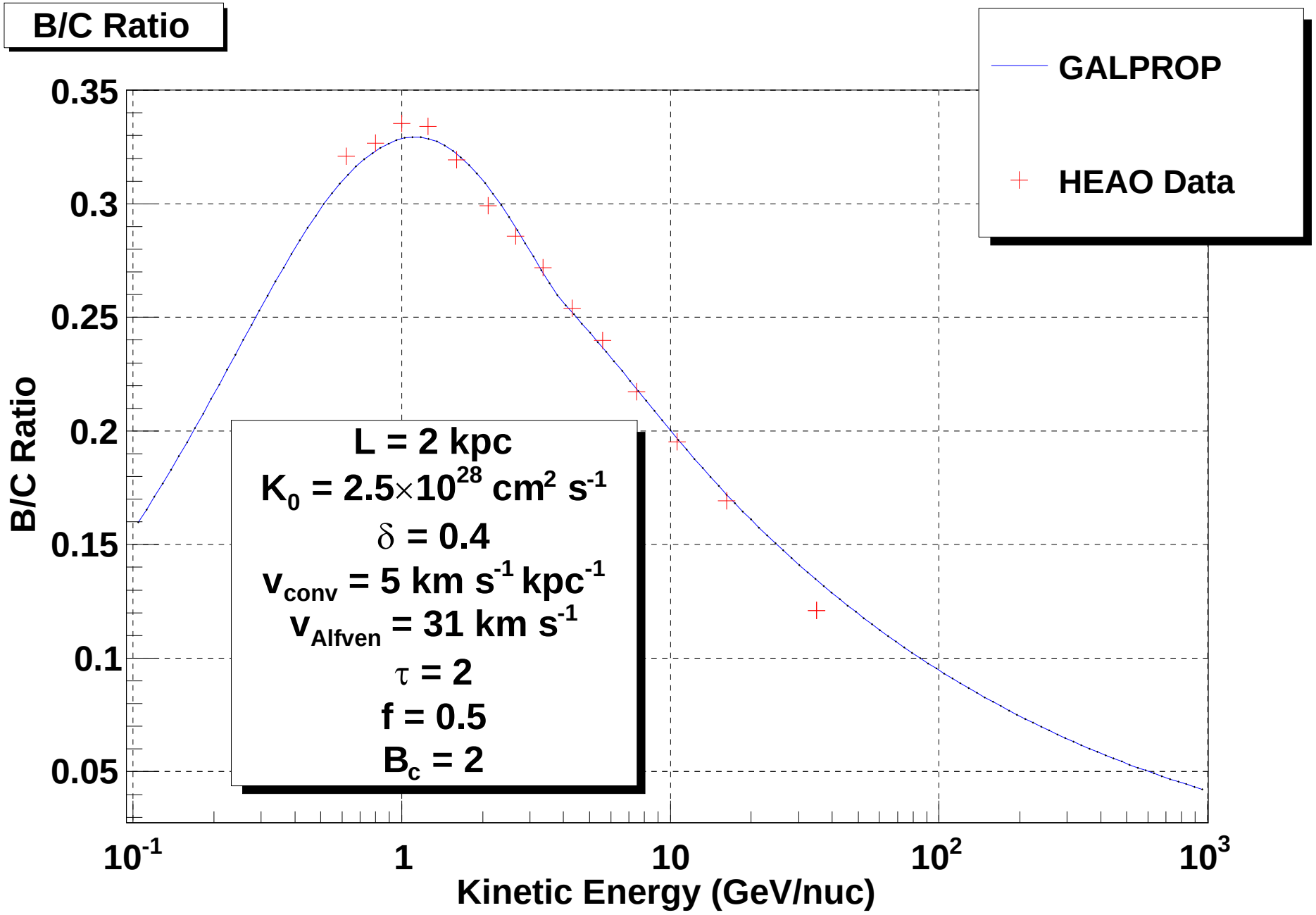
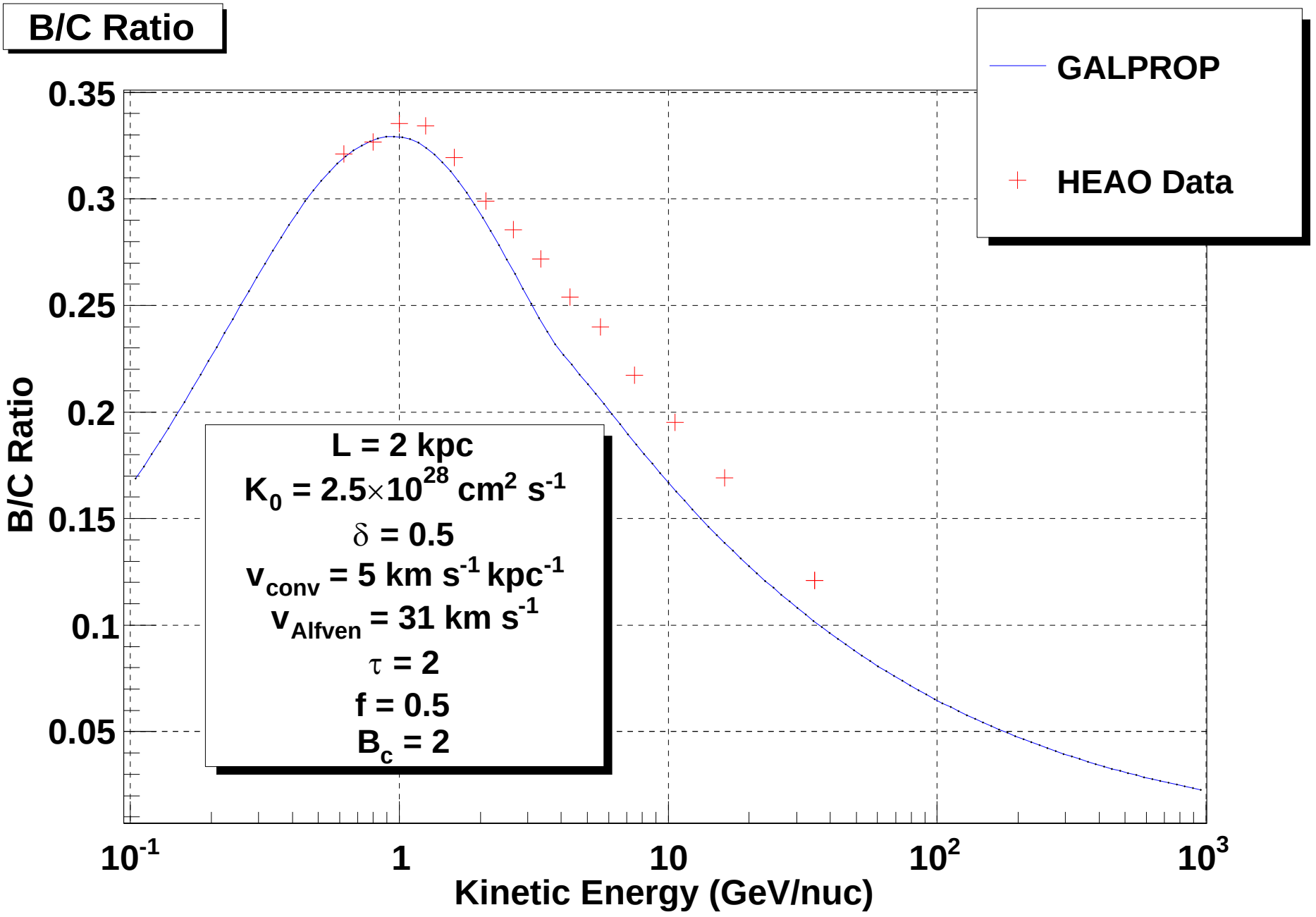
$E^2 \Phi$ [MeV^2 cm^{-2} s^{-1} MeV^{-1}]


B/C Ratio
GALPROP
HEAO Data
L = 2 kpc
K0 = 2.5×10^28 cm^2 s^-1
δ = 0.4
v_conv = 5 km s^-1 kpc^-1
v_Alfven = 31 km s^-1
τ = 2
f = 0.5
B_c = 2
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)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B/C Ratio
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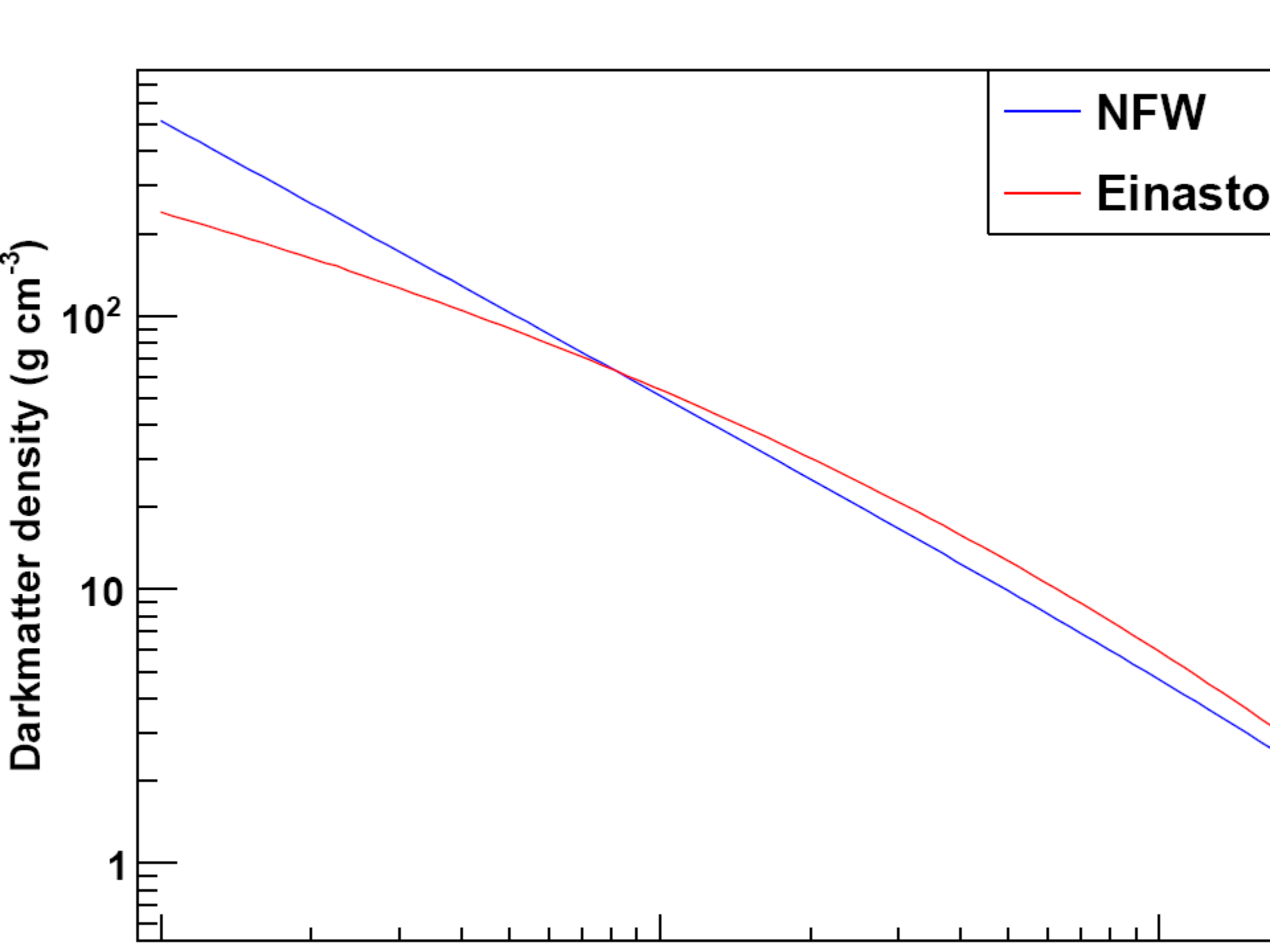
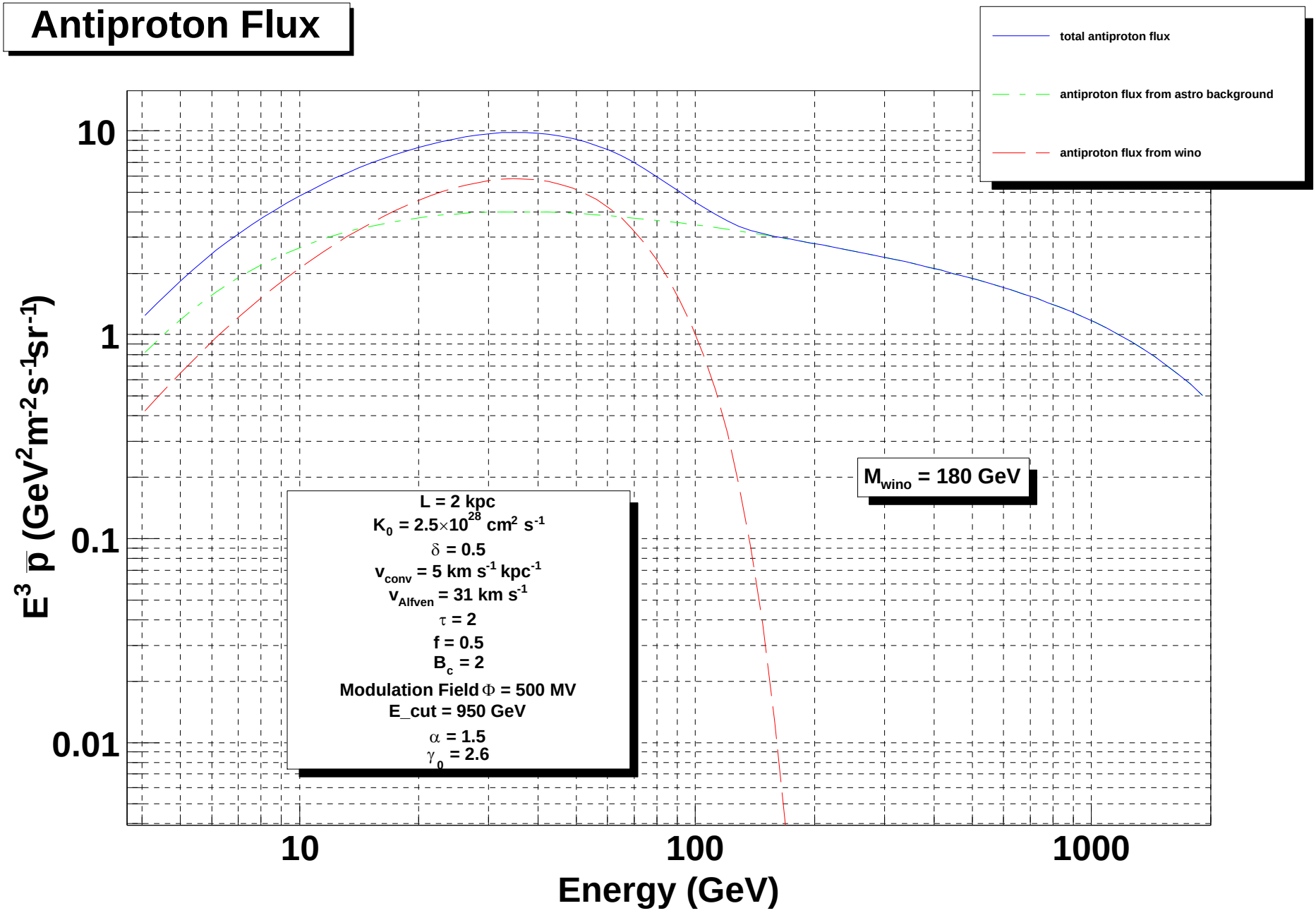
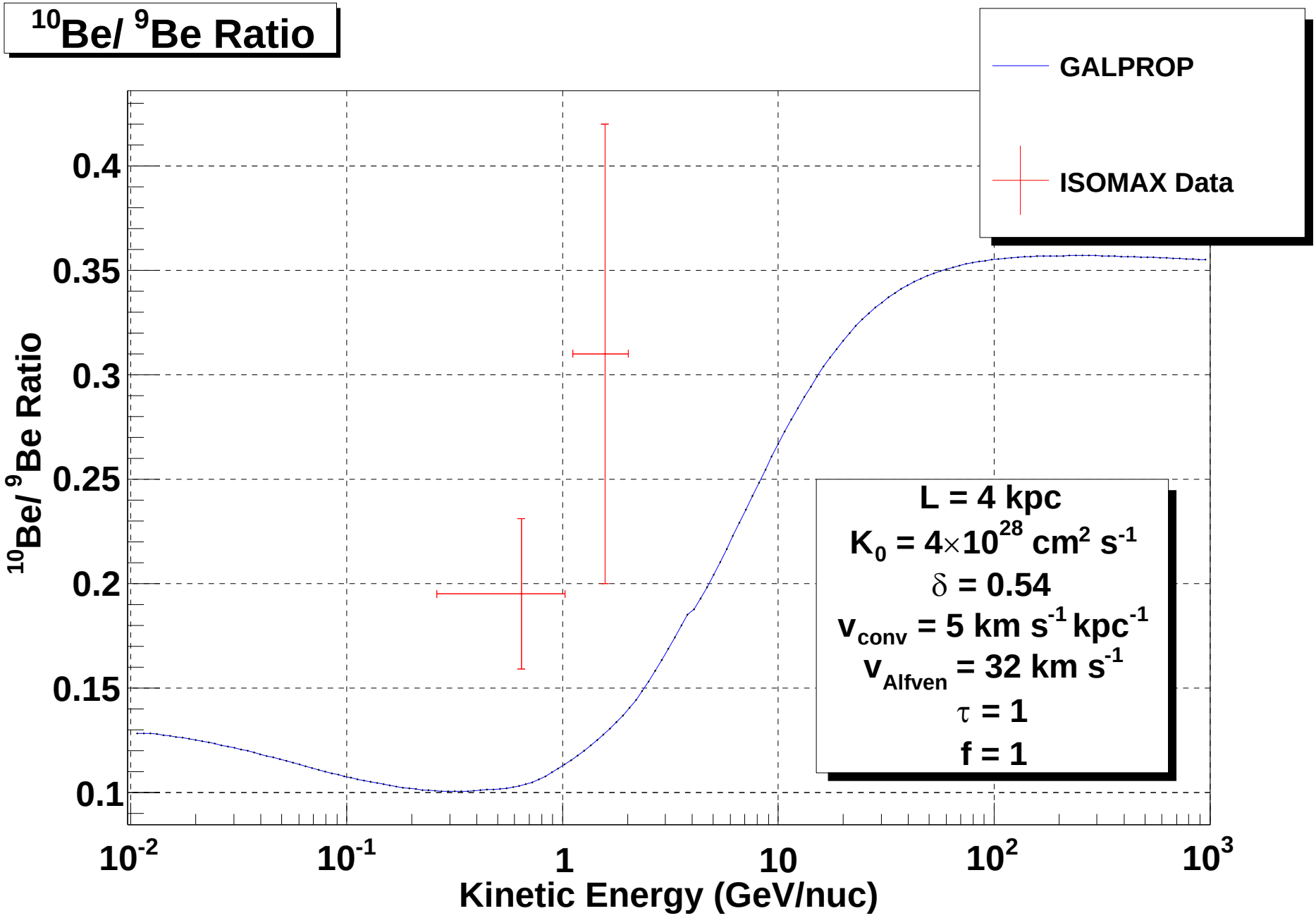
0.1
0.05
10^-1
1
10
10^2
10^3
Kinetic Energy (GeV/nuc)

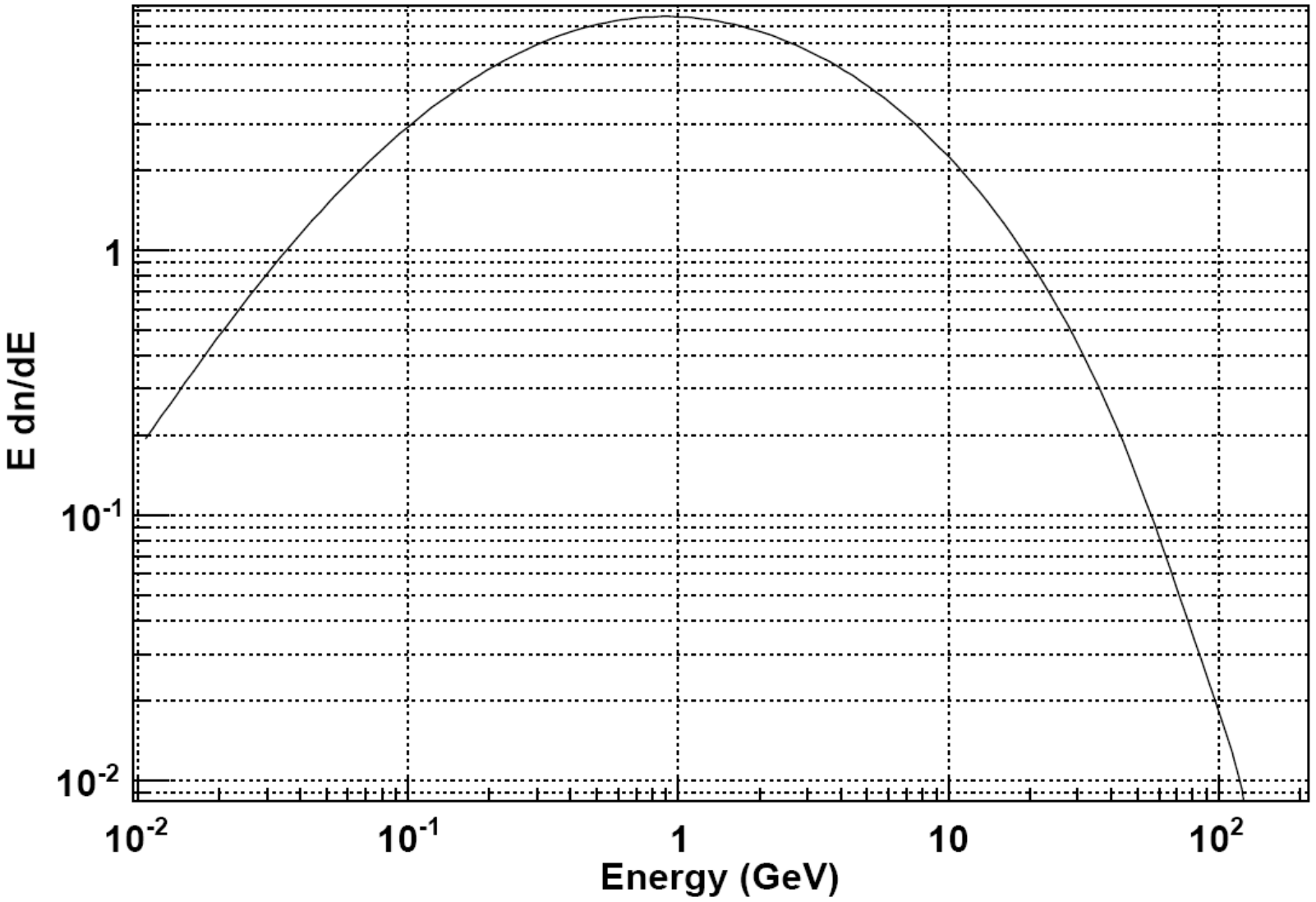

NFW
Einasto
Darkmatter density (g cm^{-3})
10^2
10
1

Antiproton Flux




^{10}Be/ ^{9}Be Ratio
GALPROP
ISOMAX Data
L = 4 kpc
$K_0 = 4\times10^{28}$ cm^2 s^{-1}
$\delta = 0.54$
$v_{conv} = 5$ km s^{-1} kpc^{-1}
$v_{Alfven} = 32$ km s^{-1}
$\tau = 1$
f = 1
^{10}Be/ ^{9}Be Ratio
0.4
0.35
0.3
0.25
0.2
0.15
0.1
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
Kinetic Energy (GeV/nuc)

Multiplicity distribution of gamma(WW)



Primary spectrum, since gammas do not lose energy as they propagate