Gamma-ray and electron signals from Kaluza-Klein dark matter annihilation

Satoshi Tsuchida and Masaki Mori

Department of Physical Sciences,

Ritsumeikan University

CALET TIM in Pisa, June 24-26, 2015

Kaluza-Klein dark matter

- UED (Universal Extra Dimension) theory
  - Assuming one extra dimension
- Mass predicted for the KK particle

$$m^{(n)} = \sqrt{\left(\frac{n}{R}\right)^2 + m_{\mathrm{EW}}^2}$$

L. Bergström et al, Phys. Rev. Lett 94(2005) 131301

- Here we assume $\boldsymbol{B}^{(1)}$, the first excitation mode (n=1), as the lightest KK particle (LKP) and consists of dark matter.
- 0.5 TeV < $m_{B^{(1)}}$ < 1 TeV for $\Omega_{\mathrm{CDM}}h^2 = 0.12 \pm 0.02$

Boost factor

- Gamma-ray/electron flux from DM annihilation in the Galactic halo ($x = E/m_{B^{(1)}}$)

$$E^2 \frac{d\Phi}{dE} = 3.5 \times 10^{-8} \left(\frac{\langle \sigma v \rangle}{3 \times 10^{-26} \mathrm{cm^3 s^{-1}}} \right) \left(\frac{800\ \mathrm{GeV}}{m_B^{(1)}} \right) \langle J_{\mathrm{GC}} \rangle_{\Delta\Omega} \Delta\Omega\, B_{\mathrm{tot}}\, x^2 \frac{dN}{dx}$$

where the boost factor is defined as

$$B_{\mathrm{tot}} = B_\rho \times B_{\sigma v} = \left(\frac{\langle \rho^2(l) \rangle_{\Delta V}}{\langle \rho_0^2\ (l) \rangle_{\Delta V}} \right) \left(\frac{\langle \sigma v \rangle_{v \approx v_{disp}}}{\langle \sigma v \rangle_{v \approx v_{freese-out}}} \right)_{\Delta V}$$

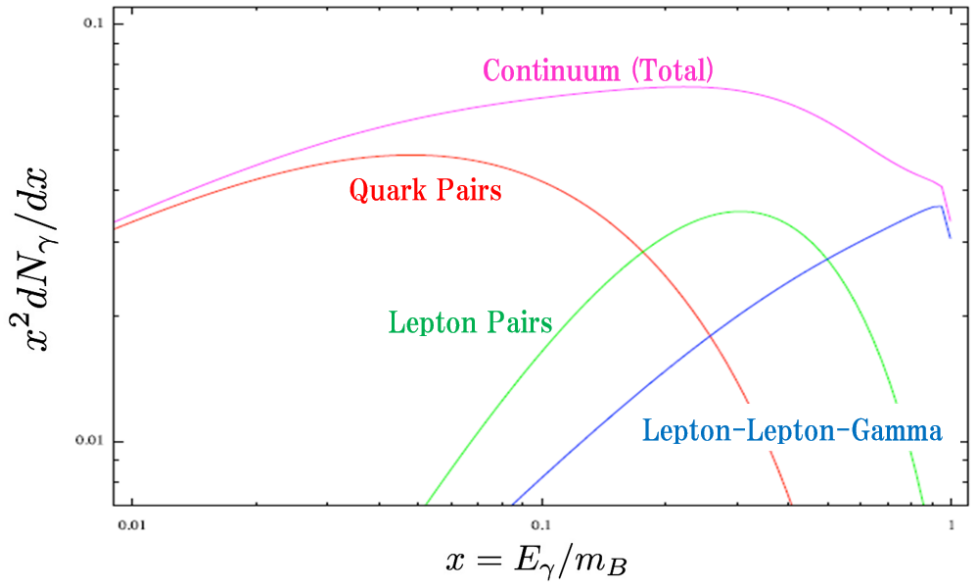
(B_ρ could be as large as 1000, as suggested by N-body simulation)

L. Bergström et al, JCAP 04 (2005) 004; Phys. Rev. Lett 94(2005) 131301

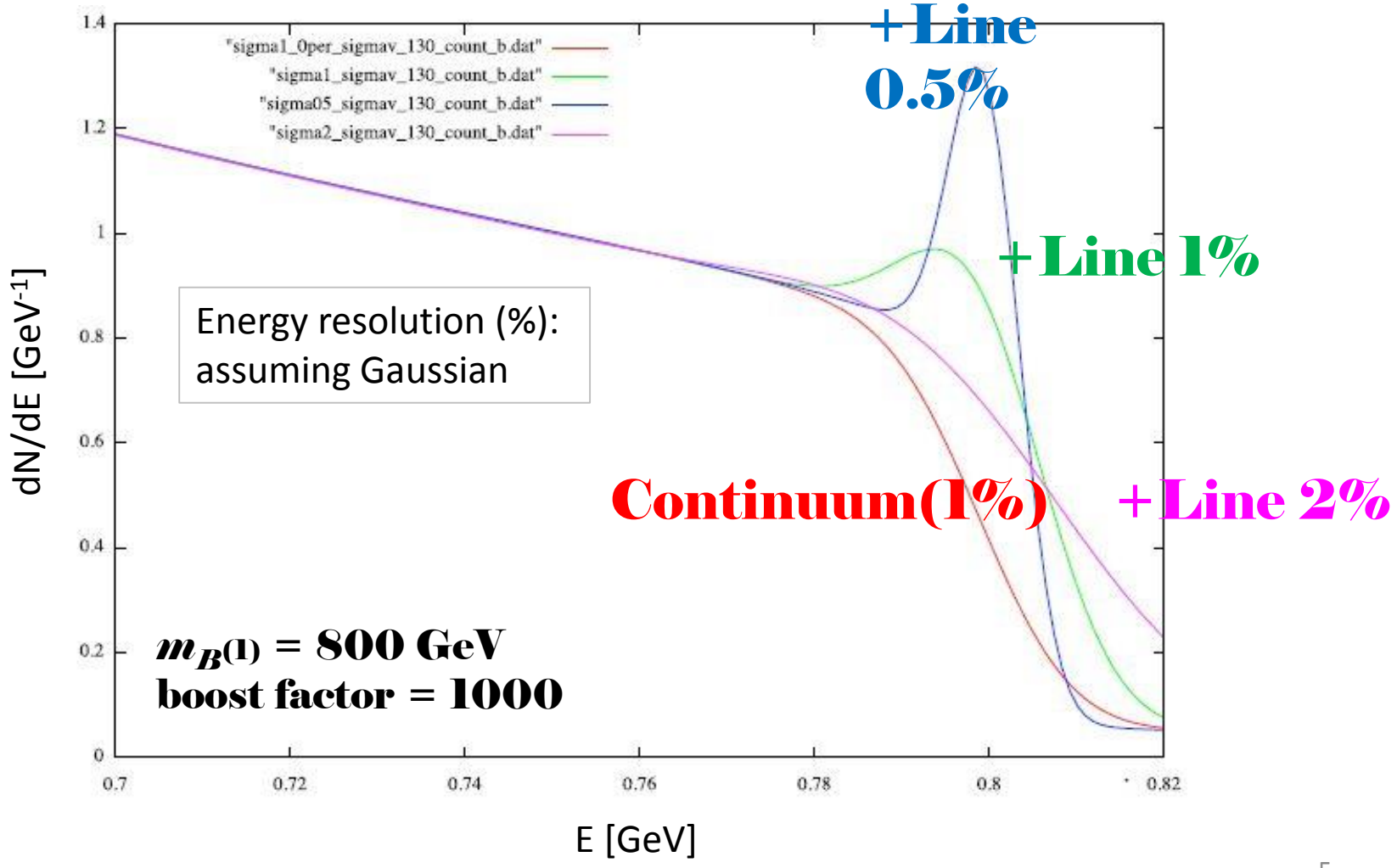
Annihilation modes to produce gamma-rays from KKDM

- $B^{(1)}B^{(1)} \rightarrow$
  - $\gamma\gamma$ — "Line" at $E_\gamma = m_{B^{(1)}}$
  - Quark pairs
  - Charged lepton pairs
  - Lepton+lepton+γ

  Fragmentation etc. $\rightarrow$ "Continuum"

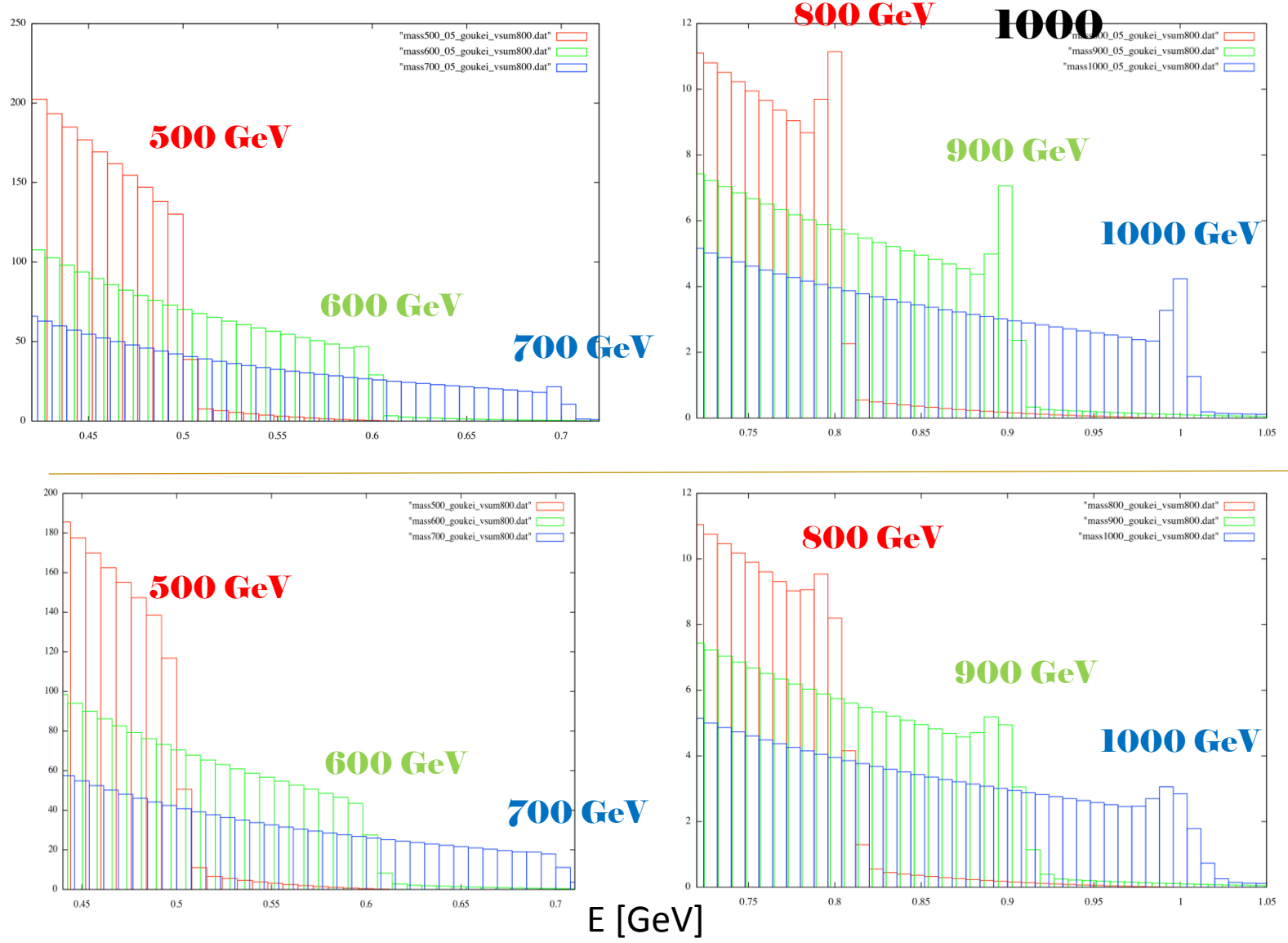


Spectra taking ΔE into account



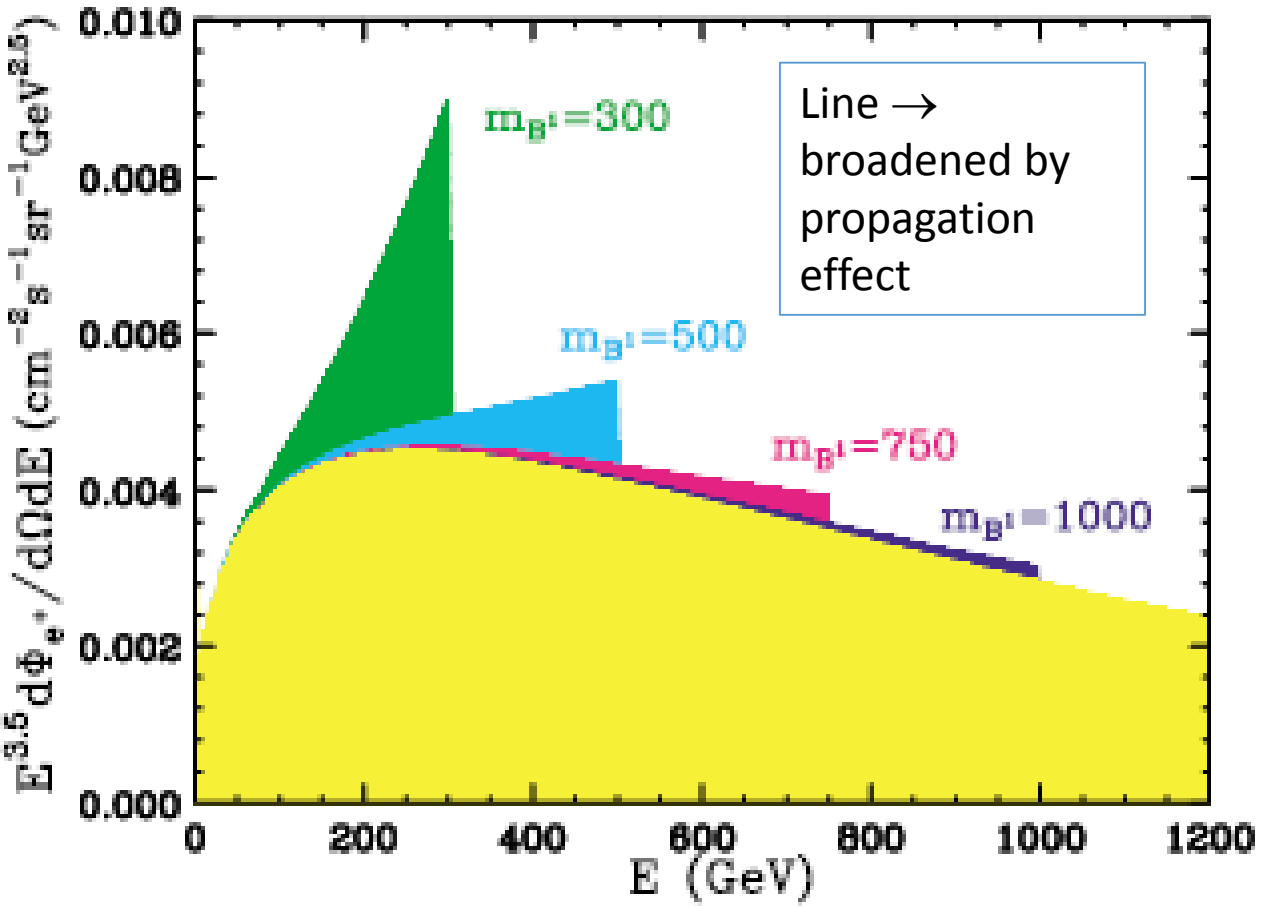
Count spectra for 1000cm^2, 1 yr

boost factor = 1000



Cheng et al., Phys. Rev. Lett. 89 (2002) 211301

Electron signal of KKDM annihilation



Moiseev et al., Frascati Phys. Ser. VVV (2007) 1-9

Prediction for Fermi-LAT

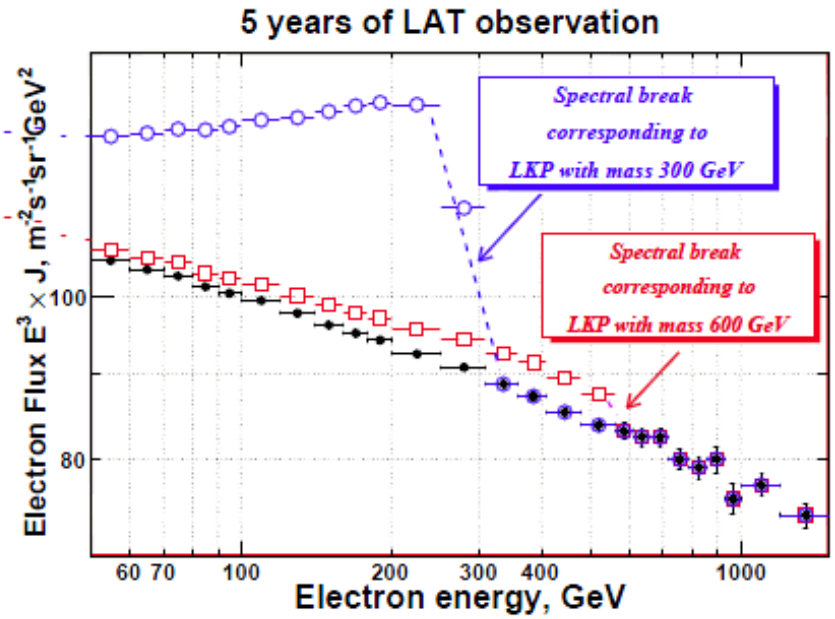


Figure 5: Illustration of the simulated reconstructed LAT electron spectrum with the presence of signal from LKP with the mass of 300 GeV and 600 GeV, for five years of observations. Black filled circles - "conventional" electron flux, blue open circles - with added signal from 300 GeV LKP, red oped squares - with added signal from 600 GeV LKP

Annihilation modes to produce e^+e^- from KKDM

- $B^{(1)}B^{(1)} \rightarrow$
  - Charged lepton pairs (59%)
    - e^+e^- (20%)
    - $\mu^+\mu^-$ (20%)
    - $\tau^+\tau^-$ (20%)
  - Quark pairs (35%)
    - bb (6%)
  - Gauge bosons (1.5%)
  - Higgs bosons (0.5%)

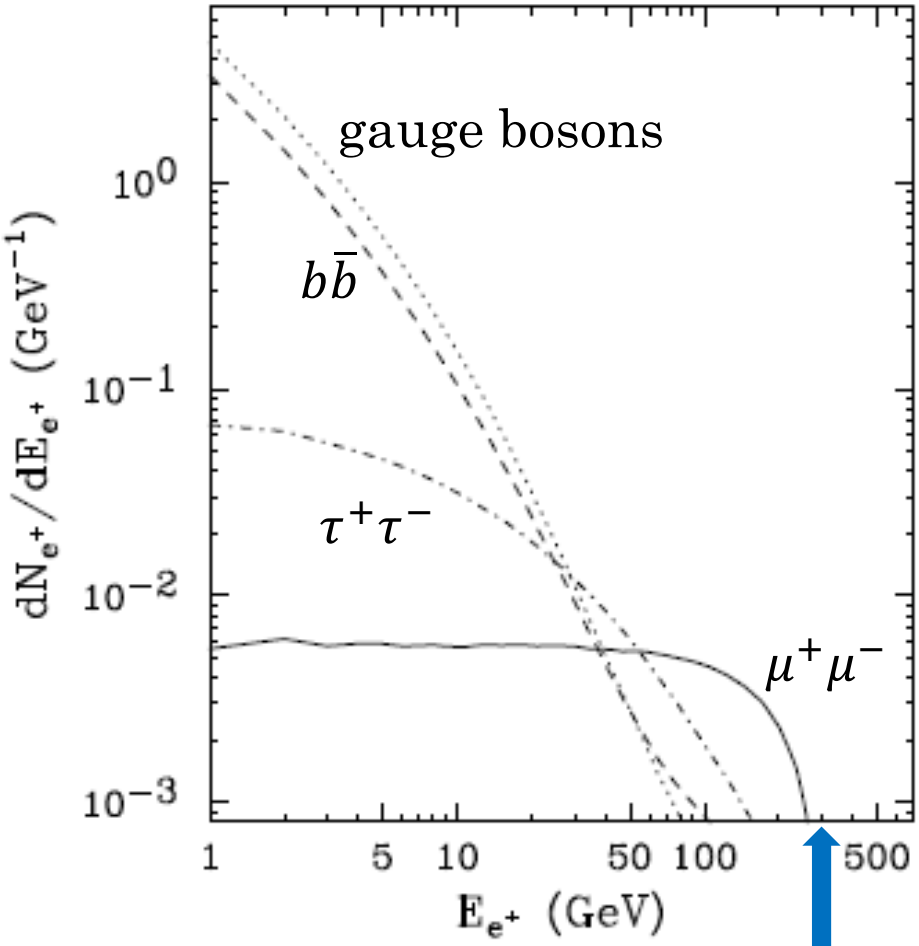
e^+e^- (20%) → "Line"

Fragmentation etc. → "Continuum"

G. Servant & T. Tait, Nucl. Phys. B 650, 391 (2003)

D. Hooper & D.Kribs, PRD 70 (2004) 115004

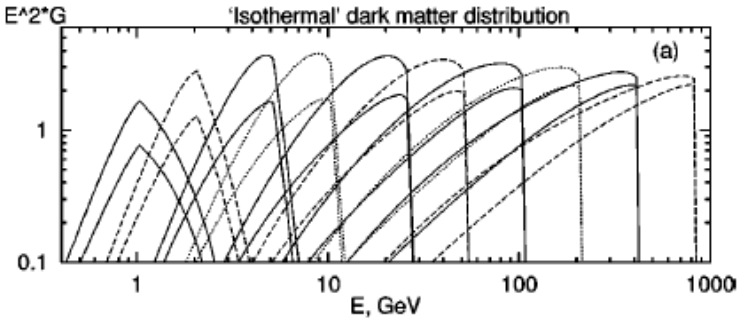
Continuum spectra at production



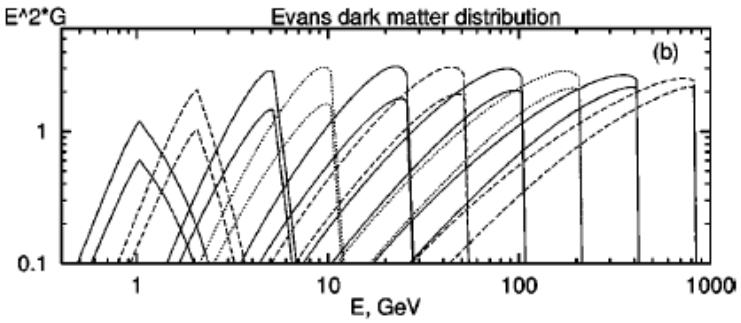
$m_{B^{(1)}} = 300$ GeV

I. V. Moskalenko & A. W. Strong, PRD 60 (1999) 063003
I. V. Moskalenko & A. W. Strong, ApJ 493 (1998) 694

Propagation effect – Green function



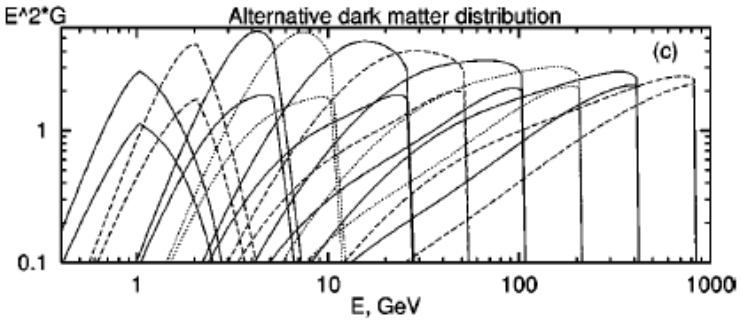
Isothermal model
$\rho = 0.43$ GeV cm^{-3} (Local DM density)
$r_c = 2.8$ kpc (Core radius)



Evans model
$\rho = 0.51$
$r_c = 7.0$ kpc

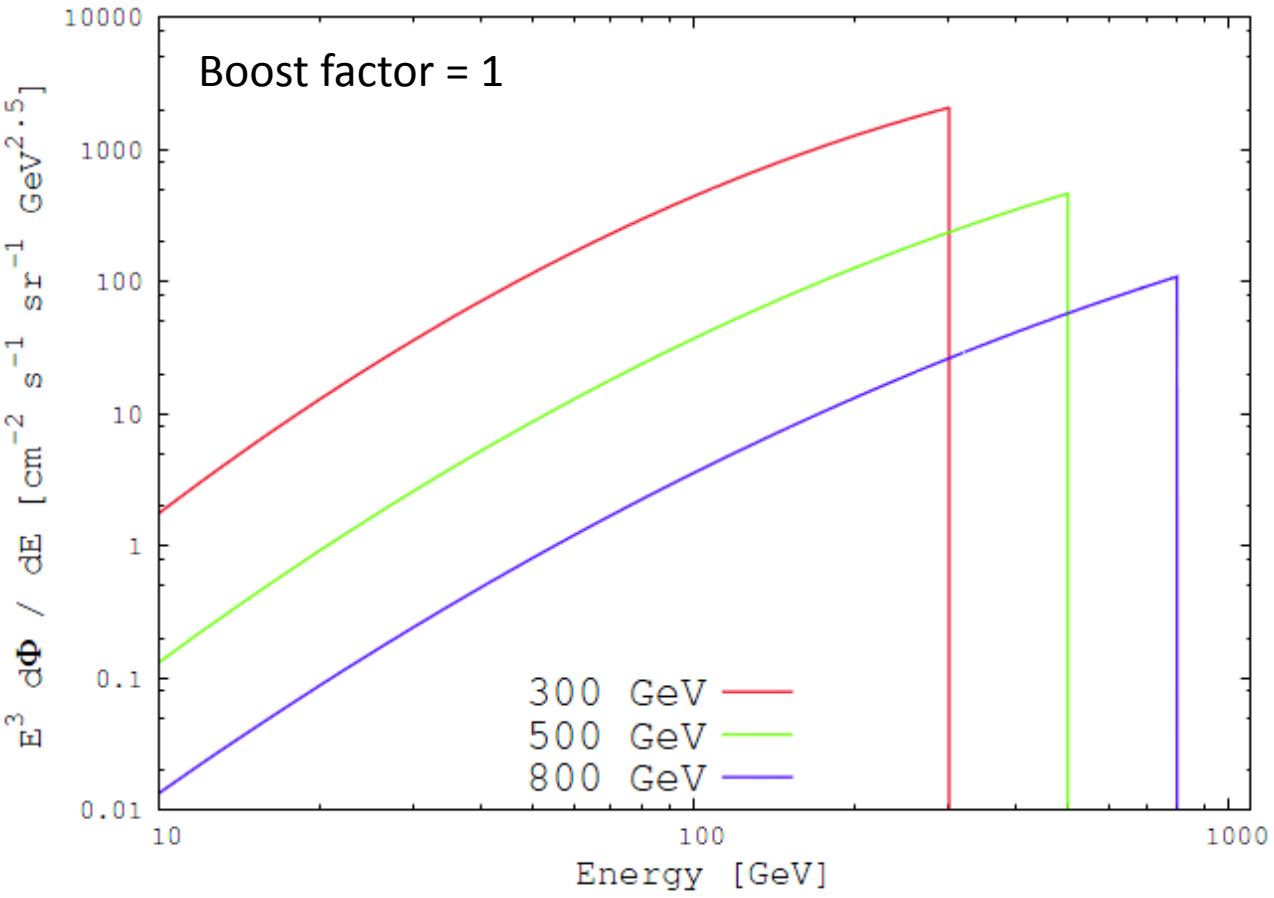
$$B = 6 \exp\left[-\frac{|z|}{5\text{kpc}} - \frac{R}{20\text{kpc}}\right] \ \mu\text{G}$$

Upper case 10 kpc
Lower case 4 kpc
Our case 8.5 kpc

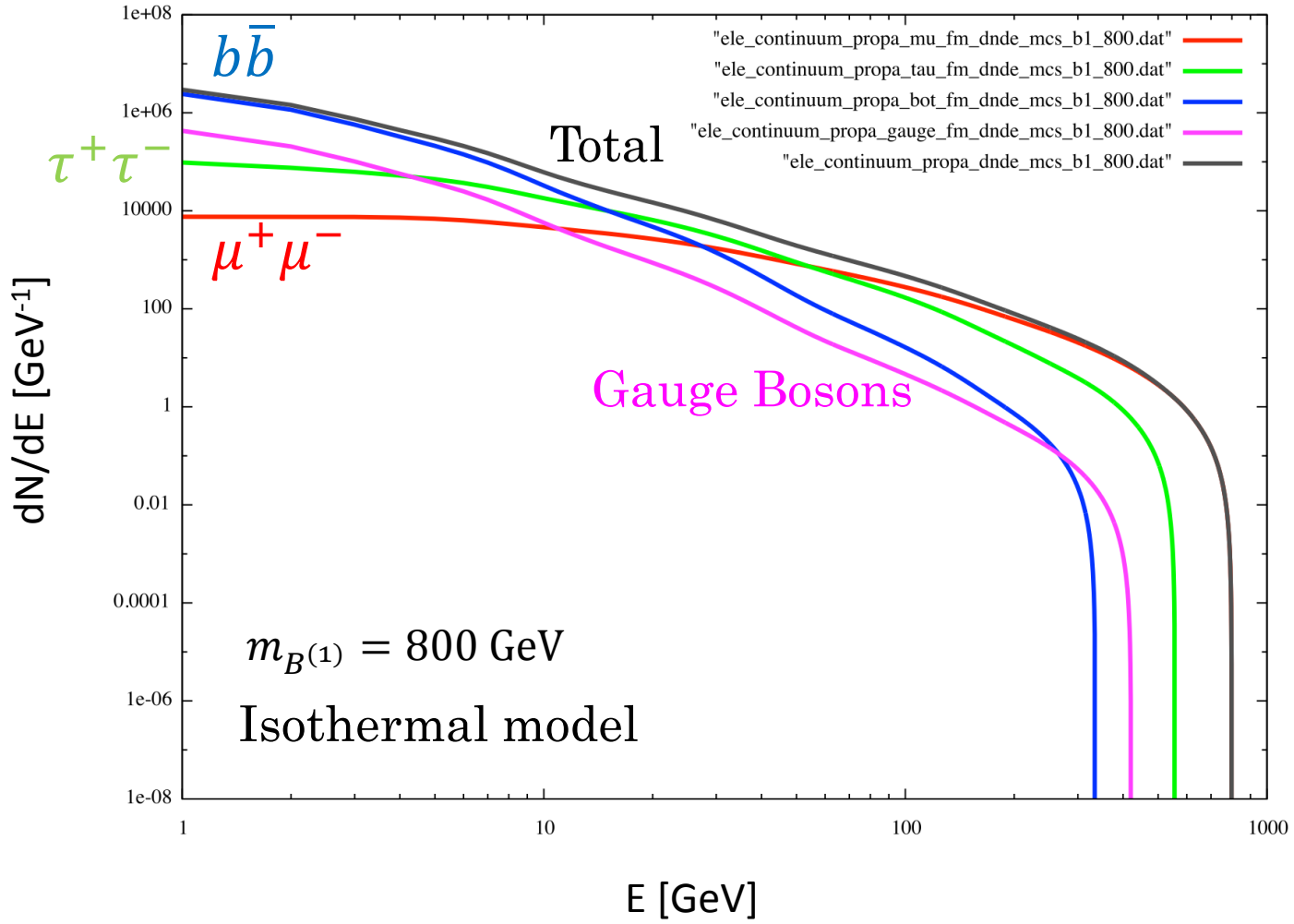


Alternative model
$\rho = 0.38$
$r_c = 0.9$ kpc

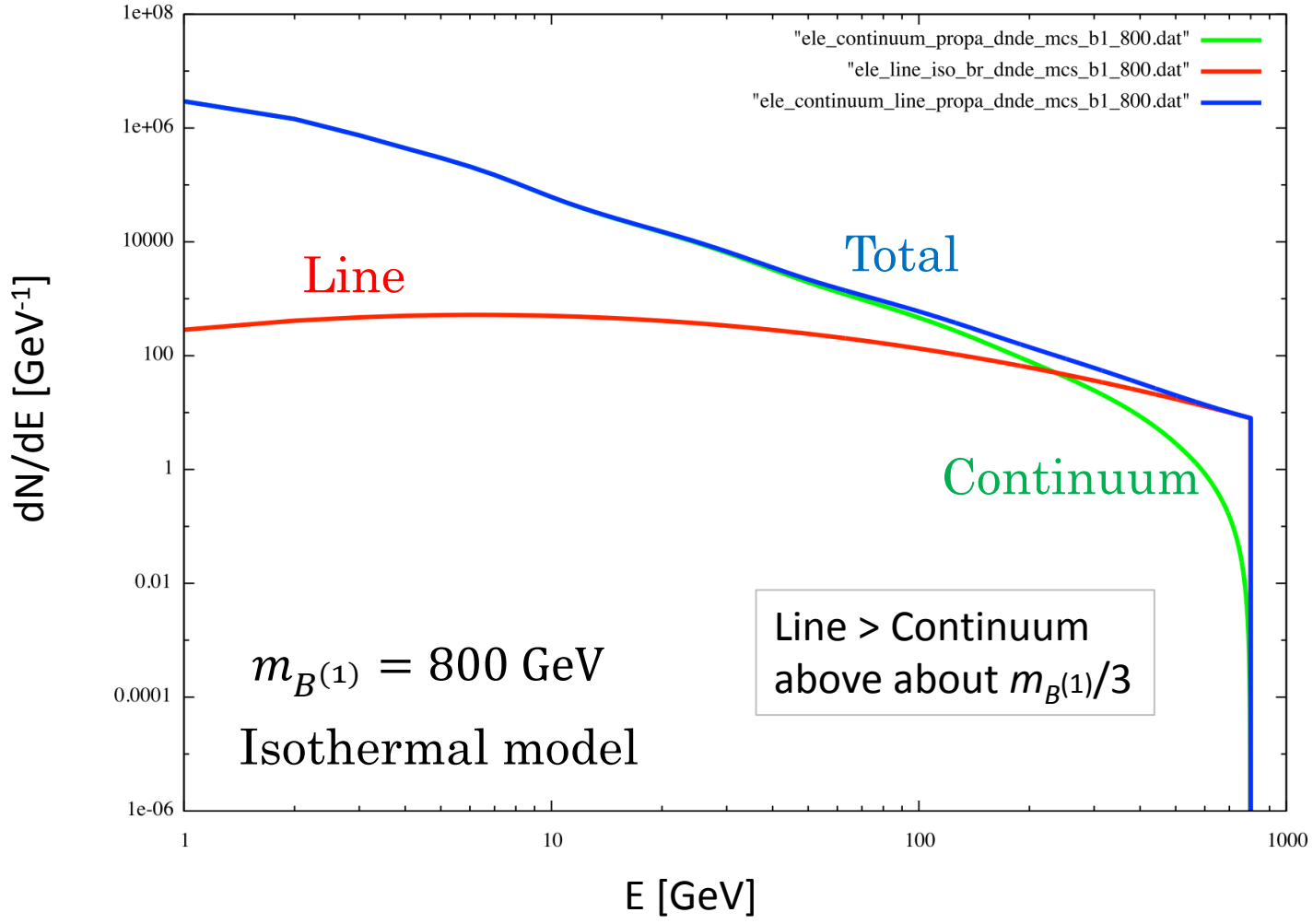
Spectra after propagation: Line



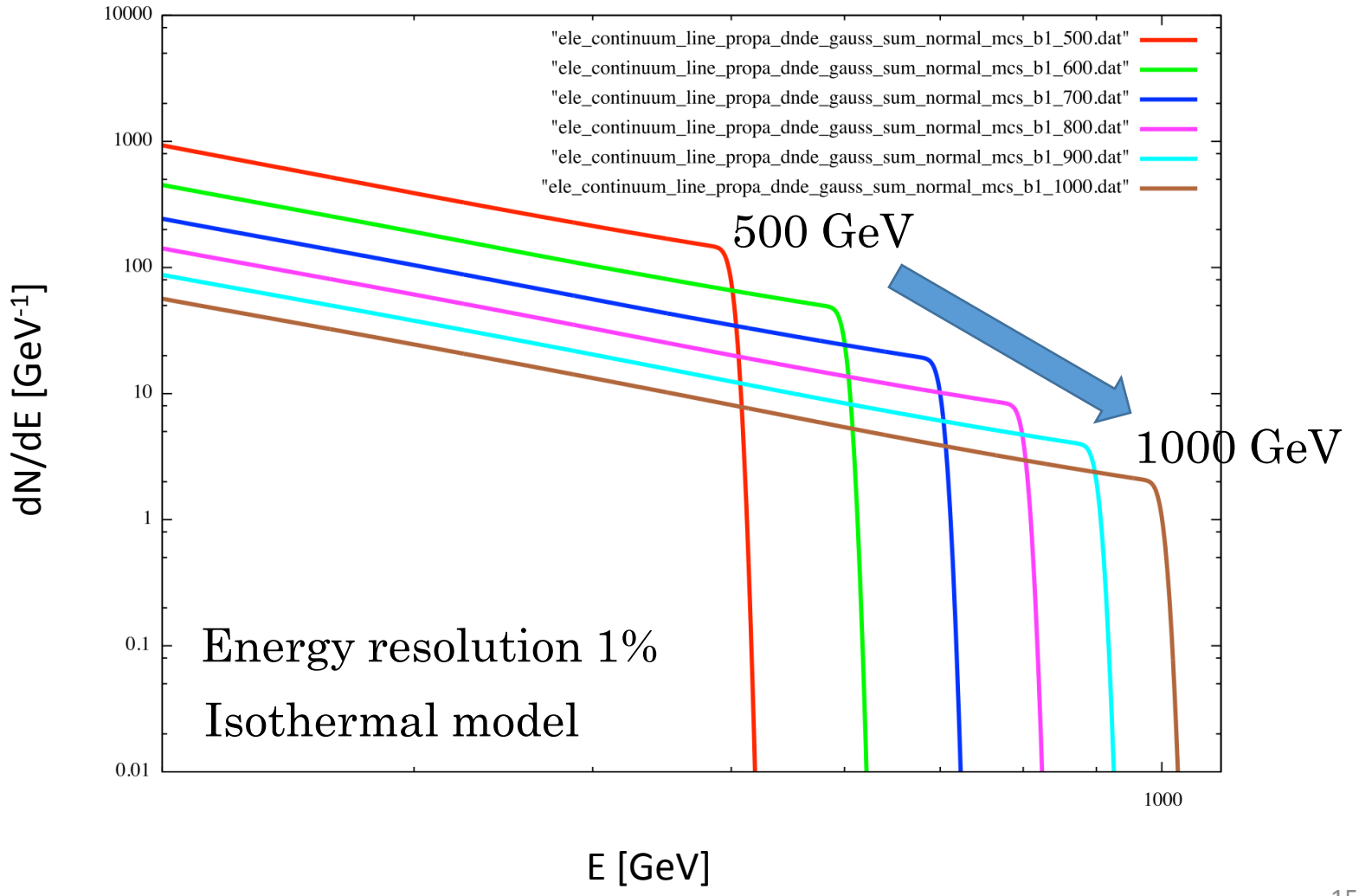
Spectra after propagation: Continuum



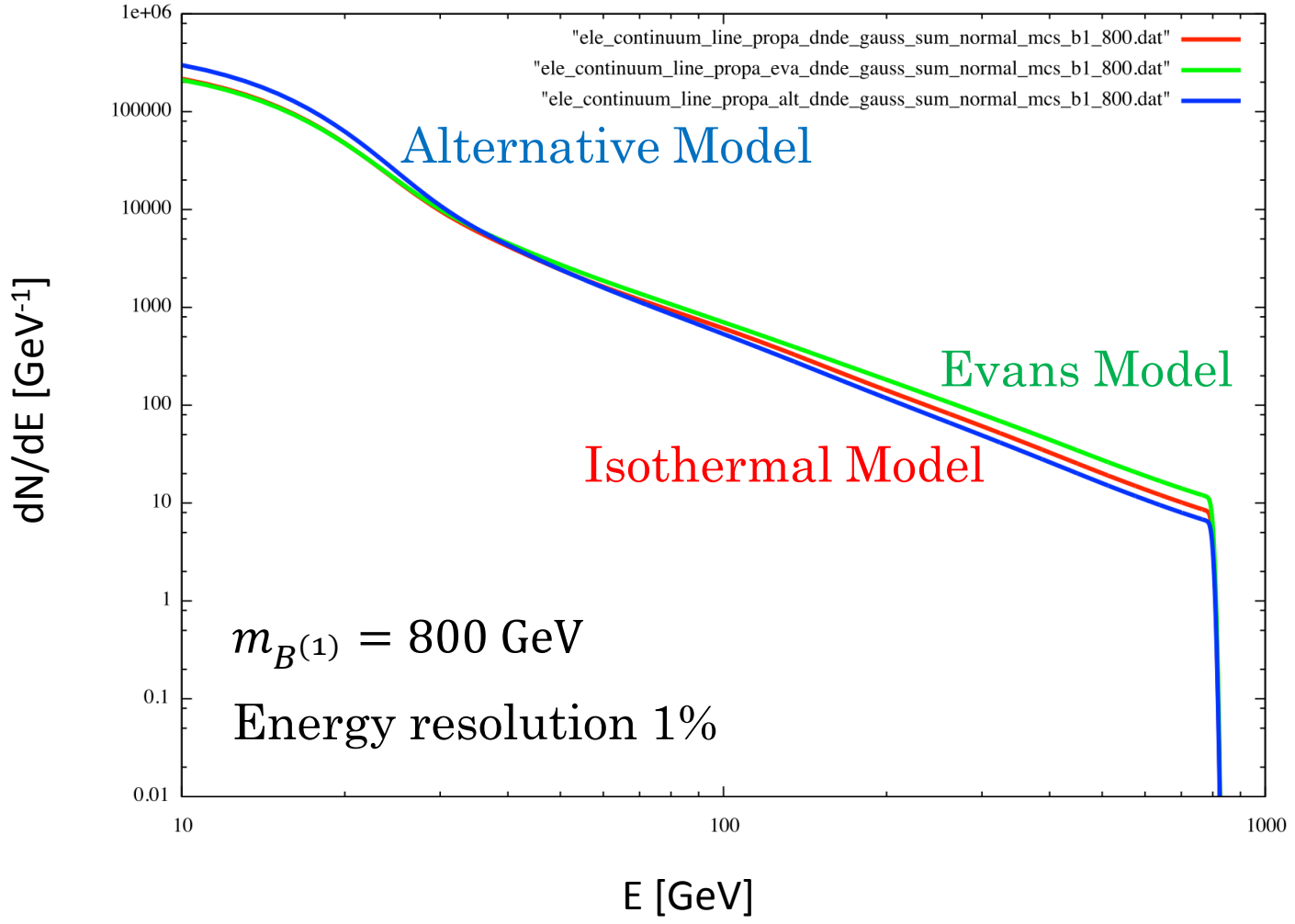
Spectra after propagation: Total



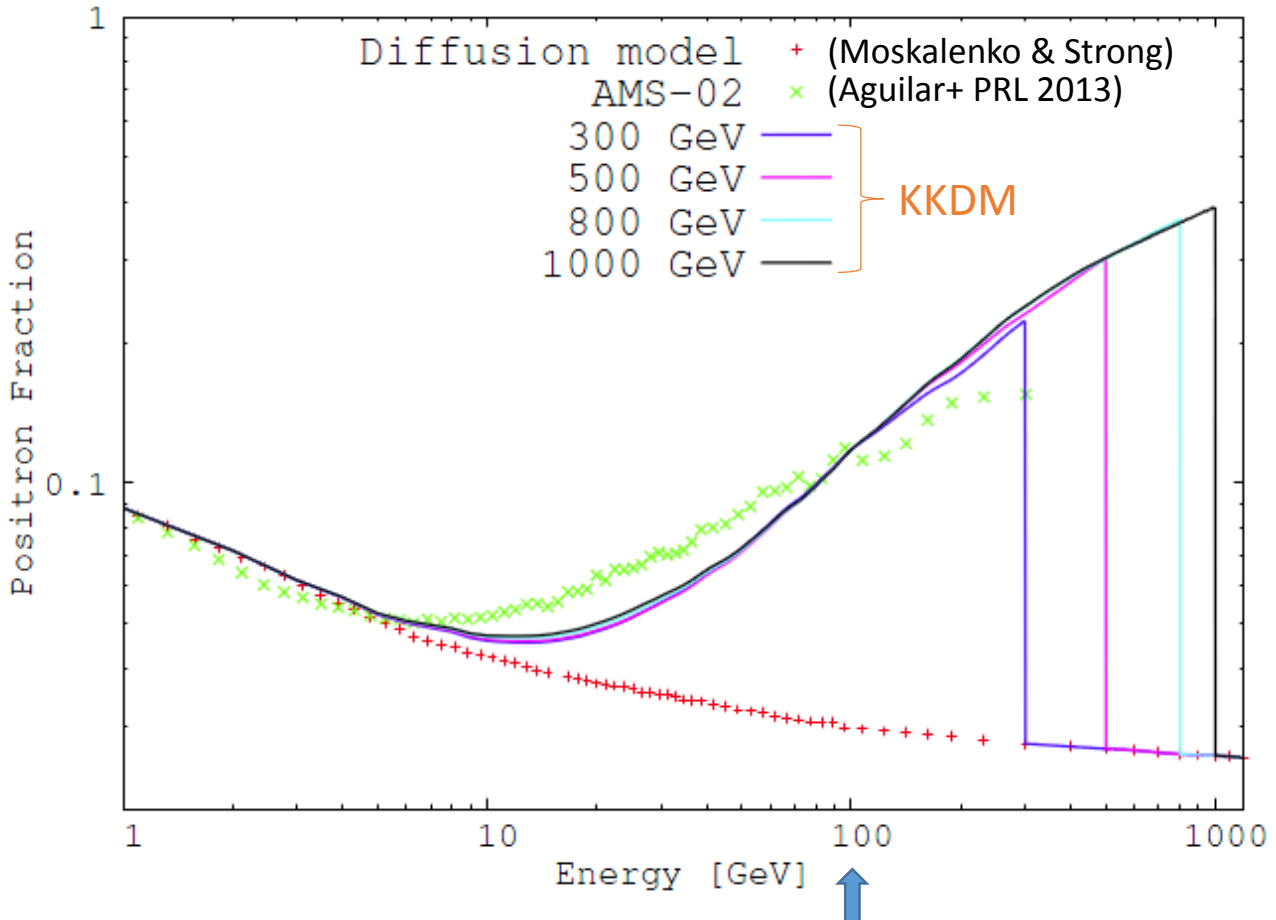
DM mass dependence on spectra



Halo model dependence on spectra

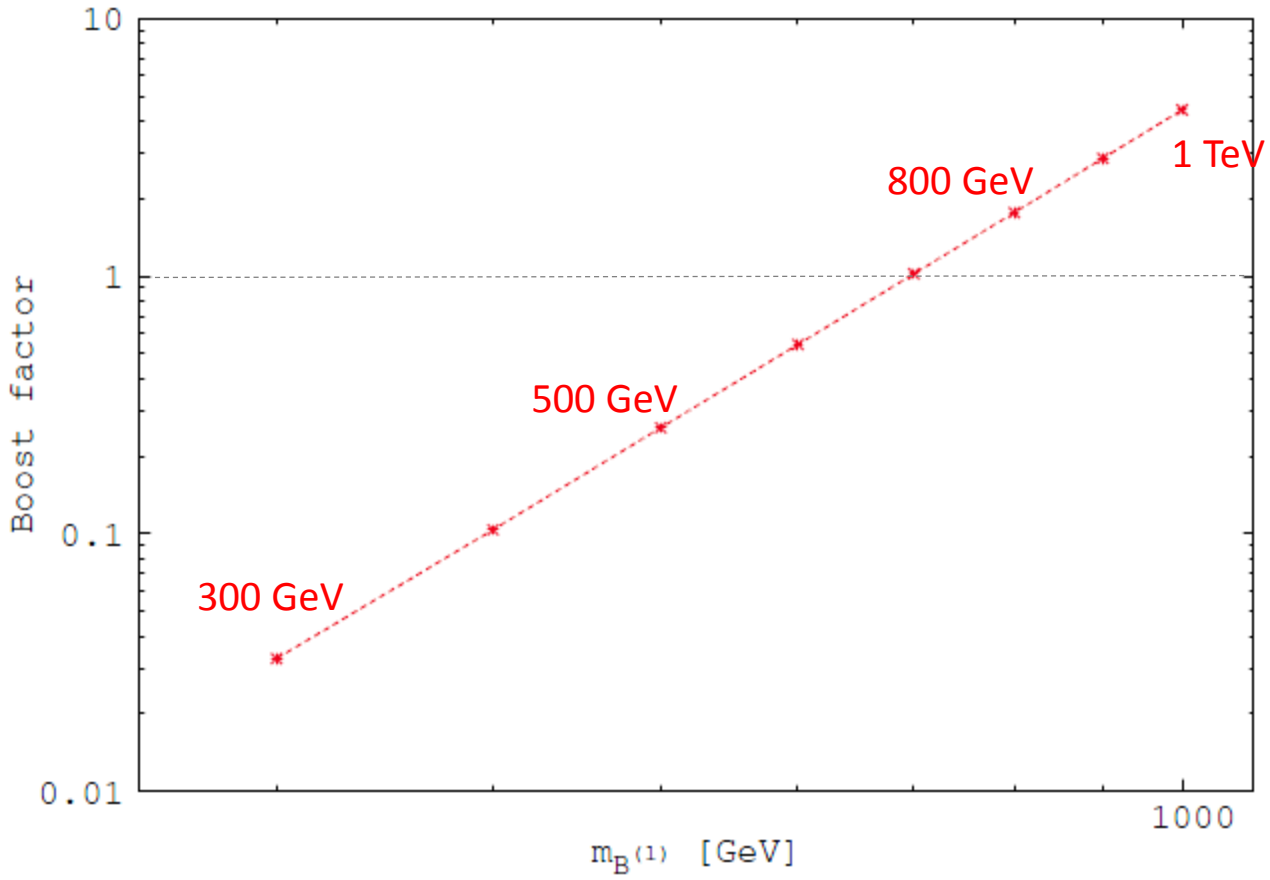


Positron fraction fit

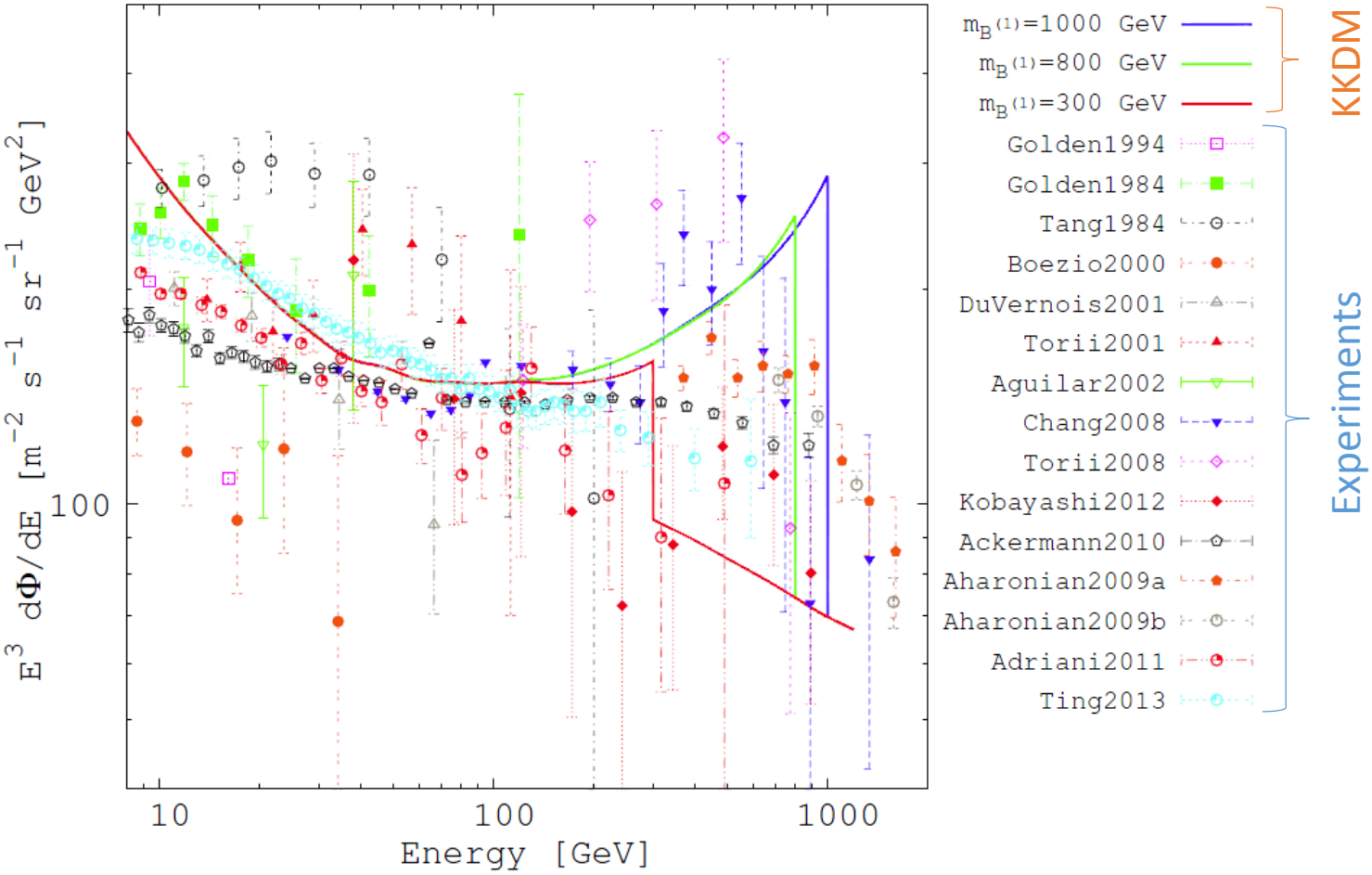


Boost factor is normalized to fit at 100 GeV

Boost factor to fit positron fraction



Electron+positron spectrum



Summary

- Gamma-ray and electron signals from Kaluza-Klein dark matter have been calculated to compare with measurements.
- Gamma-ray line signal could be seen if the energy resolution is better than 2%, but a large boost factor is required.
- Electron signal could limit the boost factor more severely, taking the AMS-02 positron fraction into account.

Gamma-rays: Tsuchida and Mori, submitted; ICRC 2015
Electrons: Tsuchida and Mori, to be submitted; ICRC2015