IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

Dark Matter and Collider Phenomenology of UED

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5/22/09 @ ppp8, NCKU

In collaboration with M. Nojiri, SC Park, J. Shu and M. Takeuchi

arXiv:0903.1971 [hep-ph]

Outline

Motivation

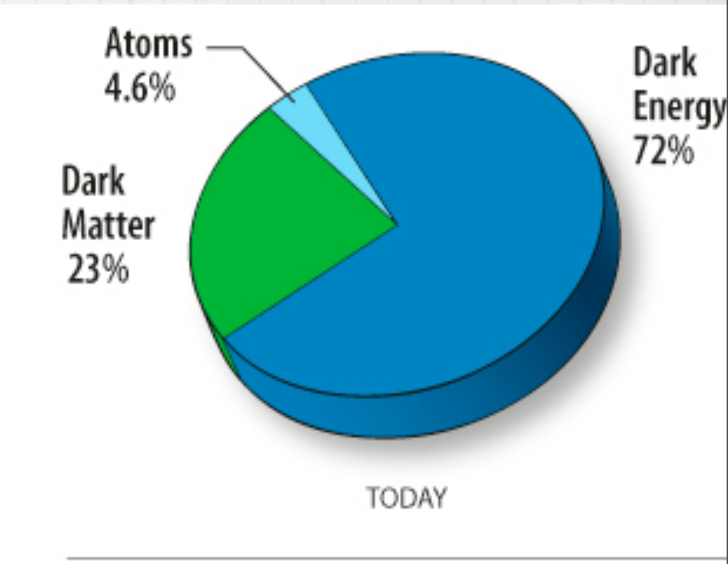
Model

Cosmic-ray

Collider

Summary

Motivation → Dark Matter Data



confidently established from observation;

WMAP5: $\Omega_{DM} = 0.228 \pm 0.013$

E. Komatsu et al, 0803.0547

BSM should include DM;

Supersymmetry, Extra-Dimension, Little Higgs, ...

LHC will/may produce DM, and discover it;

mass, spin, ...

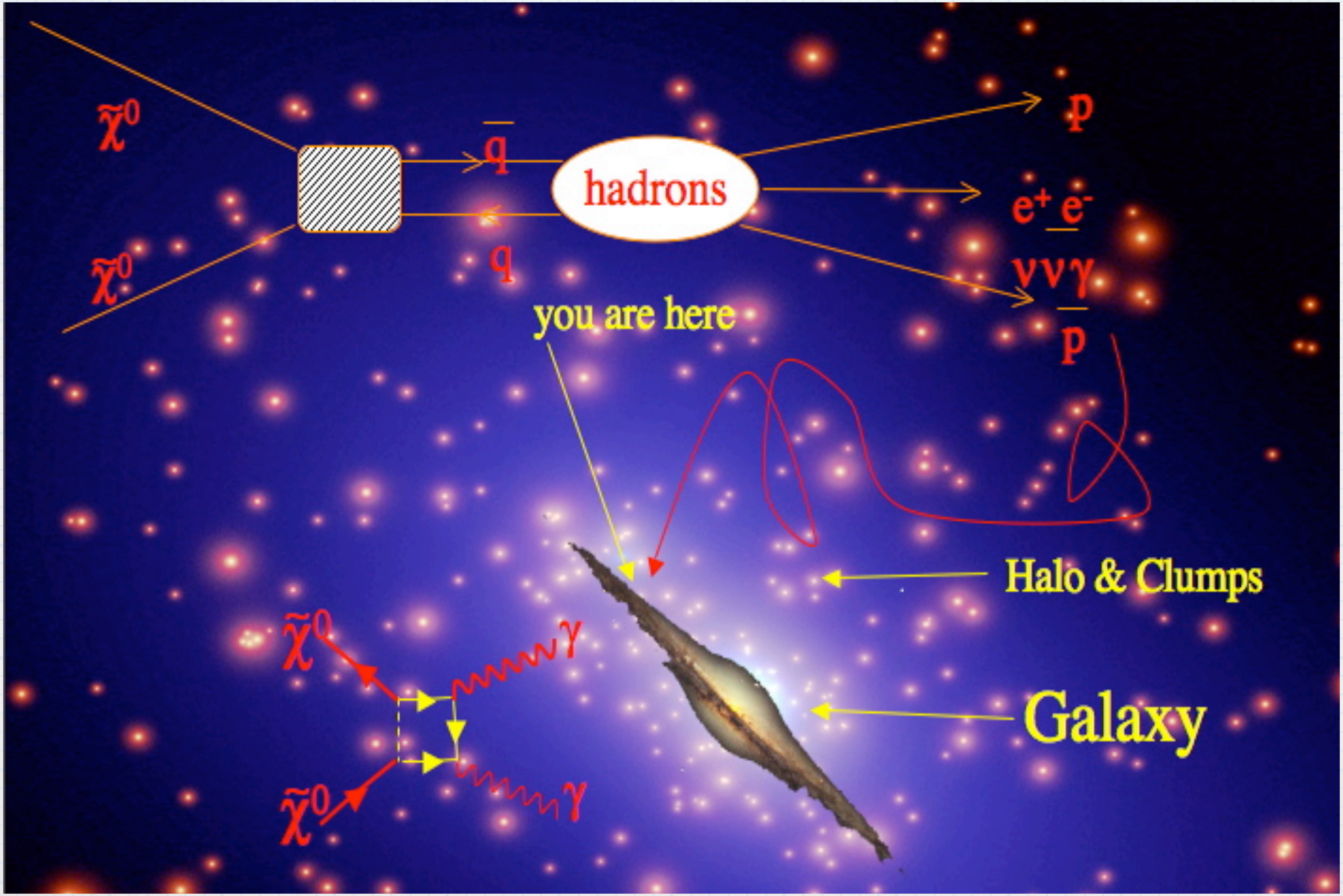
Cosmic-ray exp. may detect it, too!!

anni/decay → $e^{\pm}, \bar{p}, \gamma, \ldots$

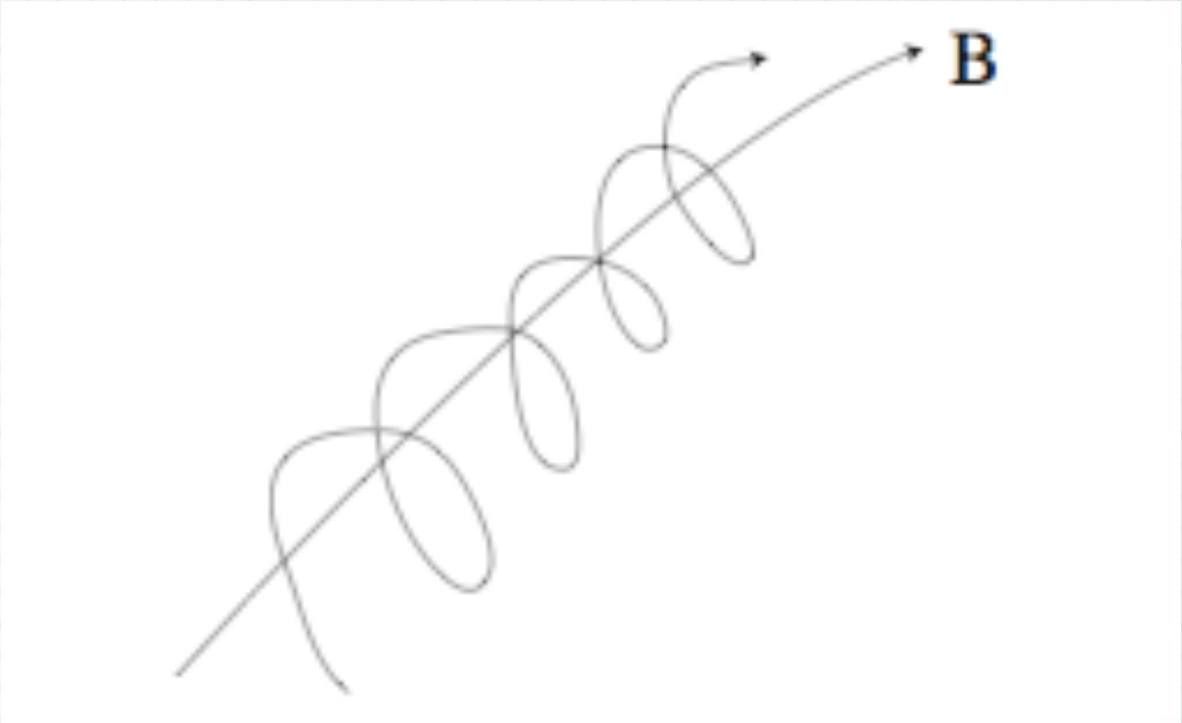
PAMELA, PPB-BETS, ATIC, HESS, FERMI

Cosmic-rays from Dark Matter (annihilation, decay)

DM (+ DM) --> hadrons, leptons --> photon, electron, positron, antiproton,...



Cosmic-rays



* photon propagate straightly

* charged particles are affected by galactic magnetic field

$$\frac{\partial \Phi}{\partial t} = \triangledown \cdot [K(r,E) \triangledown \Phi] + \frac{\partial}{E}[b(E)\Phi] + q(r,E)$$

* high energy positrons/electrons loss energy quickly

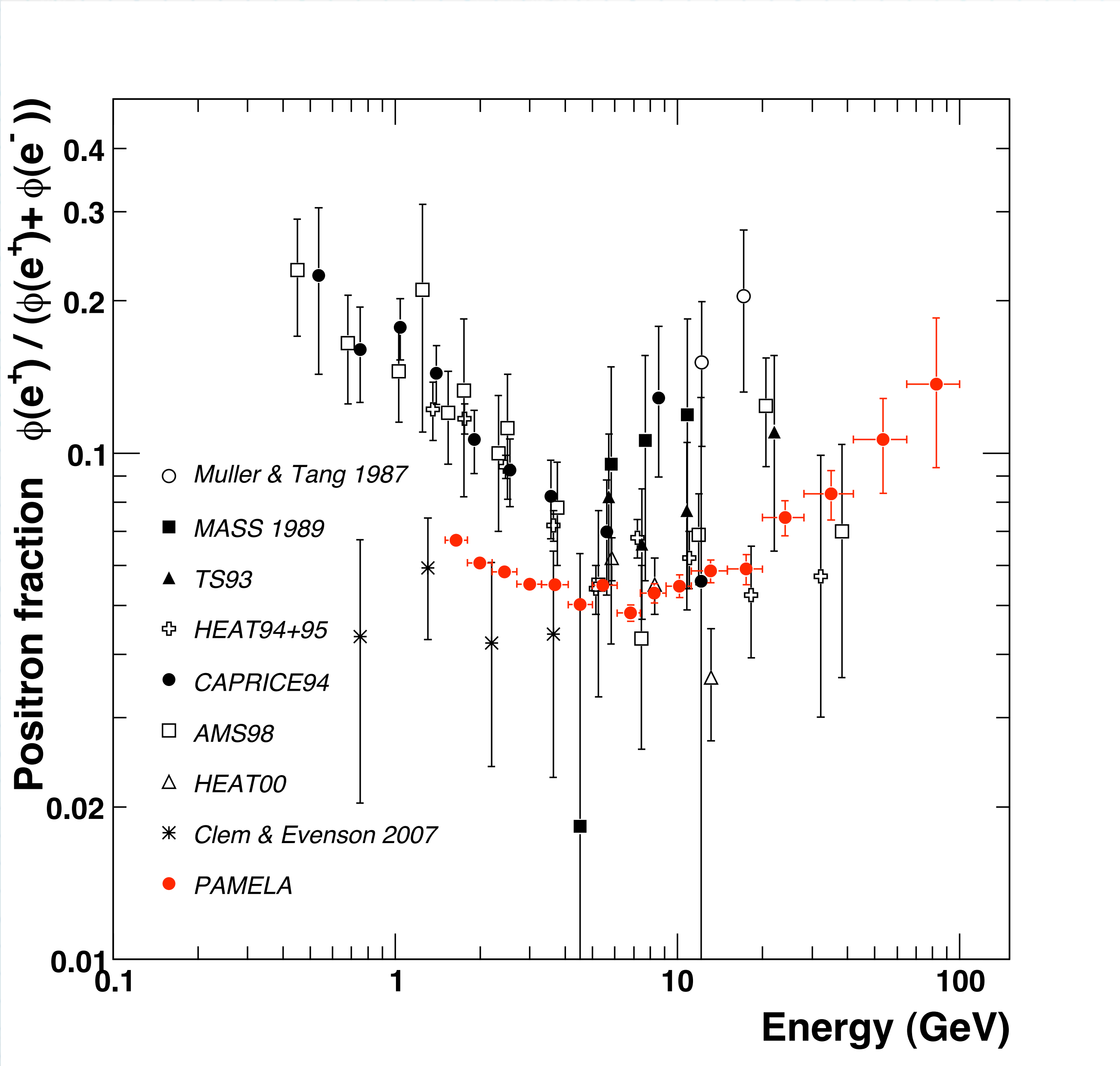
* measuring background precisely is important, i.e. primary and secondary cosmic-ray from astrophysical sources.

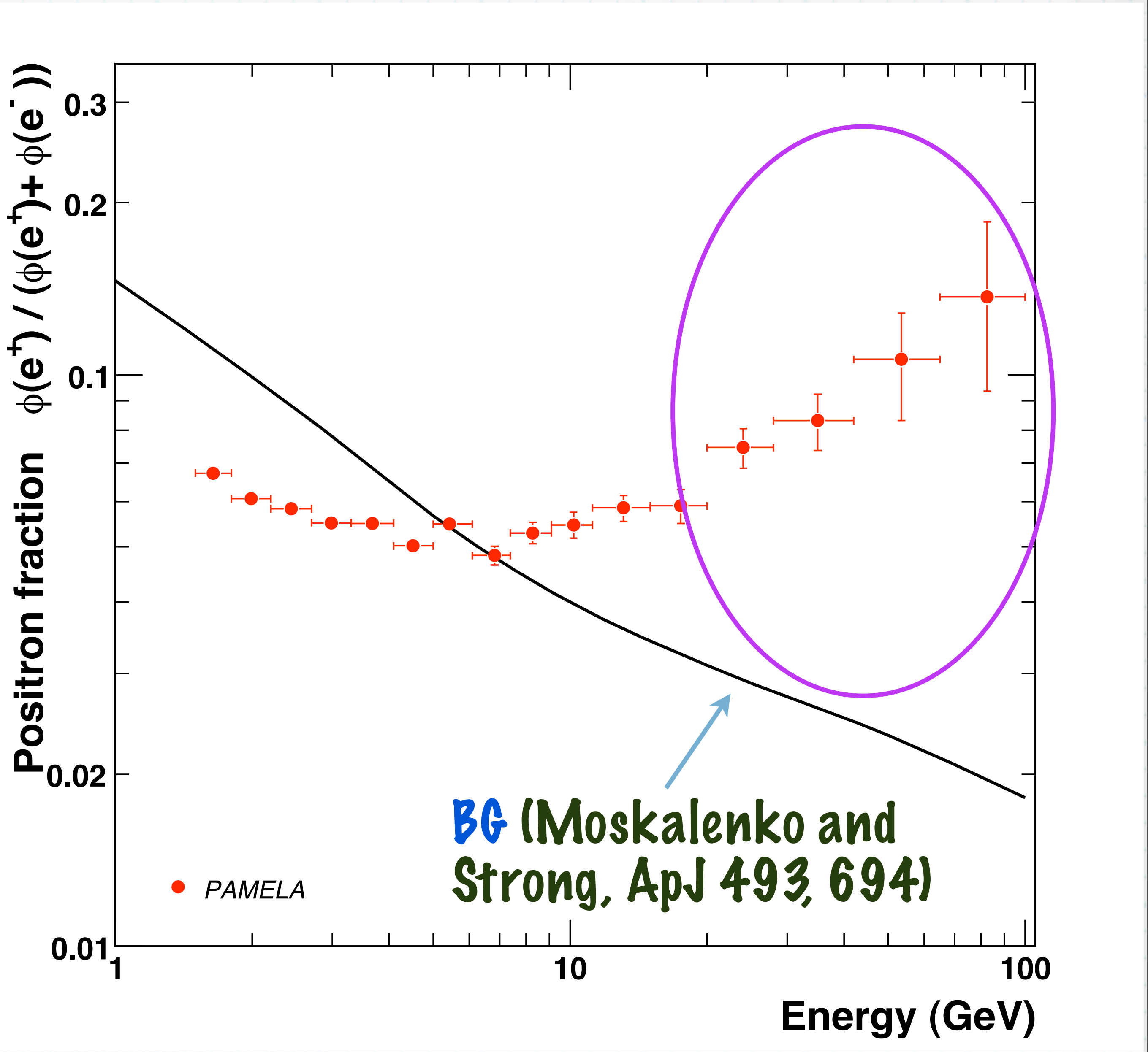
* However, the uncertainty is still big.

PAMELA

O. Adriani et al, 0810.4995

positron fraction





data taken from
06/2006 - 02/2008

turn up from ~ 10 GeV

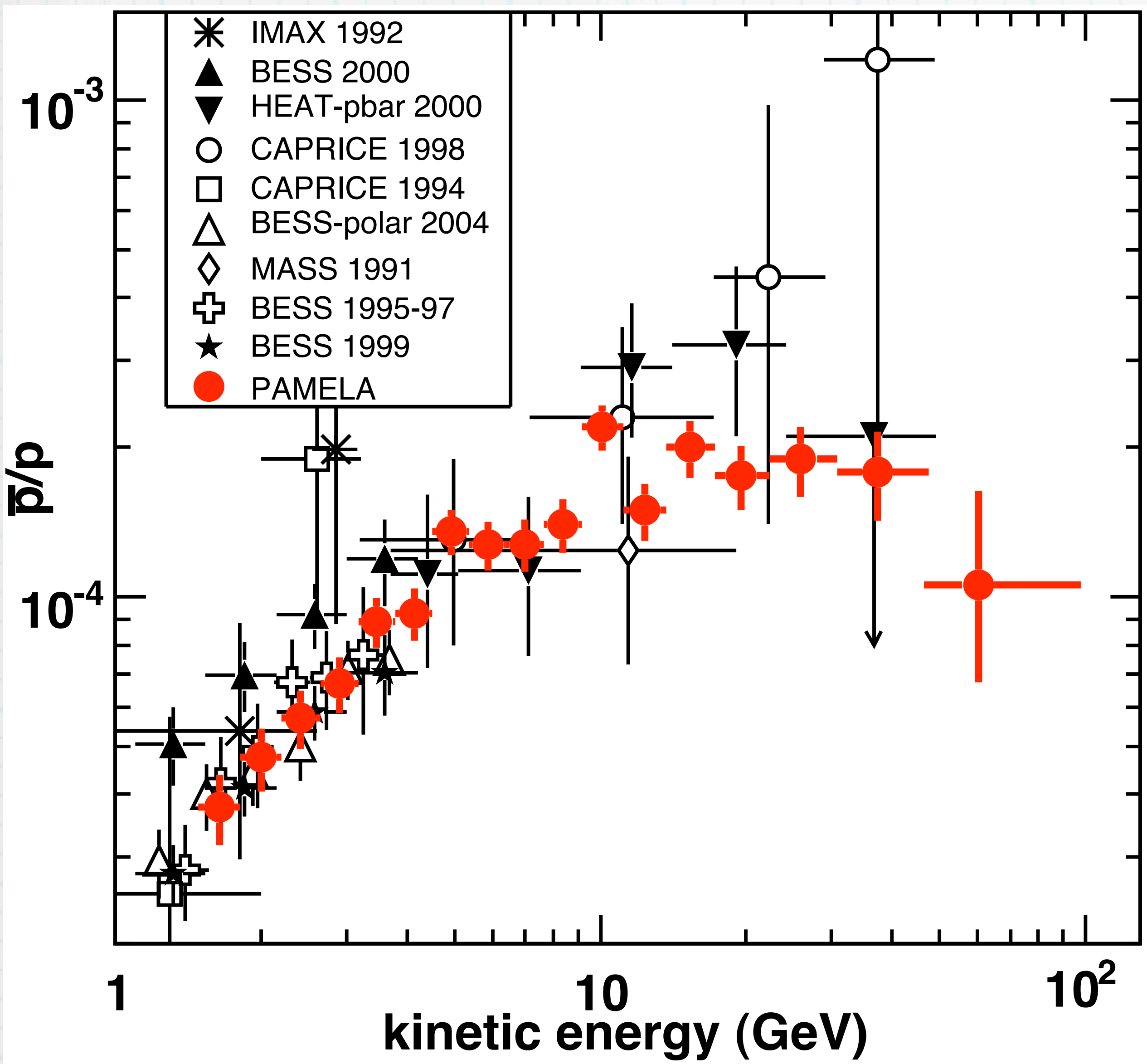
151672 electrons
9430 positrons
in 1.5 GeV - 100 GeV

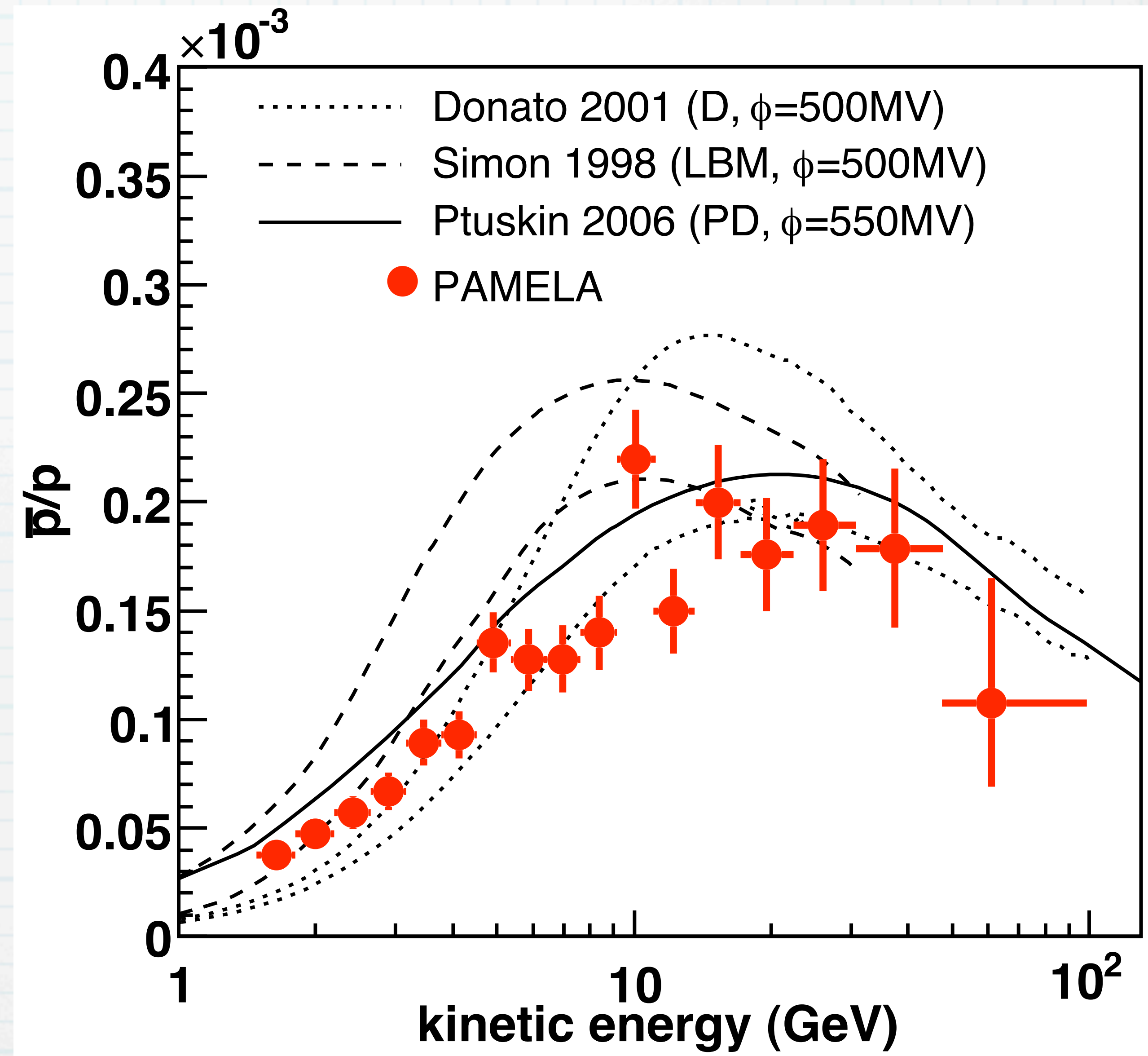
dark matter ??
astrophysics source ??

PAMELA

O. Adriani et al, 0810.4994

antiproton ratio





consistent with the prediction of secondary production

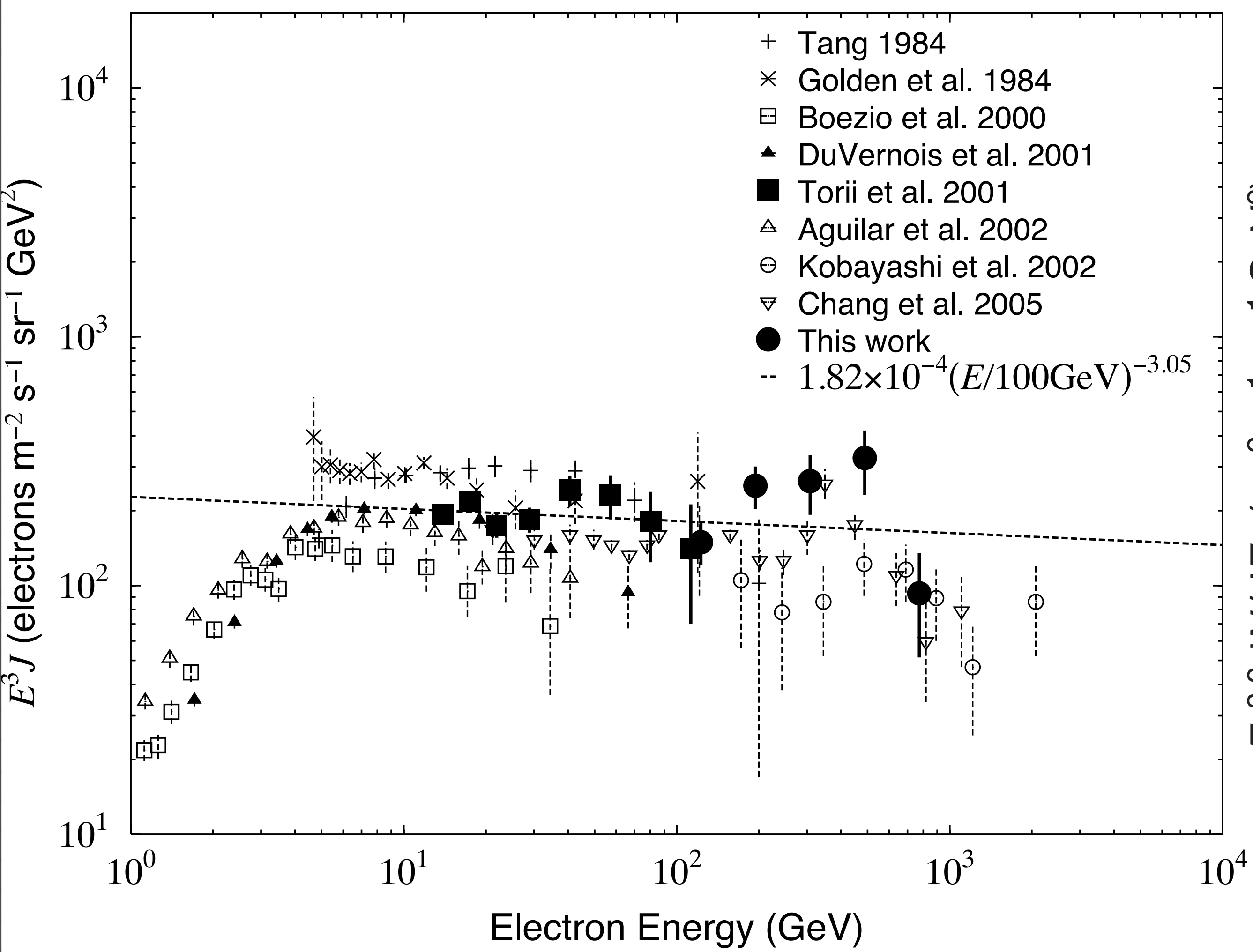
→ **NO primary source or is very suppressed!**

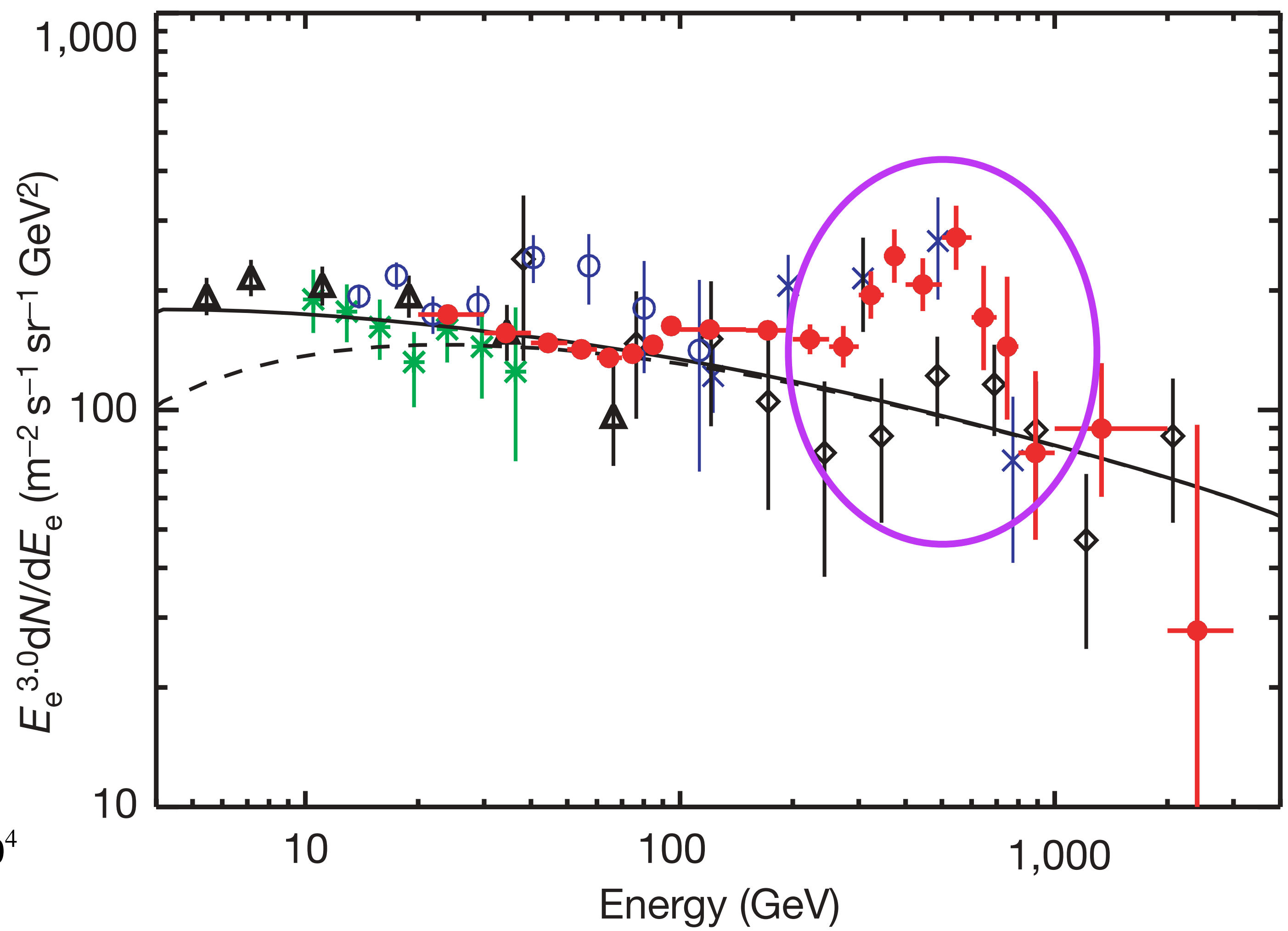
ATIC/PPB-BET

S. Torii et al, 0809.0760

electron + positron

J. Chang et al, Nature 456, 362





balloon experiments, in Antarctic

84 events >100 GeV from PPB-BETS

210 events, 300 ~ 800 GeV, ATIC

agree with each other
sharp drop-off at ~ 600 GeV

Primary source?

What We have learned from these data

There exist primary sources of electrons and positrons, however, the antiproton flux is suppressed.

If Dark Matter is responsible for the cosmic-ray data

↓

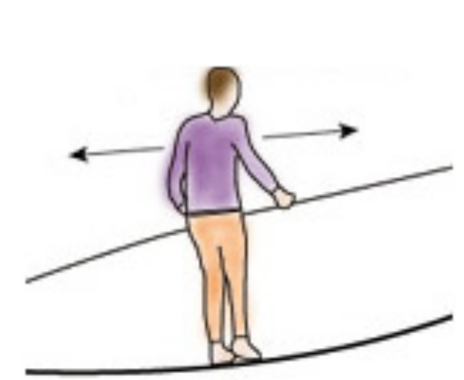
Dark Matters prefer to anni/decay to charged lepton!!

It is interesting to see how Dark Matter can explain the data!

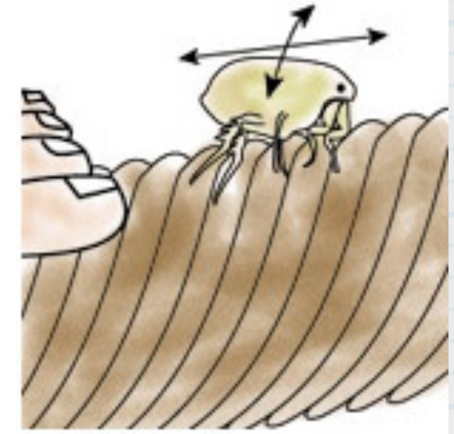
Model

Universal Extra Dimensions (UED)

T. Appelquist, H-C Cheng, B. A. Dobrescu , hep-ph/0012100



An acrobat can only move in one dimension along a rope..



...but a flea can move in two dimensions.

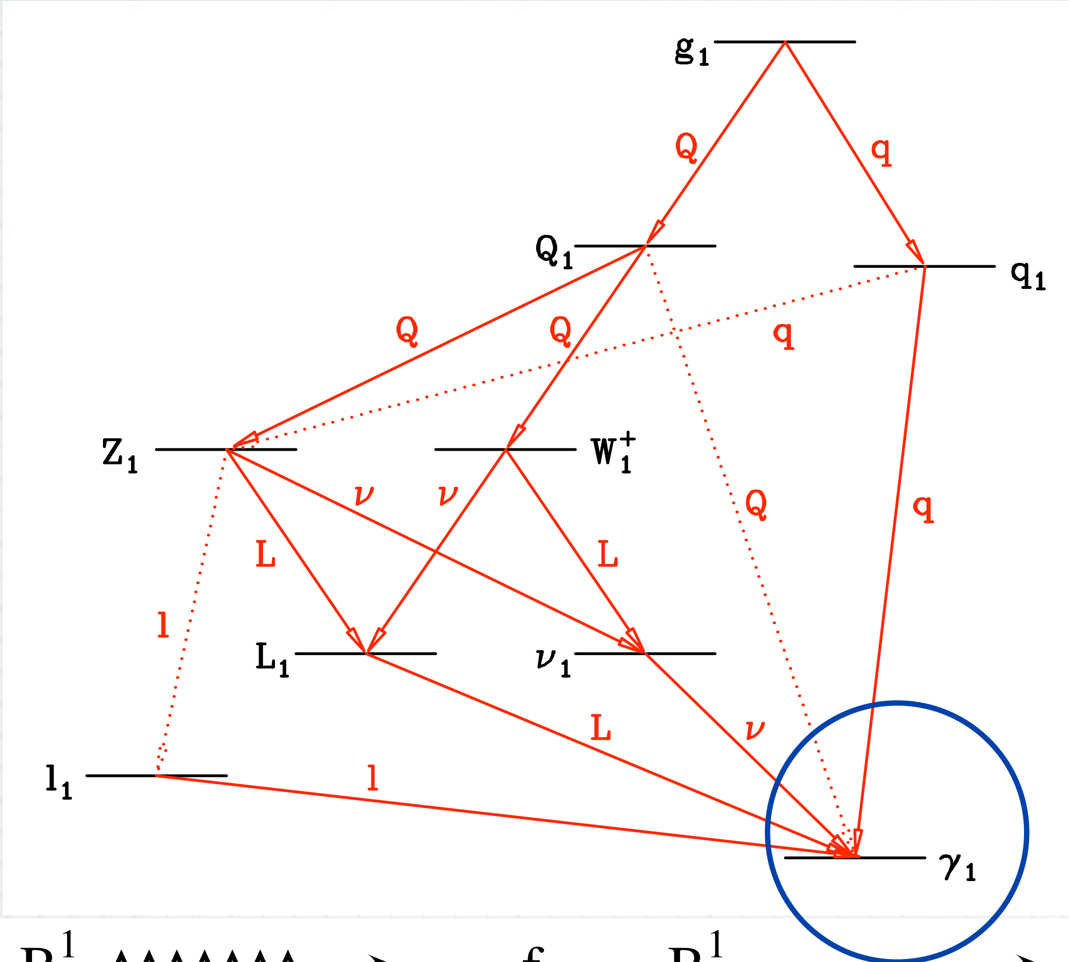
$$
\begin{aligned}
\mathcal{L}(x^\mu) \; = \; & \int \mathrm{d}^D y \Big\{ -\sum_{i=1}^{3} \frac{1}{2\hat{g}_i^2} \mathrm{Tr}\Big[F_i^{AB}(x^\mu, y^a) F_{iAB}(x^\mu, y^a)\Big] + \\
& + |(D_\mu + D_{3+a}) H(x^\mu, y^a)|^2 + \mu^2 H^*(x^\mu, y^a) H(x^\mu, y^a) - \lambda \big[H^*(x^\mu, y^a) H(x^\mu, y^a)\big]^2 + \\
& + i \left(\overline{Q}, \overline{u}, \overline{d}, \overline{L}, \overline{e}\right)(x^\mu, y^a) \left(\Gamma^\mu D_\mu + \Gamma^{3+a} D_{3+a}\right) (Q, u, d, L, e)(x^\mu, y^a) + \\
& \Big[\overline{Q}(x^\mu, y^a) \Big(\hat{\lambda}_u \; u(x^\mu, y^a) i\sigma_2 H^*(x^\mu, y^a) + \hat{\lambda}_d \; d(x^\mu, y^a) H(x^\mu, y^a)\Big) + \mathrm{H.c.}\Big] + \\
& \Big[\overline{L}(x^\mu, y^a) \hat{\lambda}_e \; e(x^\mu, y^a) H(x^\mu, y^a) + \mathrm{H.c.}\Big]. \qquad (3)
\end{aligned}
$$

$$
\psi(x^\mu, y) = \frac{1}{\sqrt{\pi R}} \left[\psi^{\mathrm{SM}}(x^\mu) + \sqrt{2} \sum_{n=1}^{\infty} P_L \; \psi_{L,n}(x^\mu) \cos\left(\frac{ny}{R}\right) + P_R \; \psi_{R,n}(x^\mu) \sin\left(\frac{ny}{R}\right)\right].
$$

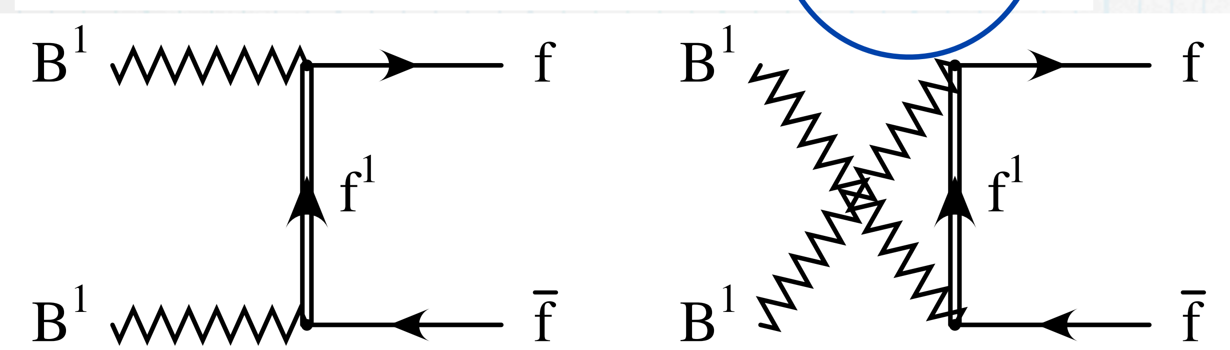
$$
m^2_{X^{(n)}} = \frac{n^2}{R^2} + m^2_{X^{(0)}} + \delta(m^2_{X^{(n)}})
$$

with exact KK-parity (a Z2 symmetry), the lightest KK-odd particle (LKP) is stable

→ **Dark Matter candidate**



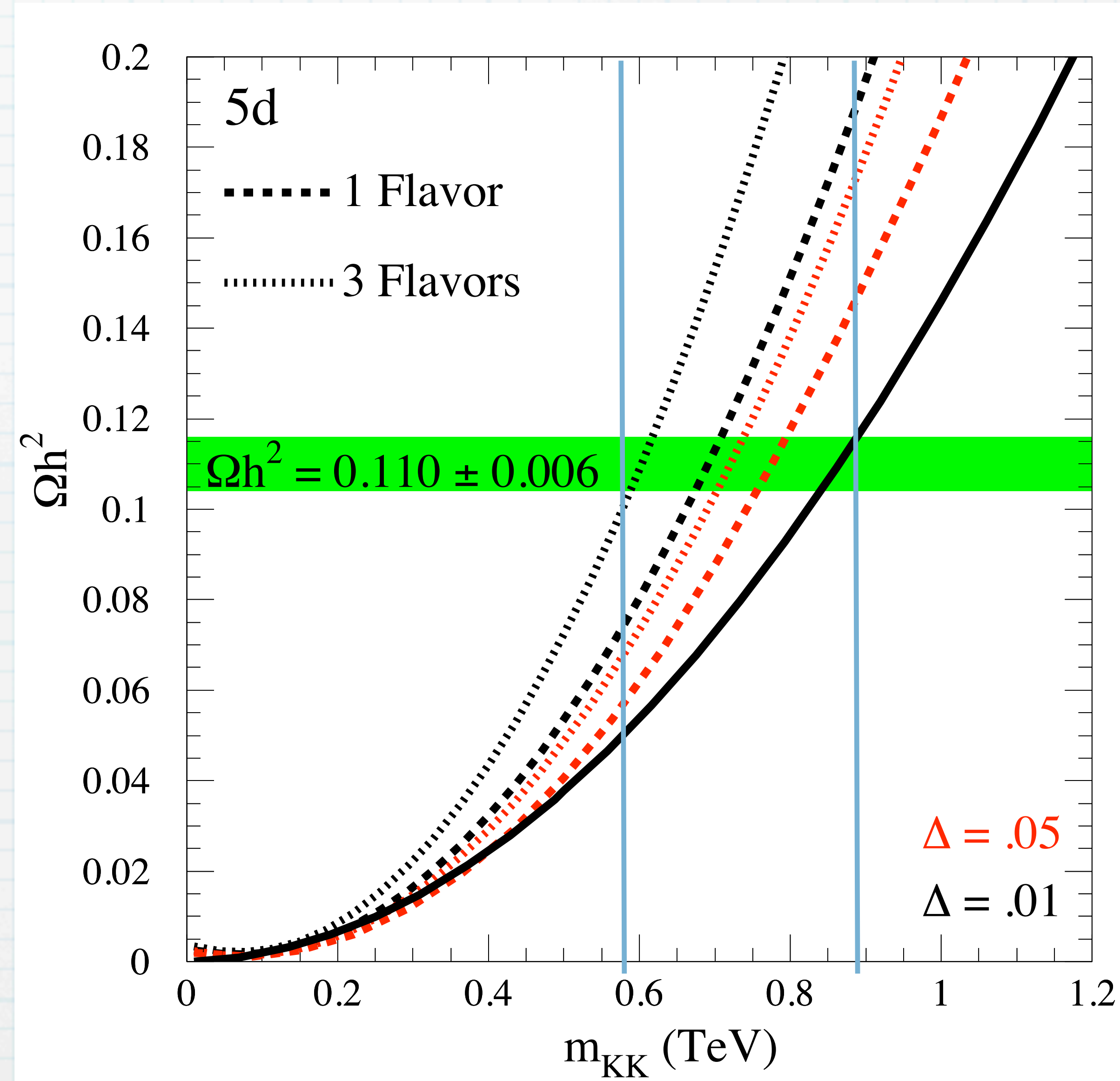
1st KK gamma is usually the LKP



$$< \sigma v > \propto \frac{C_f m_{\gamma_1}^2}{(m_{\gamma_1}^2 + m_{f_1}^2)^2}$$

$$C_f = N_c Y_f^4$$

$$m_{\gamma_1} = 600\, GeV \sim 900\, GeV$$

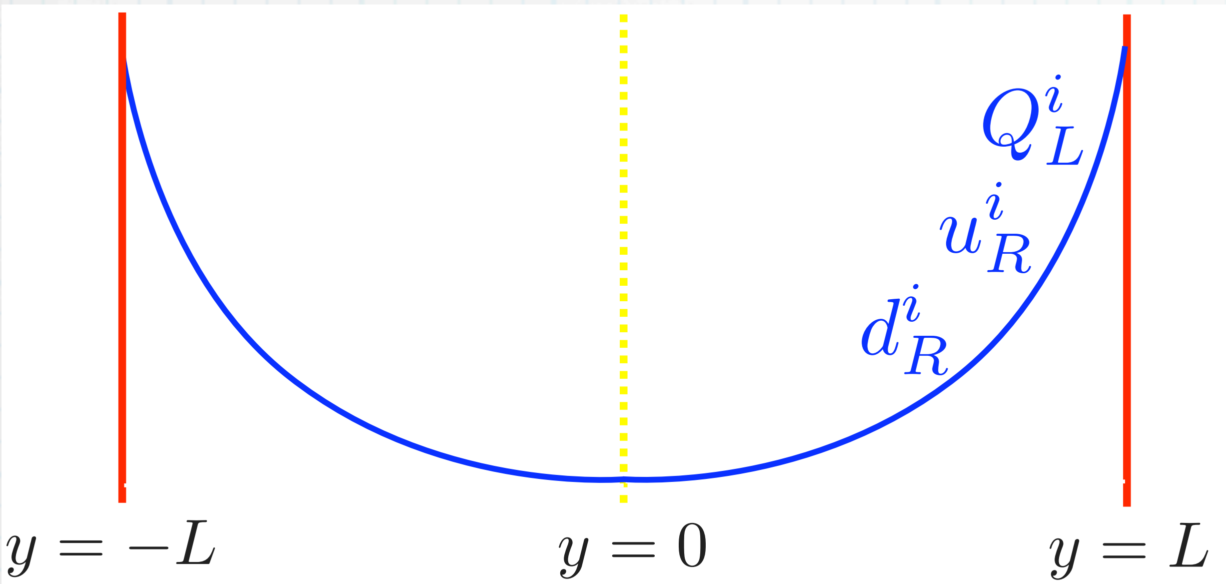


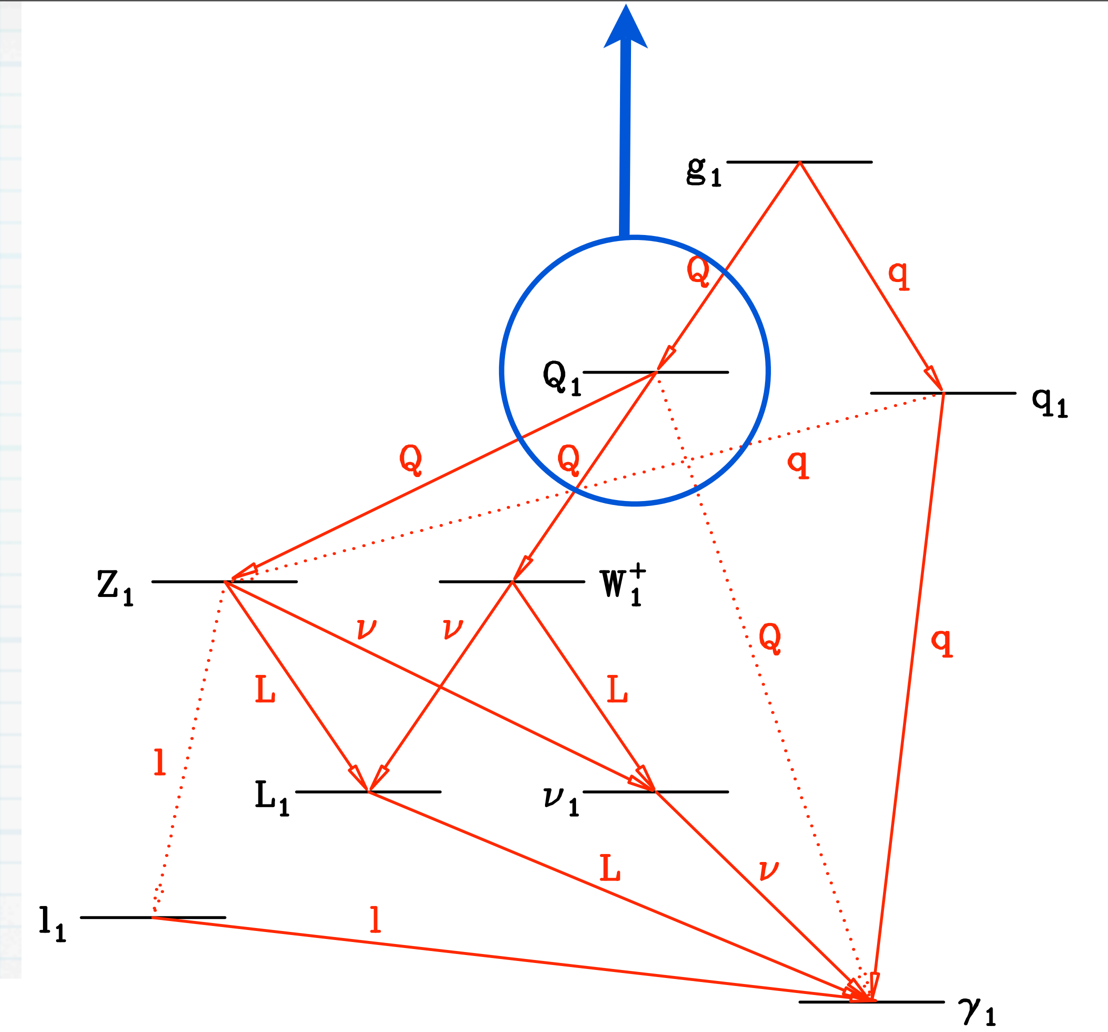
G. Servant and T. Tait, hep-ph/0206071

enhance m_{q_1} will decrease $< \sigma v >_{\gamma_1 \gamma_1 \to qq}$

split-UED

SC. Park and J. Shu, 0901.0720





$$S = \int d^5x\left(\frac{i}{2}(\bar{\Psi}\Gamma^M\partial_M\Psi - \partial_M\bar{\Psi}\Gamma^M\Psi) - \lambda\Phi(y)\bar{\Psi}\Psi\right)$$

$$\lambda < \Phi(y) > = \mu\epsilon(y) \qquad \Phi(-y) = -\Phi(y)$$

$$\Psi_+(x,y) = \sum_{n^+,n^-} g_{n^+}(|y|)\chi_{n^+}(x) + \epsilon(y)g_{n^-}(|y|)\chi_{n^-}(x),$$

$$\Psi_-(x,y) = \sum_{n^+,n^-} \epsilon(y)f_{n^+}(|y|)\psi_{n^+}(x) + f_{n^-}(|y|)\psi_{n^-}(x),$$

$$m_n = \sqrt{\mu^2 + k_n^2}$$

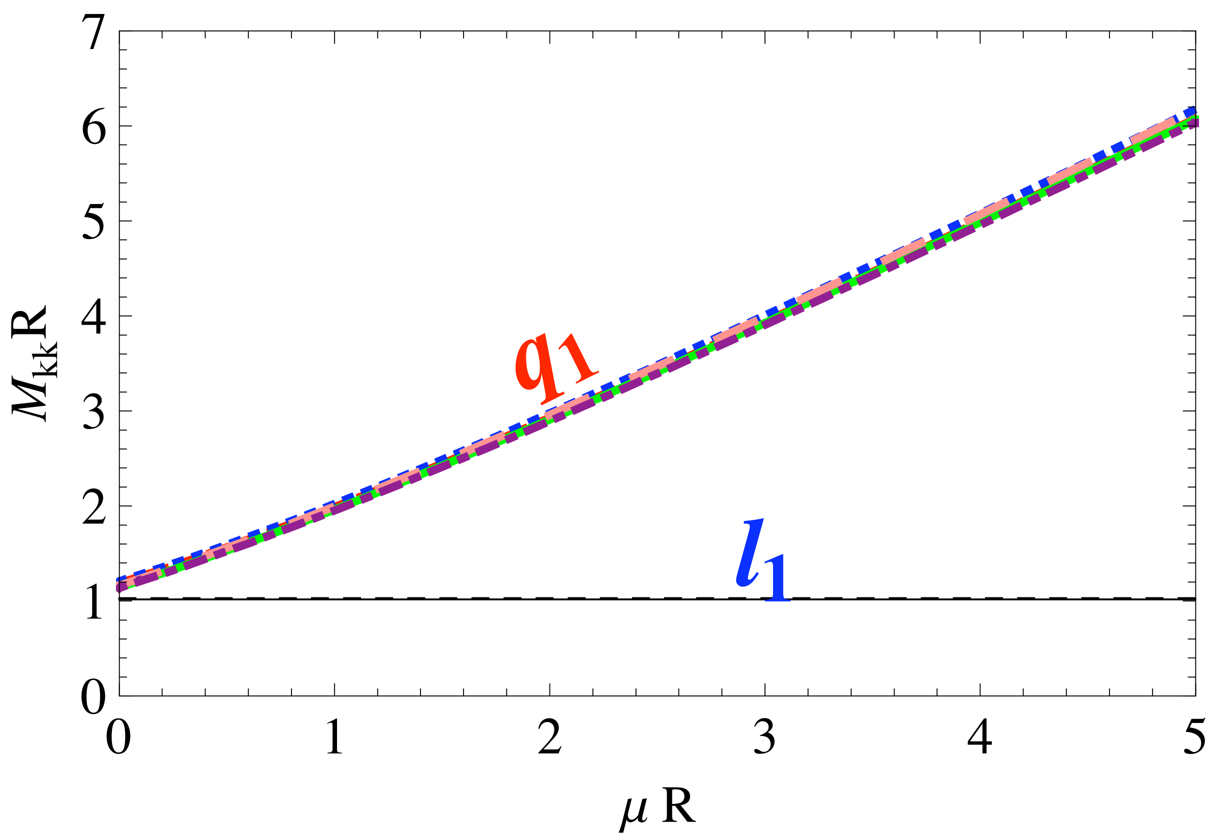
quarks interact with a scalar background

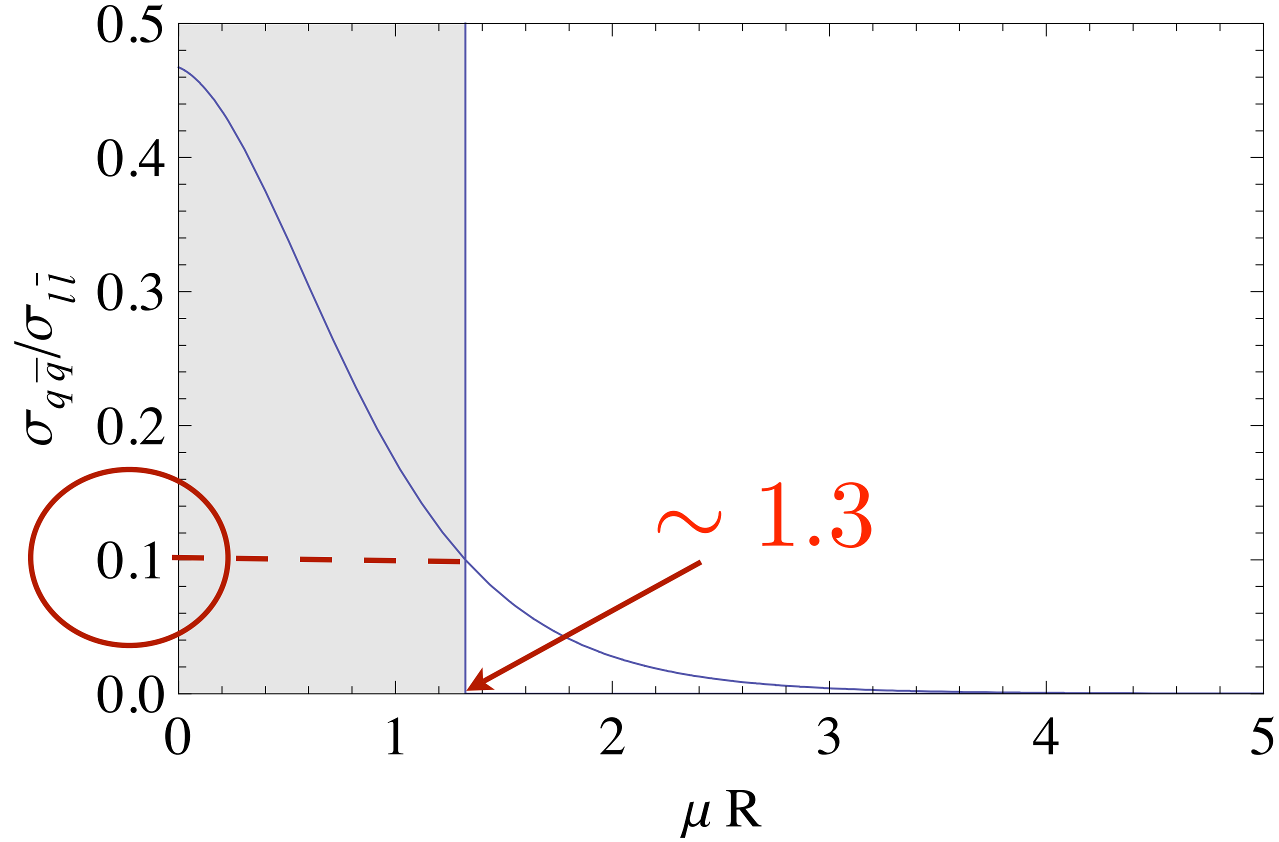
KK quarks receive additional bulk mass

split KK quark from other particles

$\mu \longrightarrow \infty$ KK quark decoupled $\qquad \mu \longrightarrow 0$ mUED limit

CRC, M. M. Nojiri, SC. Park, J. Shu and M. Takeuchi 0901.0720





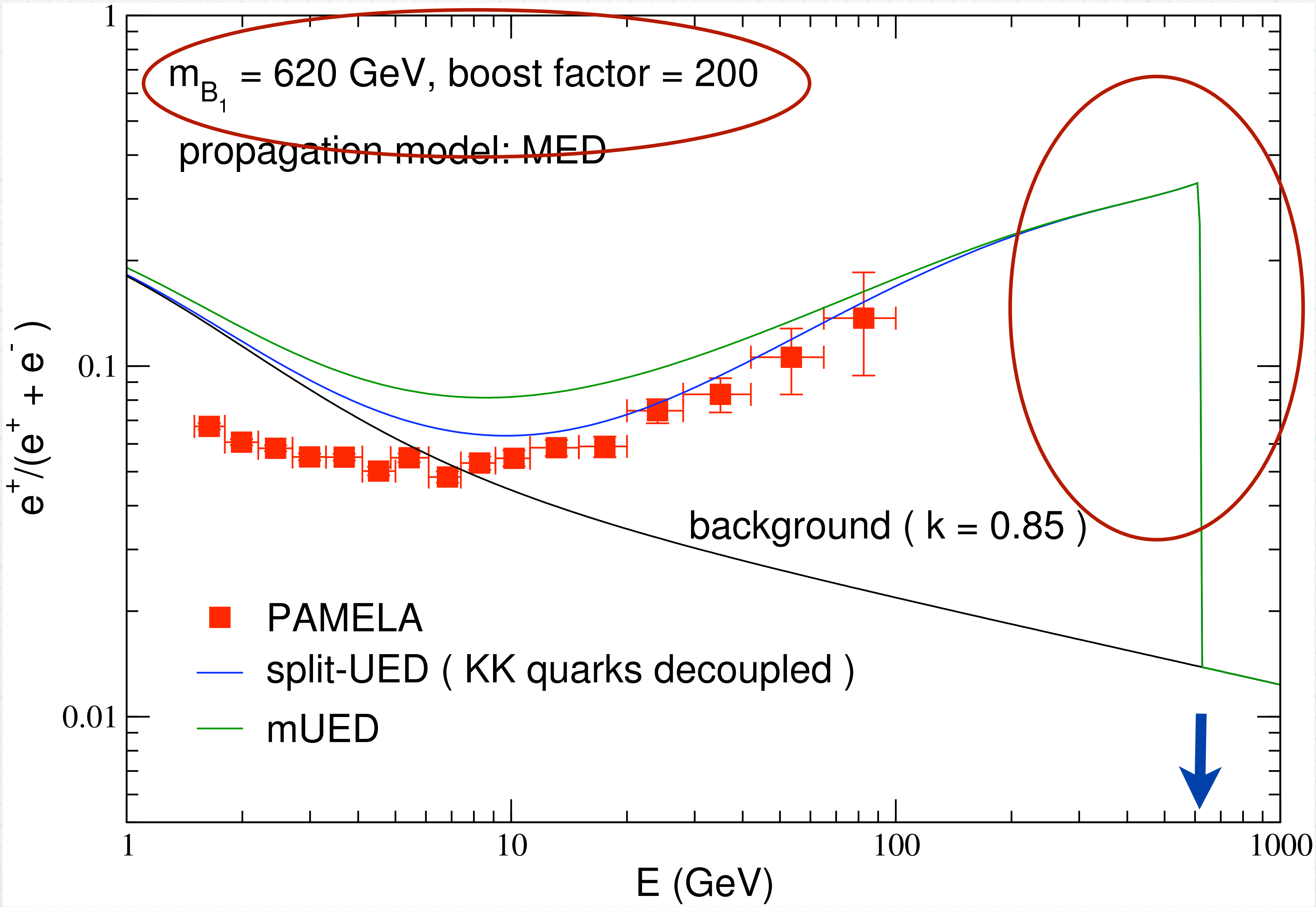
μ (GeV)	0	200	400	600	800	1000
M_{q_1} (GeV)	713	863	1026	1198	1378	1566
$BR(B_1B_1 \to q\bar{q})$	29.4%	26.4%	20.6%	14.3%	8.9%	5.2%
$BR(B_1B_1 \to l\bar{l})$	64.3%	67.1%	72.3%	78.2%	83.0%	86.5%
$BR(B_1B_1 \to \nu\bar{\nu})$	3.8%	3.9%	4.3%	4.6 %	4.9%	5.1%
$BR(B_1B_1 \to \phi\phi^*)$	2.3%	2.4%	2.6%	2.8%	3.0%	3.1%

$$\frac{1}{R} = 620GeV$$

Cosmic-ray

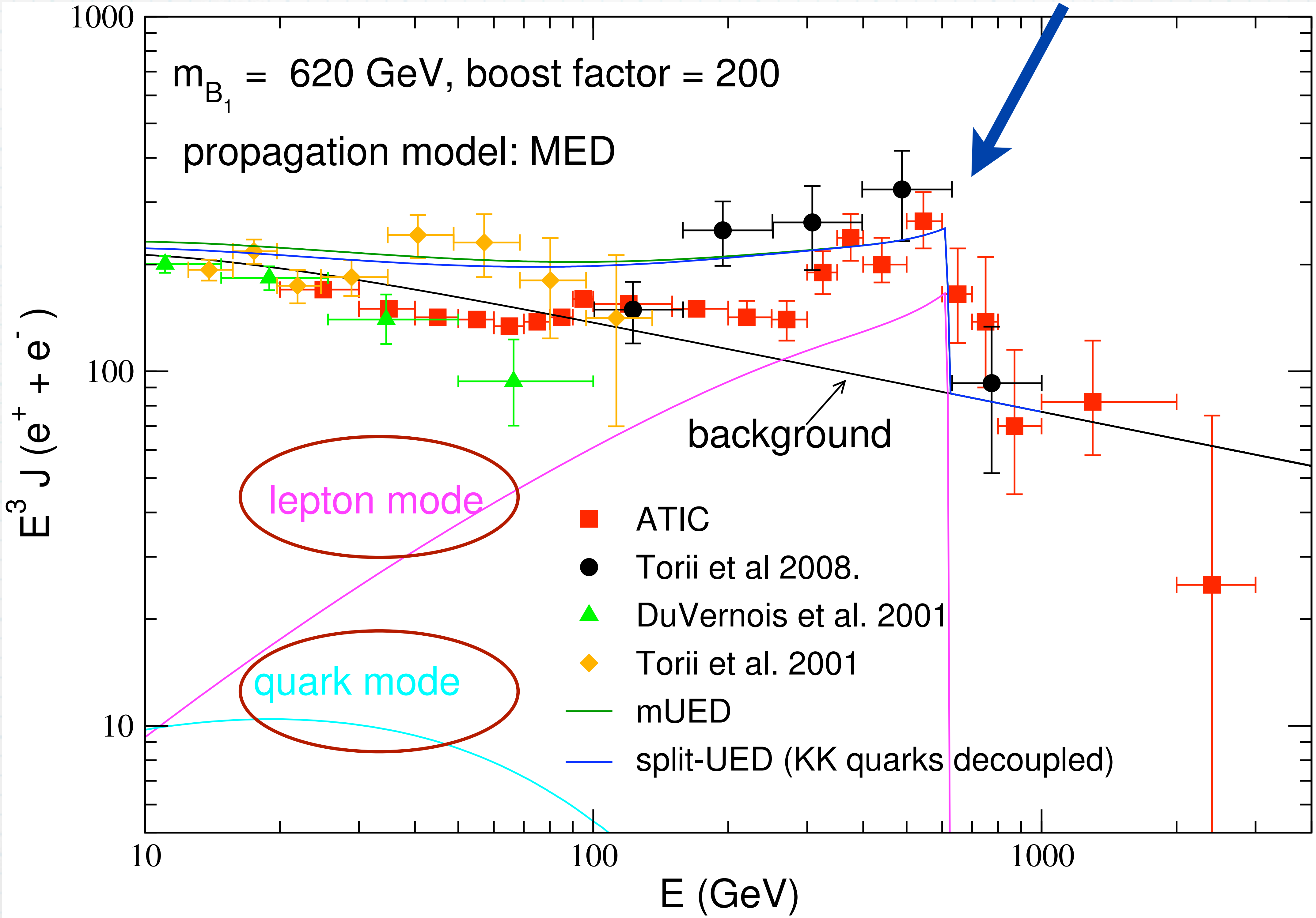
PAMELA (positron fraction)

sharp drop-off
@ E = m

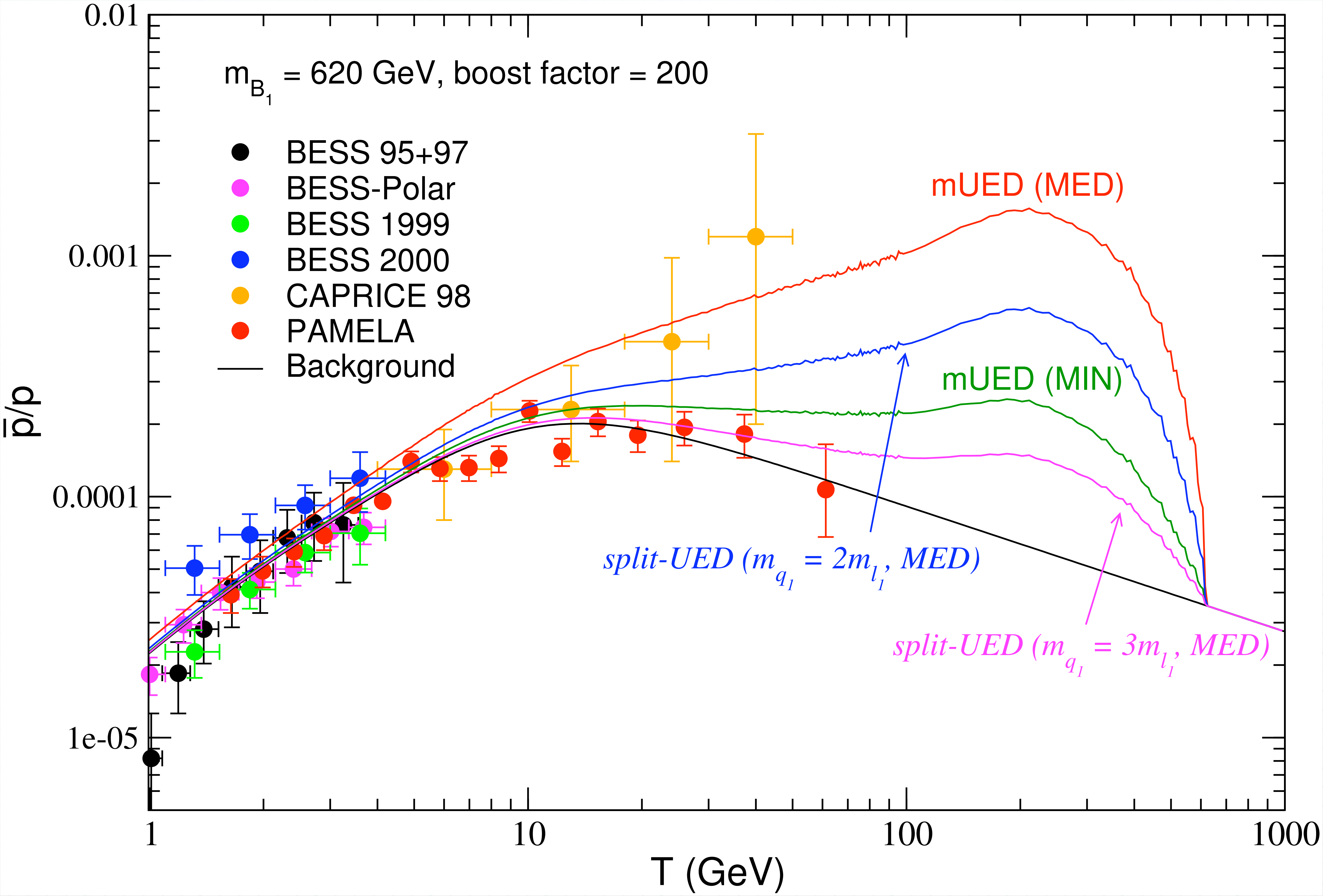


ATIC/PPB-BETS (total flux of e- and e+)

sharp drop-off
@ E = m

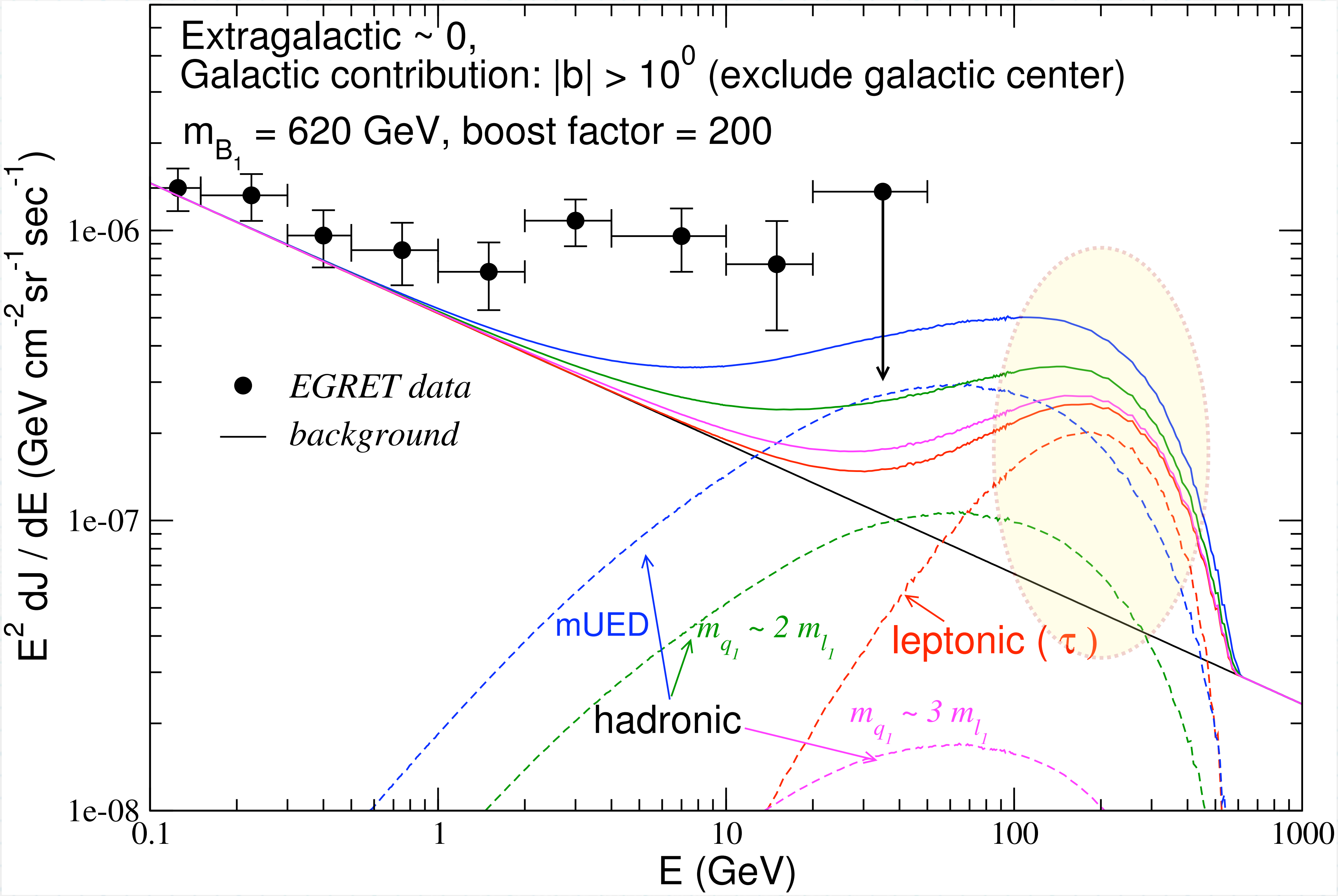


PAMELA (antiproton to proton ratio)



split-UED agree with observations well

upcoming data from FERMI (gamma)



predict a bump @ E $\approx 200\, GeV$

upcoming Fermi data can check this!

Collider

LHC: p p collider

↓

colored particles can be produced copiously

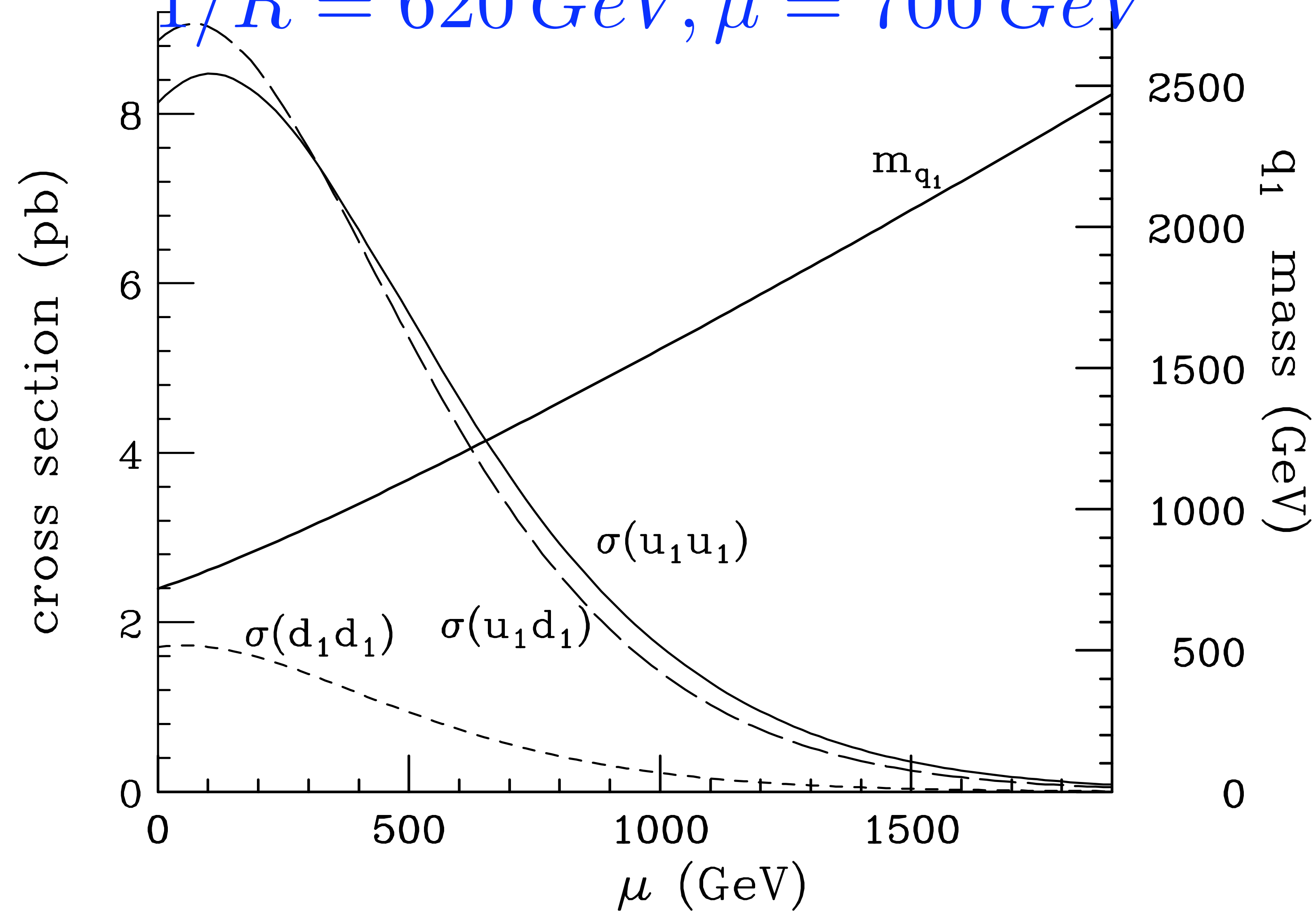
$\sigma \approx 8pb$

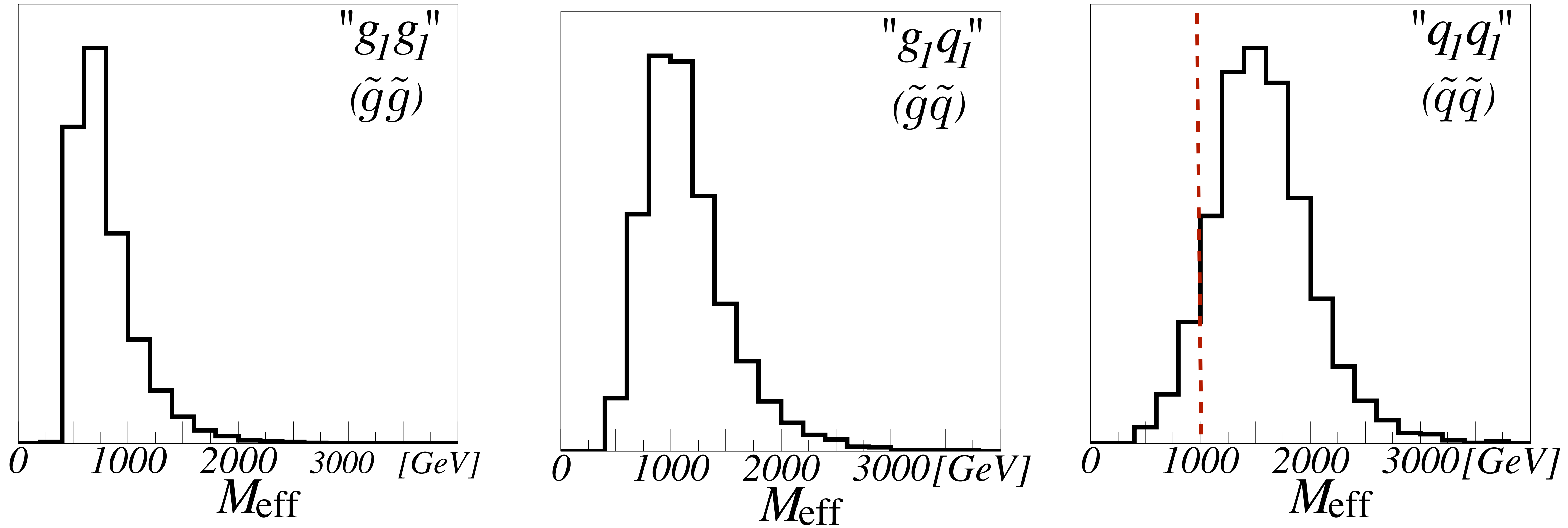
$q_1 \rightarrow g_1 q \rightarrow B_1 g q$

4 jets with missing ET

split-UED	mass	SUSY	mass
q_{L1}	1347 GeV	$\tilde{u}_L$,$\tilde{d}_L$	1355, 1358 GeV
u_{R1}	1322 GeV	$\tilde{u}_R$	1304 GeV
d_{R1}	1318 GeV	$\tilde{d}_R$	1263 GeV
g_1	794 GeV	$\tilde{g}$	799 GeV
B_1	621 GeV	$\tilde{\chi}_1^0$	622 GeV

$1/R = 620\,GeV, \mu = 700\,GeV$





$$M_{\rm eff} > 500 \text{ GeV}, \;\; E_{\rm Tmiss} > \max(100 \text{ GeV}, 0.2 M_{\rm eff}), \;\; n_{100} \geq 1, \;\; n_{50} \geq 4,$$

	after standard cut	$M_{\rm eff} > 1$ TeV	$M_{\rm eff} > 1.5$ TeV
$q_1 q_1$	0.40	0.37	0.21
$q_1 g_1$	0.30	0.18	0.049
$g_1 g_1$	0.18	0.04	0.007

with $1\, fb^{-1}$, our signal 2800 >> SM BG (< 300)

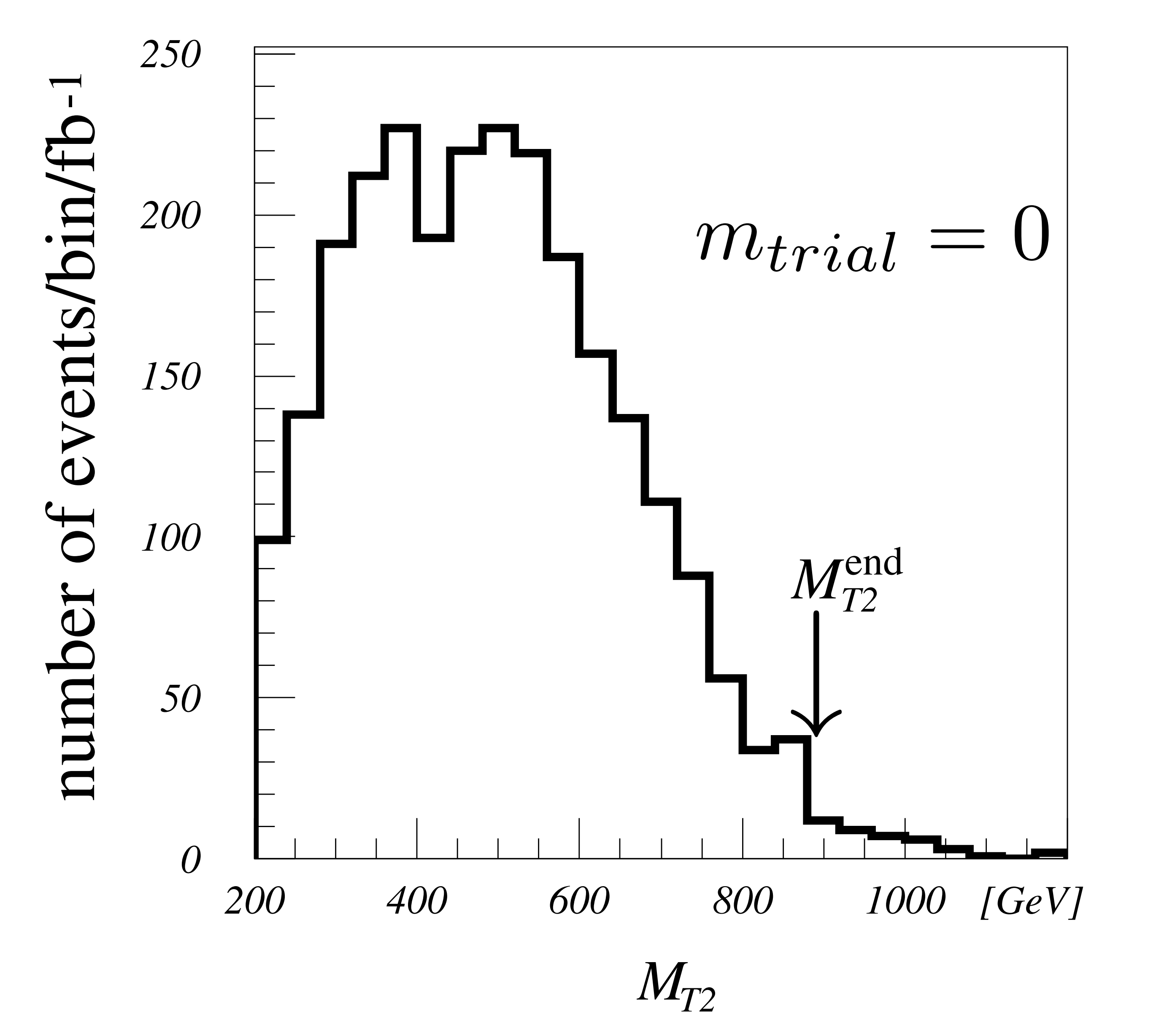
using MT2 to study the mass determination (signal with missing ET)

$$pp \to AA \to BBXX$$ missing

$$(pp \to q_1 q_1 \to qqg_1 g_1)$$

C. Lester and D. Summers, hep-ph/9906349
A. Barr, C. Lester and P. Stephens, hep-ph/0304226

$$M_{T2} = \min_{p_{T\text{miss}} = q_{T1} + q_{T2}} \left[\max\{M_T(q_{T1}, p_{j_1}, m_{\text{trial}}), M_T(q_{T2}, p_{j_2}, m_{\text{trial}})\}\right],$$



$$M_{T_2}^{end} = M_A - \frac{M_X^2}{M_A}$$

$$M_{T_2}^{end} \sim 1320 - \frac{800^2}{1320} \sim 835$$

Summary

Updated cosmic-ray data of electrons/positrons show the excesses while antiproton flux is consistent with BG

Dark Matter may be responsible for these data

LKP in UED models is a good candidate, splitting kk quarks can satisfy the constraints from antiproton data

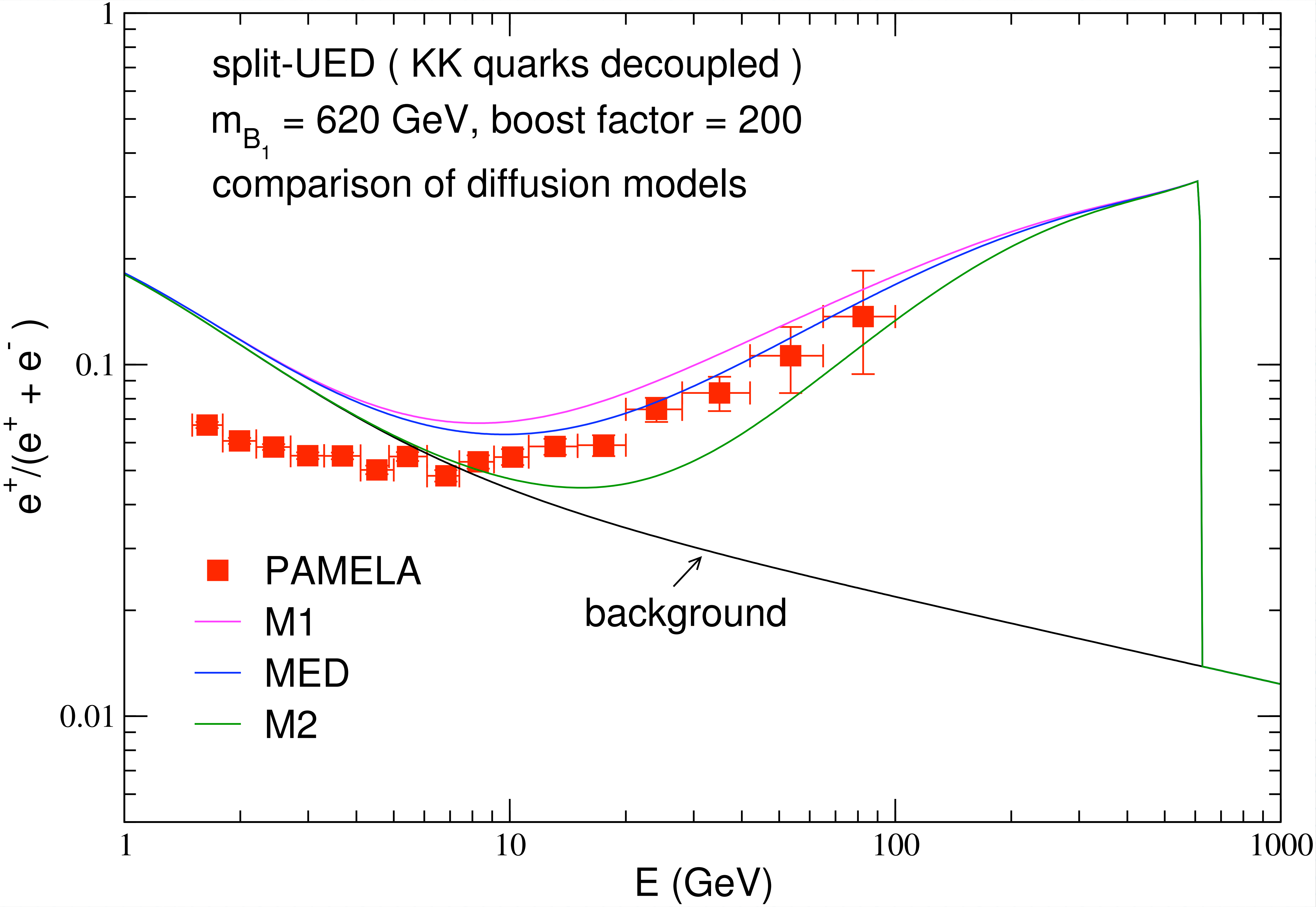
LHC pheno of split-UED is different from mUED

DOUBLE CHECK

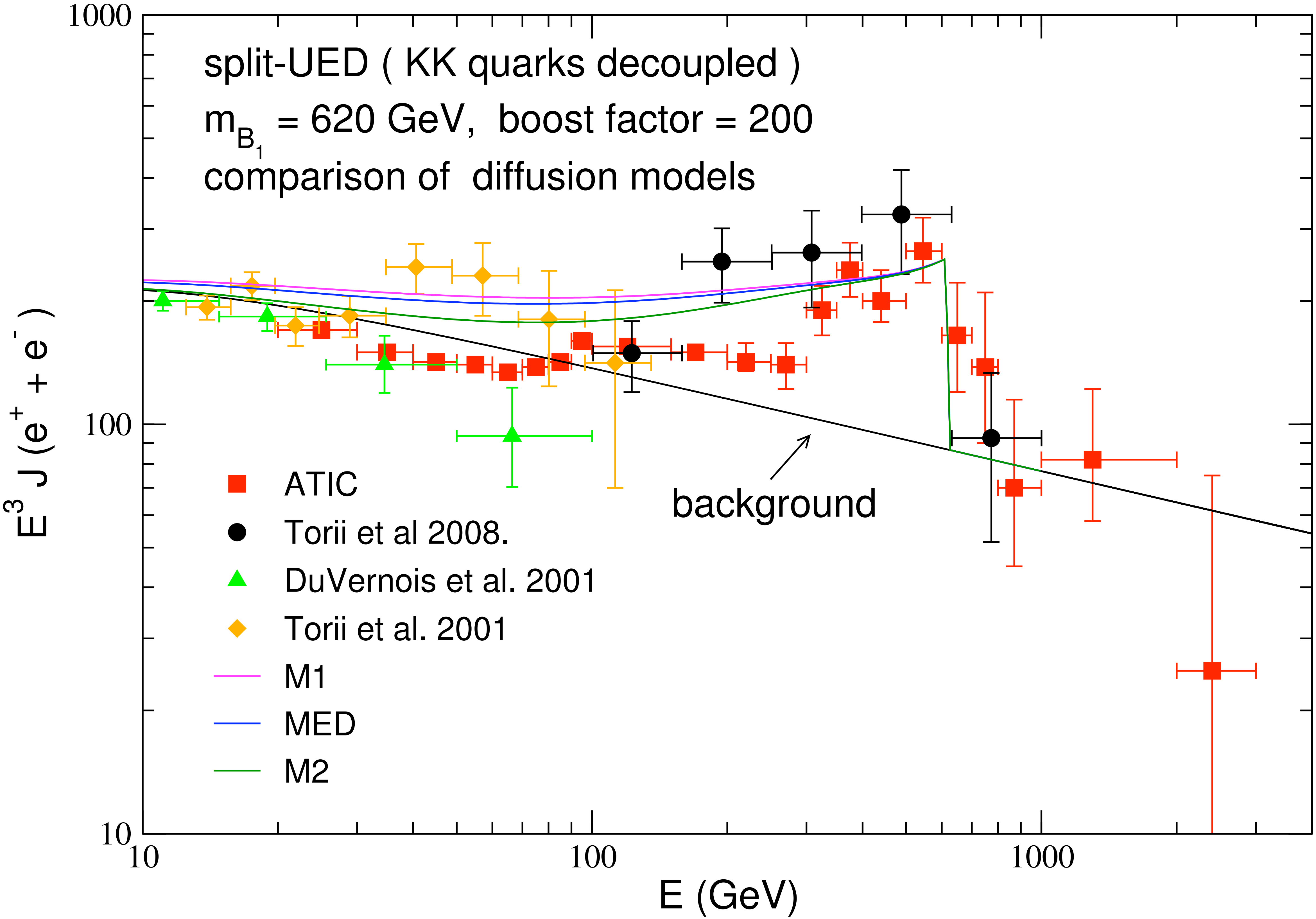
LHC (mass, spin of DM), gamma-ray data, more data in higher energy

NOTE:

astrophysical source can explain as well, e.g. Pulsars

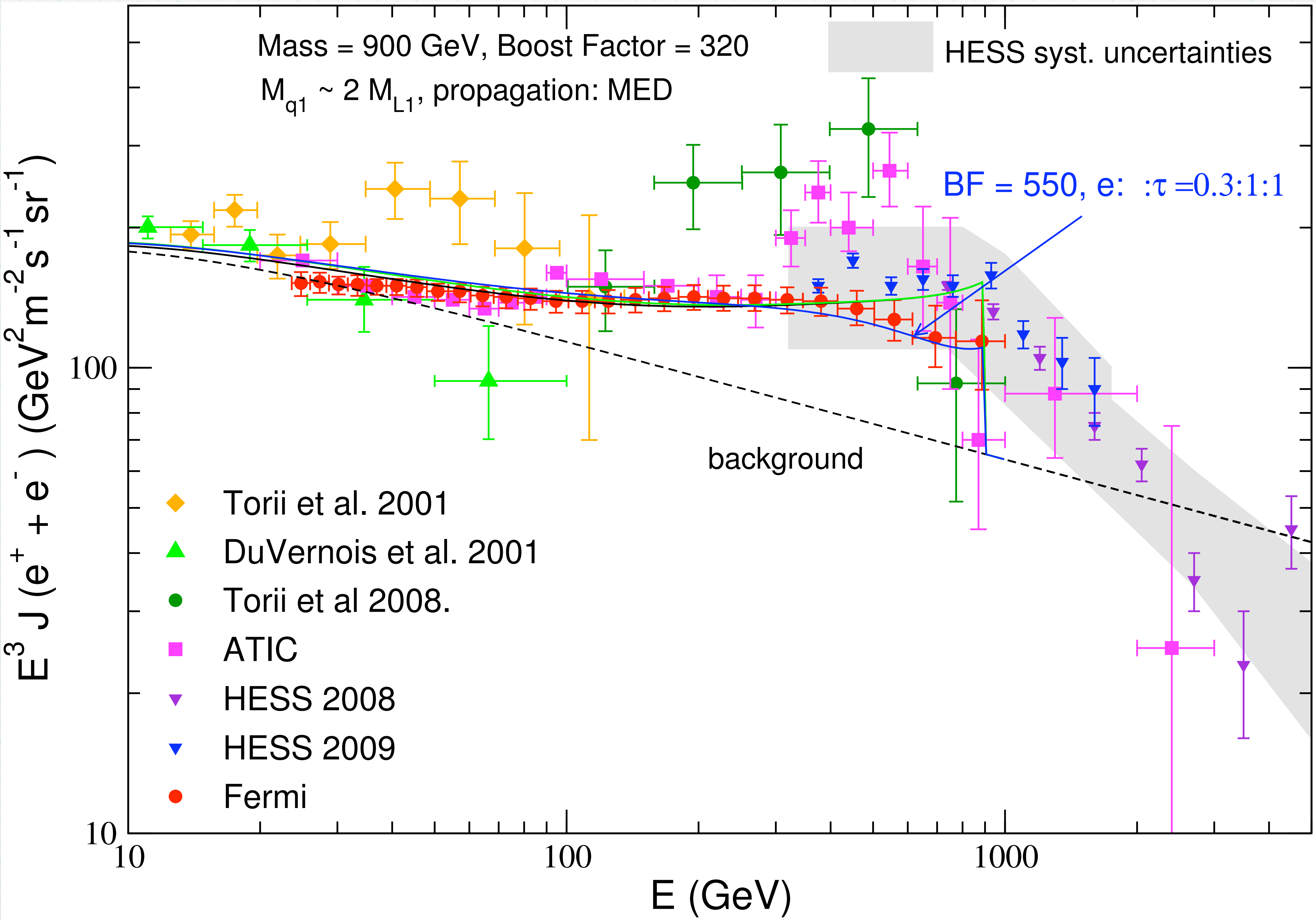


split-UED (KK quarks decoupled)
m_{B_1} = 620 GeV, boost factor = 200
comparison of diffusion models
PAMELA
M1
MED
M2
background
$e^+/(e^+ + e^-)$
E (GeV)
1
0.1
0.01
1
10
100
1000

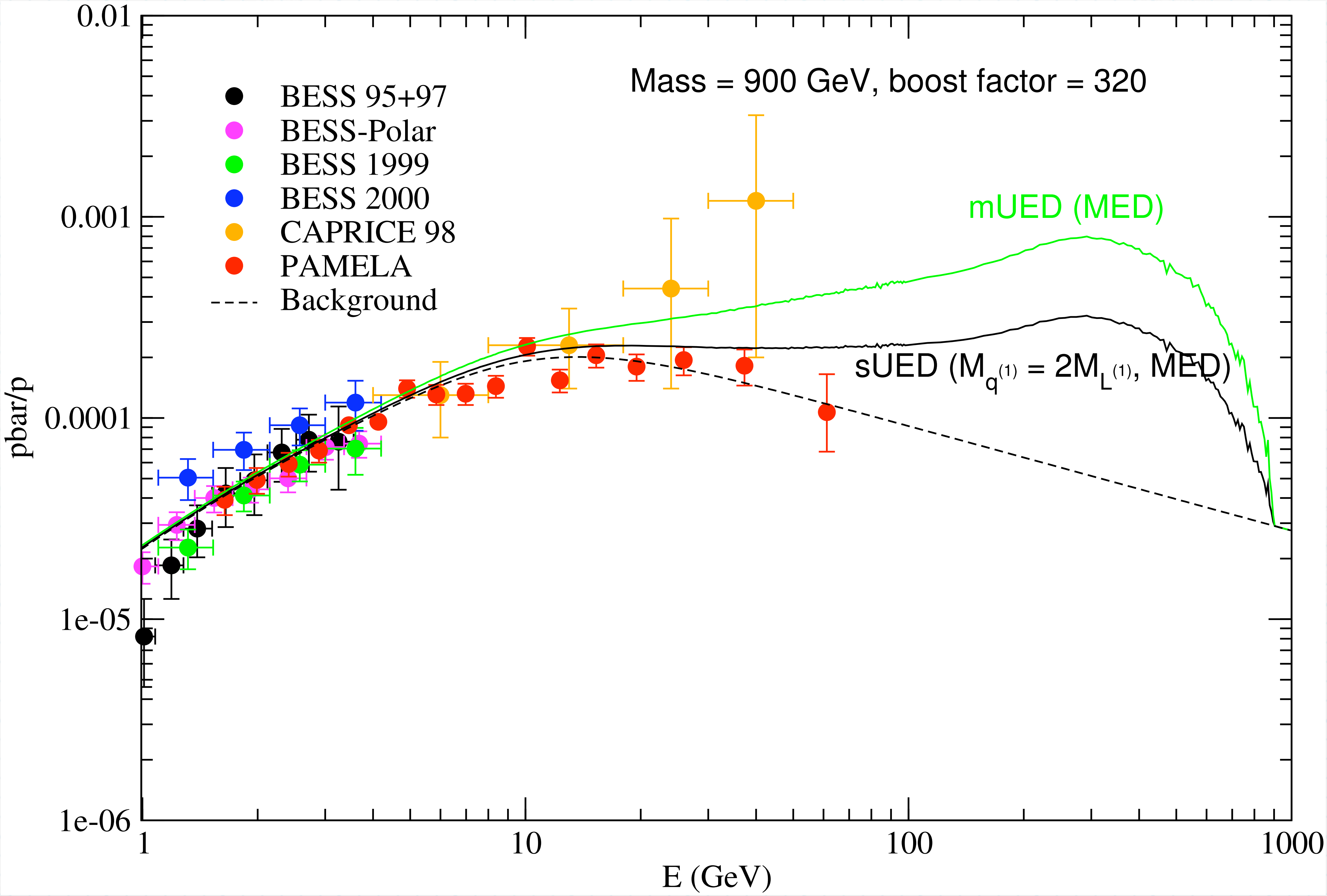


split-UED (KK quarks decoupled)
m_B1 = 620 GeV, boost factor = 200
comparison of diffusion models
background
ATIC
Torii et al 2008.
DuVernois et al. 2001
Torii et al. 2001
M1
MED
M2
E³ J (e⁺ + e⁻)
E (GeV)
1000
100
10
10
100
1000

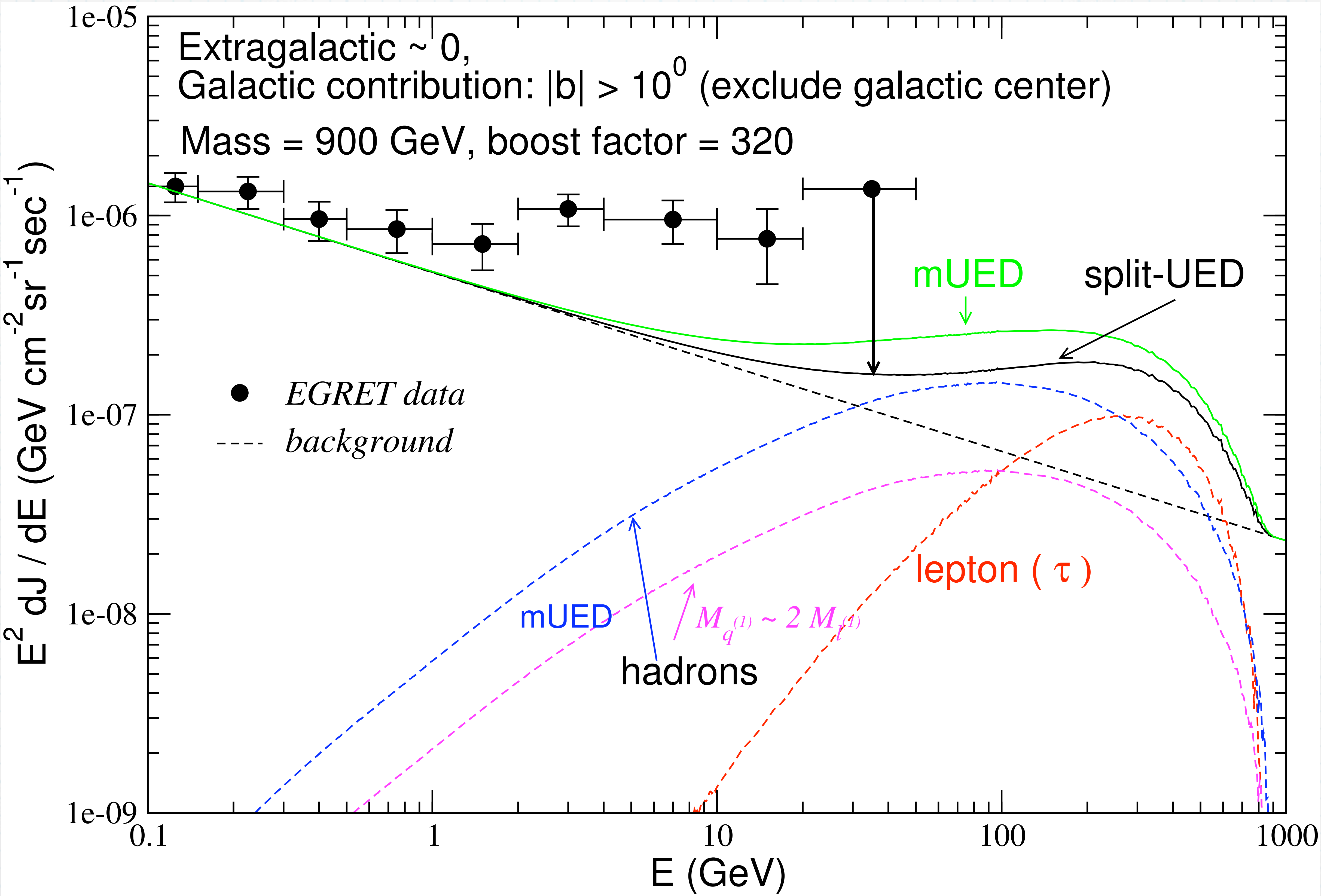
Fermi/HESS



Mass = 900 GeV, Boost Factor = 320
$M_{q1} \sim 2\, M_{L1}$, propagation: MED
HESS syst. uncertainties
BF = 550, e: :τ =0.3:1:1
background
Torii et al. 2001
DuVernois et al. 2001
Torii et al 2008.
ATIC
HESS 2008
HESS 2009
Fermi
$E^3\, J\, (e^+ + e^-)\ (GeV^2 m^{-2} s^{-1} sr^{-1})$
E (GeV)
10
100
1000



Mass = 900 GeV, boost factor = 320
BESS 95+97
BESS-Polar
BESS 1999
BESS 2000
CAPRICE 98
PAMELA
Background
mUED (MED)
sUED ($M_{q^{(1)}} = 2M_{L^{(1)}}$, MED)
pbar/p
E (GeV)
0.01
0.001
0.0001
1e-05
1e-06
1
10
100
1000


Extragalactic ~ 0,
Galactic contribution: |b| > 10^0 (exclude galactic center)
Mass = 900 GeV, boost factor = 320
EGRET data
background
mUED
split-UED
lepton (τ)
mUED
hadrons
$M_{q^{(1)}} \sim 2\, M_{\ell^{(1)}}$
E^2 dJ / dE (GeV cm^{-2}sr^{-1}sec^{-1})
E (GeV)
1e-05
1e-06
1e-07
1e-08
1e-09
0.1
1
10
100
1000