Kaluza-Klein Dark matter

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Focus week on indirect Dark matter search

Dec 09, 2009

— SCP, Shu, Phys. Rev. D 79, 091702(*Rapid*) (2009)

— Chen, Nojiri, SCP, Shu, Takeuchi, JHEP 0909.078 (2009)

— Chen, Nojiri, SCP, Shu, Takeuchi, [arXiv 0908.4317]

— Csaki, Heinonen, Hubsiz, SCP, Shu, in preparation

contents

- Dark matter problem in particle physics
- Kaluza-Klein Dark matter in UED & split-UED
- Fitting Pamela+Fermi excesses

Dark matter problem

- WMAP data implies : DM >> Baryon
- Chandra-X observation of bullet cluster: DM is made of matter (not MOND)
- No candidate in the SM

WIMP is a wonderful solution

- Consistent with the standard Big-Bang thermal history
- O(100) GeV, weakly interacting stable massive particle can nicely fit WMAP result.

[Lee-Weinberg, PRL 1977]

Stability of WIMP

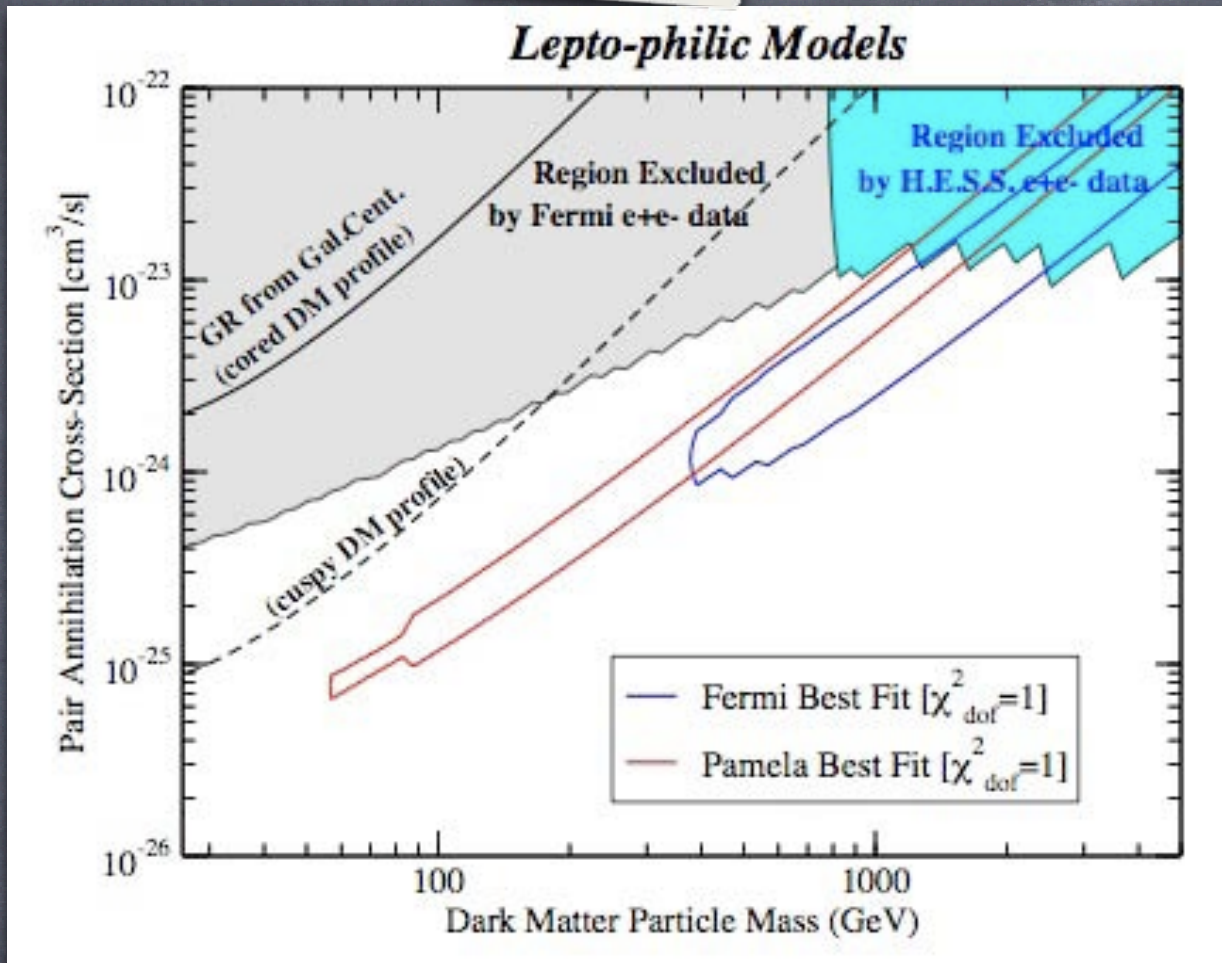
- Stability of a particle can be guaranteed by a symmetry
- The simplest choice is Parity (Z_2)
- Examples: R-parity in MSSM, T-parity in Little Higgs, KK-parity in extra dimension, possibly many more

Examples of WIMP candidates

- LSP in MSSM with R-parity (neutralino, s=1/2, Majorana particle)
- LTP in Little Higgs with T-parity (A_H, s=1, m<350 GeV)
- LKP in extra dimension with KK-parity (B_1, s=1, couples to hypercharge)
- possibly many more..

Info from recent CR-data

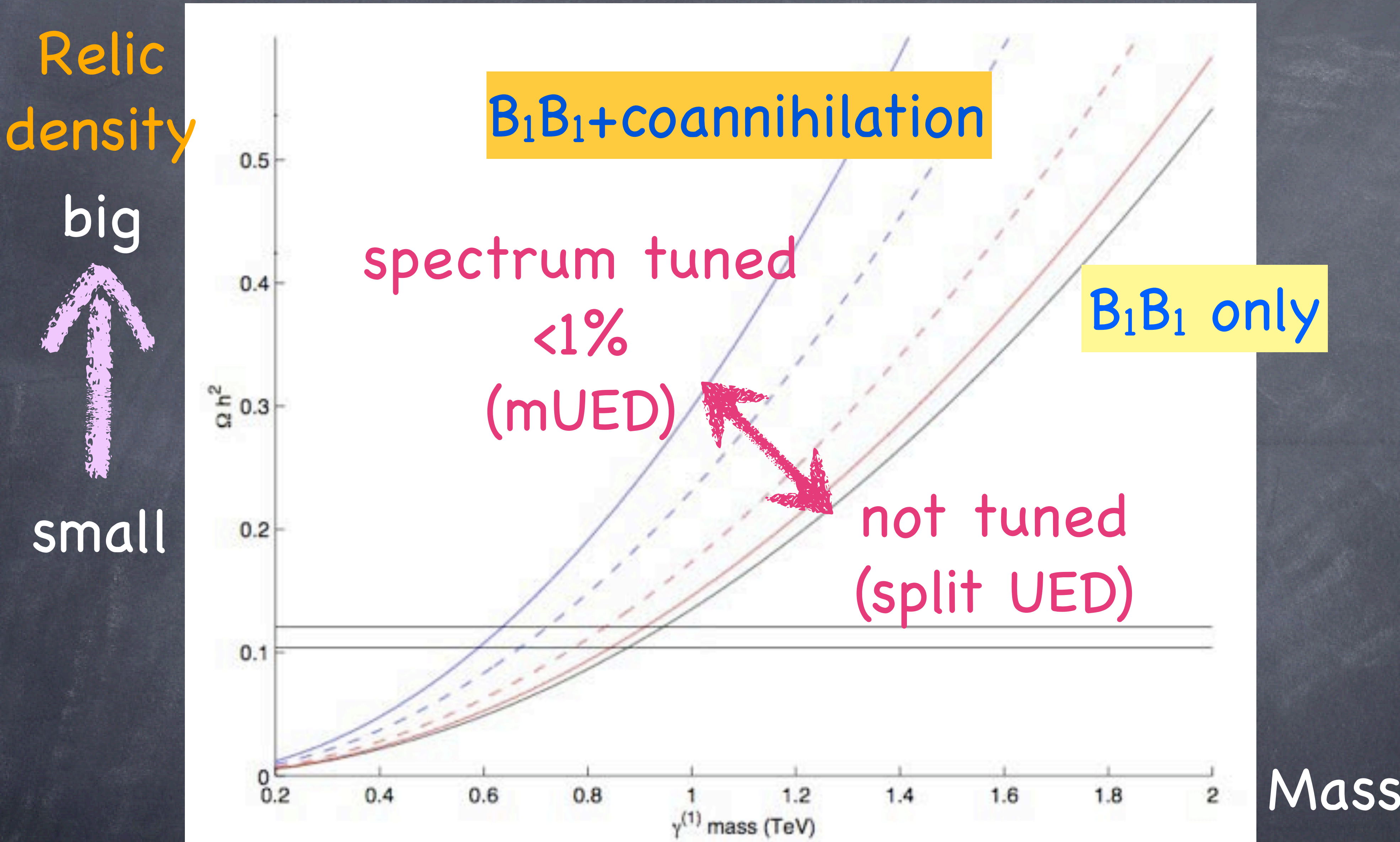
- If DM is responsible for Pamela, ATIC, Fermi "excesses", we can learn more about the details of DM properties.
- Pamela p^-/p and Fermi gamma-ray data seem to imply leptophilic DM. (neutralino disfavored, KK dm favored)
- Mass of DM can be determined by the "peak" position (ATIC=> 600-800 GeV, Fermi=>900 GeV or larger) (LTP disfavored, KK dm favored)



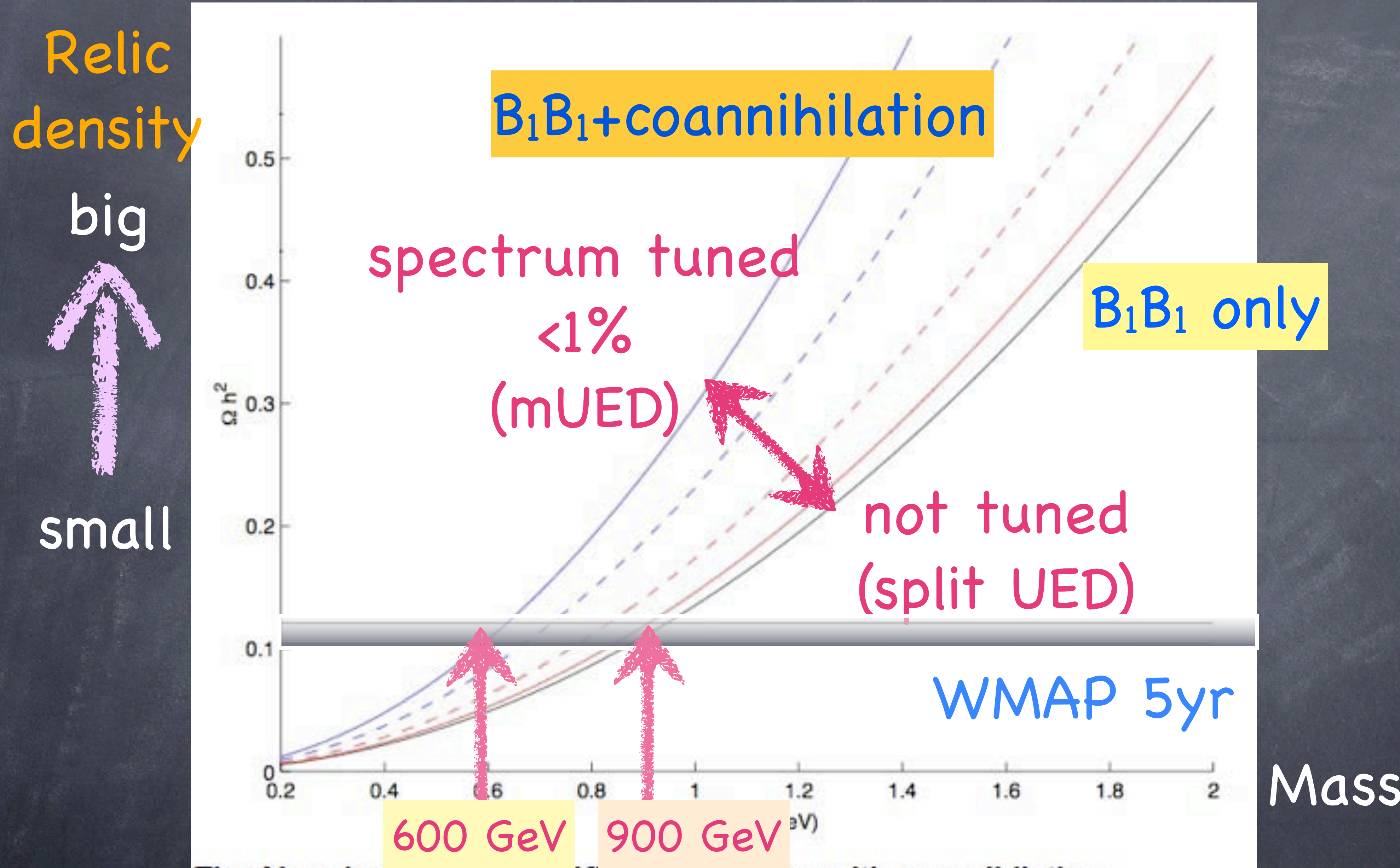
[Fermi-Lat: arXiv 0905.0636]

DM annihilation into charged leptons can explain the Fermi and Pamela if m>400 GeV

*Tesla Jeltema this workshop showed that non-detection of clusters (end EGB) by Fermi-LAT "excludes" high mass models with m > 1-2 TeV fitting the Pamela positron excess.



The Abundance of Kaluza-Klein dark matter with coannihilation.
Fiona Burnell, (Princeton U.) , Graham D. Kribs, (Oregon U.) . Sep 2005. 38pp.
Published in **Phys.Rev.D73:015001,2006.**
e-Print: **hep-ph/0509118**



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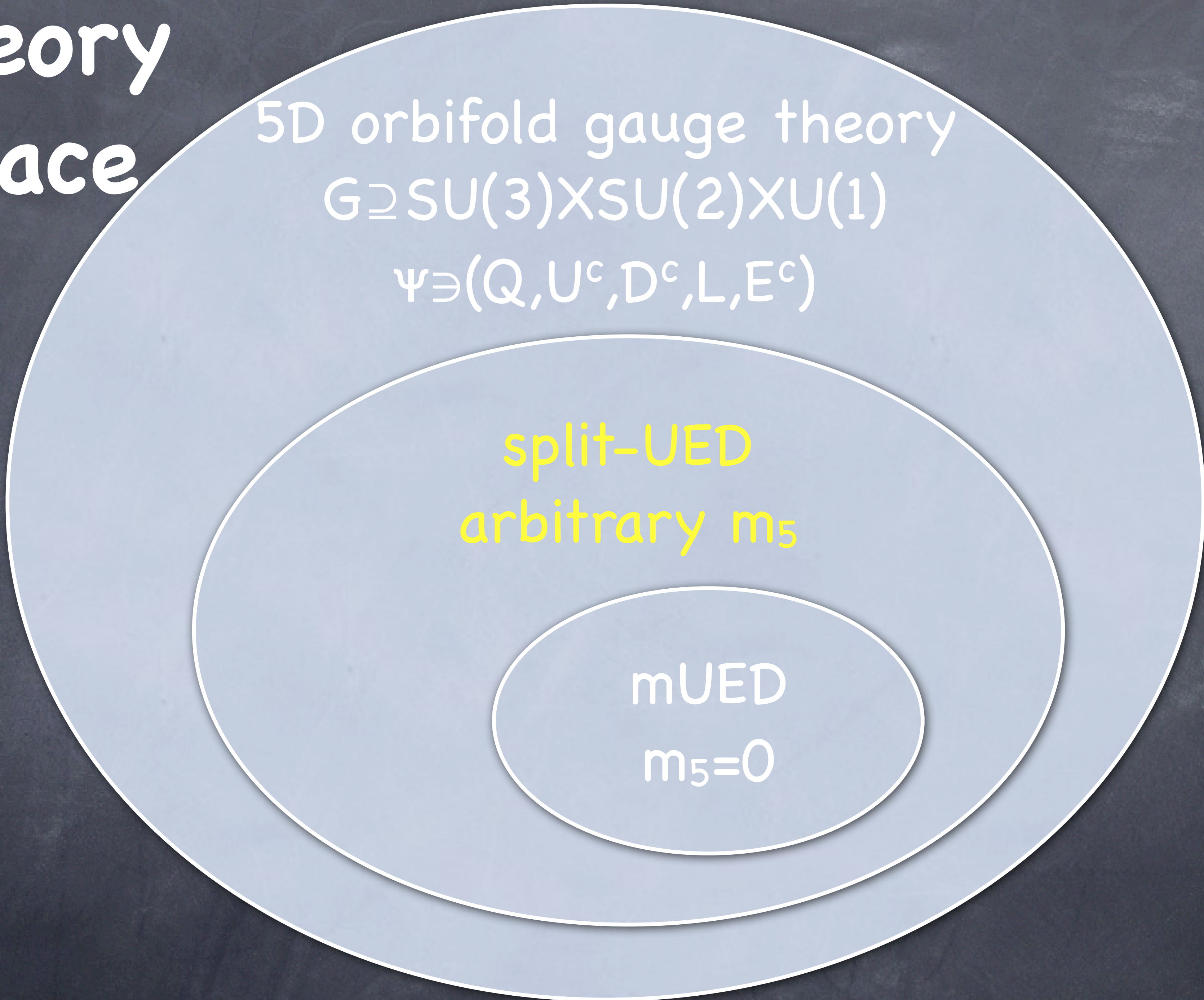
Kaluza-Klein DM in UED & split-UED

Split-UED

- A model with the minimal extension of spacetime whose low energy effective theory is nothing but the SM. D=5, $M^4 X S^1/Z_2$, G=SU(3)XSU(2)XU(1)
- All matters in the bulk. Matter=Q (3,2,1/6), U^c (3,1,-2/3), D^c(3,1,1/3), L(1,2,-1/2), E^c(1,1,1)
- Bulk Dirac Mass term introduced. (m->0 limit corresponds conventional "UED")

Theory space



Bulk Action

the most generic, lowest order 5D-Lorentz & gauge invariant action

$$\mathcal{L}_5^{UED} = \sum_{ij} \frac{i}{2}(D_M \bar{\Psi}_i \Gamma^M \Psi_j - \bar{\Psi}_i \Gamma^M D_M \Psi_j)$$

$$+\mathcal{L}_H + \mathcal{L}_{g,W,B}$$

$$\Psi = (Q, U^c, D^c, L, E^c)$$

$$\Gamma^M = (\gamma^\mu, i\gamma_5)$$

$$D = \partial - ig_3 \lambda G - ig_2 \frac{T}{2} \cdot W - ig_1 \frac{Y}{2} B$$

without loss of generality $m_{ij} = \mu_i \delta_{ij}$ 5 mu's for each gen.

Bulk Action

the most generic, lowest order 5D-Lorentz & gauge invariant action

split-

$$\mathcal{L}_5^{UED} = \sum_{ij} \frac{i}{2}(D_M \bar{\Psi}_i \Gamma^M \Psi_j - \bar{\Psi}_i \Gamma^M D_M \Psi_j)$$

$$-m_{ij}(y)\bar{\Psi}_i \Psi_j \quad + \mathcal{L}_H + \mathcal{L}_{g,W,B}$$

$$\Psi = (Q, U^c, D^c, L, E^c)$$

$$\Gamma^M = (\gamma^\mu, i\gamma_5)$$

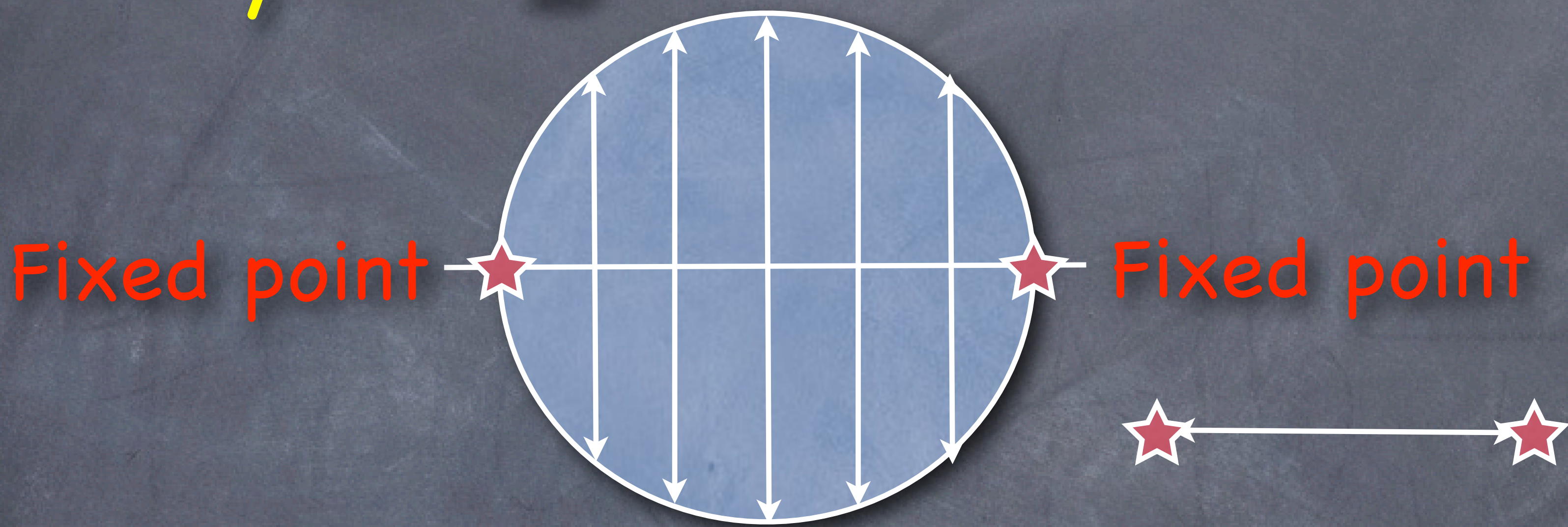
$$D = \partial - ig_3 \lambda G - ig_2 \frac{T}{2} \cdot W - ig_1 \frac{Y}{2} B$$

without loss of generality $m_{ij} = \mu_i \delta_{ij}$ 5 mu's for each gen.

Property #1: Orbifold

- The theory (5D) is vectorlike, but the SM (4D) is a chiral theory. The best thing we hope is that a chiral theory appears as a low energy effective theory below compactification scale.
- Orbifold compactification is a good example. Unnecessary chiral states are projected out by orbifold BC.
- The simplest orbifold: S^1/Z_2

S^1/Z_2



- Z_2: Identify the opposite points, there are two fixed points
- Equivalent to an interval with two boundaries
- Orbifold condition determines BCs for fields

On orbifold S^1/Z_2, a field has a "Z=+-1" parity

$$\Psi_Z(x, y_f) \to \Psi_Z(x, y_f - \epsilon) = Z\gamma_5 \Psi_Z(x, y_f + \epsilon)$$

$$\Psi_{L/R} = \sum_n \psi^n_{L/R}(x) f_{L/R}(y)$$

$$\Psi_Z(y_f - \epsilon) = Z\gamma_5 \sum_n \psi^n_L f^n_L(y_f + \epsilon) + \psi^n_R f^n_R(y_f + \epsilon)$$

$$= Z \sum_n -\psi^n_L f^n_L(y_f + \epsilon) + \psi^n_R f^n_R(y_f + \epsilon)$$

f_L and f_R have the opposite parities.

$$f^n_L(y_f - \epsilon) = -Z f^n_L(y_f + \epsilon)$$

$$f^n_R(y_f - \epsilon) = +Z f^n_R(y_f + \epsilon)$$

If one of them is odd (satisfying Dirichlet BC) ,the other one is even (satisfying Neumann BC)

Neumann BCs are imposed on:

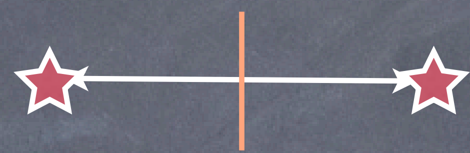
$$H, G_\mu^A, W_\mu^a, B_\mu, Q_L, L_L, U_R, D_R, E_R$$

Dirichlet BCs are imposed on:

$$G_5^A, W_5^a, B_5, Q_R, L_R, U_L, D_L, E_L$$

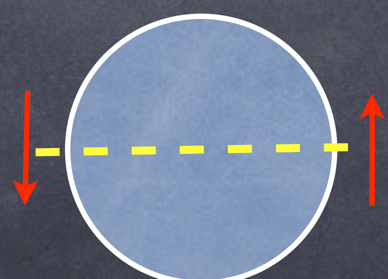
*The resultant zero mode spectrum is the same as the SM.

Property #2: KK-parity

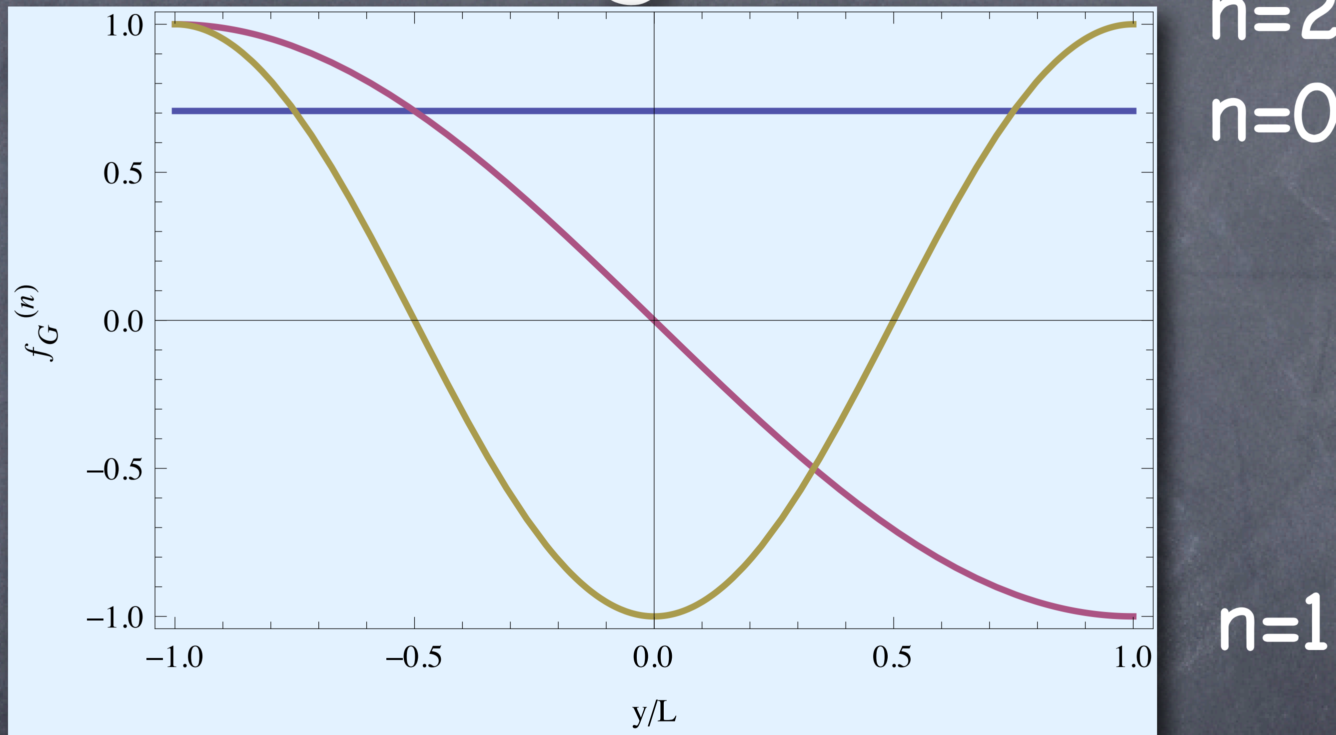


- The reflection symmetry about the mid point of extra dimension.

- Remnant symmetry of KK-number conservation (=momentum conservation along 5th direction coming from translational invariance which is broken by fixed points)



e.g. Wave function of KK gluons



1. Gluon respects Neumann BCs.==> have zero mode
2. n=even Kk modes are symmetric (parity even)

n=odd KK modes are antisymmetric (parity odd)

Property #3: Bulk mass

No "chirality" in odd dim.

- The minimal spinor in 5D is Dirac-like spinor

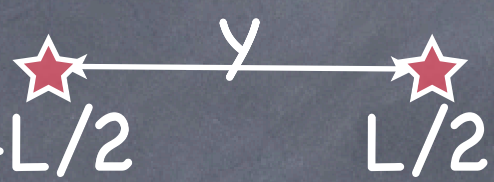
$$\Psi = \Psi_L(1/2, 0) + \Psi_R(0, 1/2)$$

- Dirac mass is generically allowed. No symmetry forbids it. This mass is nothing to do with the electroweak symmetry breaking. Zero mode remains massless regardless this mass:

$$m\bar{\Psi}\Psi$$

- In split-UED, we introduce an odd mass so that KK-parity is respected.

Inversion about the middle point



$$S^1/Z_2$$

$$\Psi(x,y) \to \Psi(x,-y) = \pm\gamma_5\Psi(x,y)$$

$$\bar{\Psi}\Psi \to -\bar{\Psi}\Psi$$

Thus, we need an intrinsically "odd" mass term for keeping KK-parity.

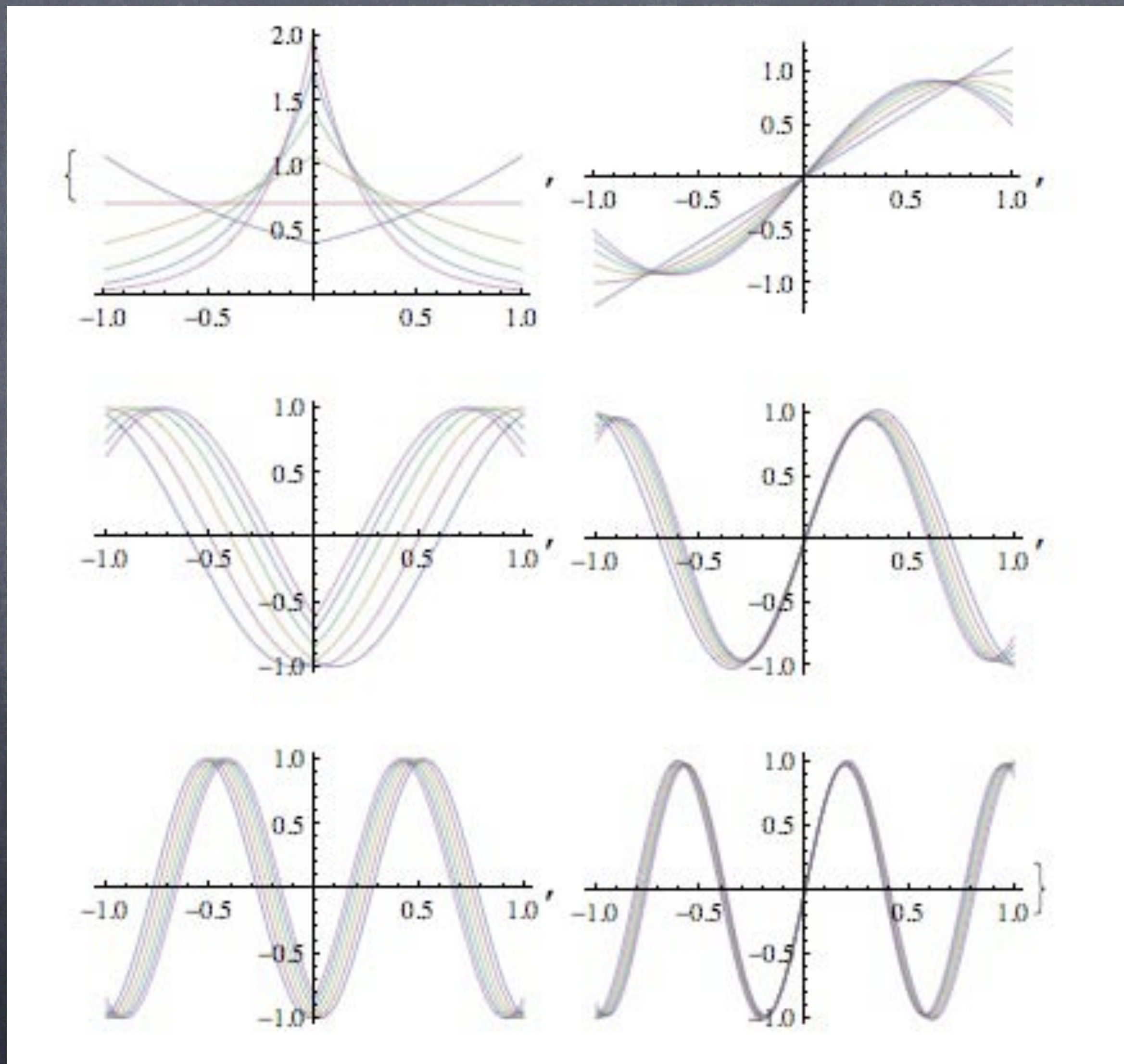
$$M_5(y)\bar{\Psi}\Psi$$

$$M_5(y) \to M_5(-y) = -M_5(y)$$

The simplest choice:

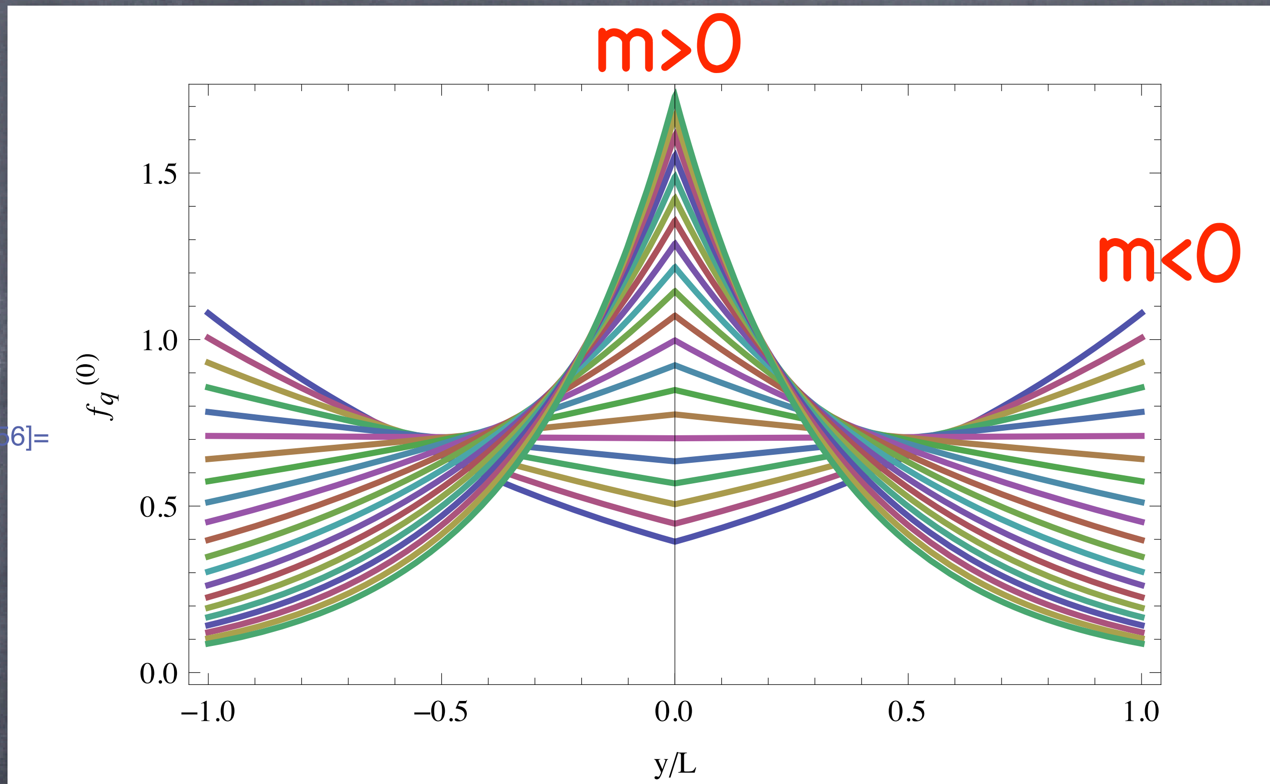
$$m(y) = m\theta(y) \approx m\tanh(\mu y)$$

Wave functions for KK modes



Zero mode
:all massless

$$m(y) = m\theta(y)$$



$$(\partial_y + m(y))f_R^0 = 0$$

$$f_R^0 \sim e^{-\int dy m(y)} = e^{-m|y|}$$

KK-gauge coupling

$$\mathcal{L}_{\rm int} \ni \int dy g_5 \bar{\psi} T^a \gamma^\mu \psi G^a_\mu$$

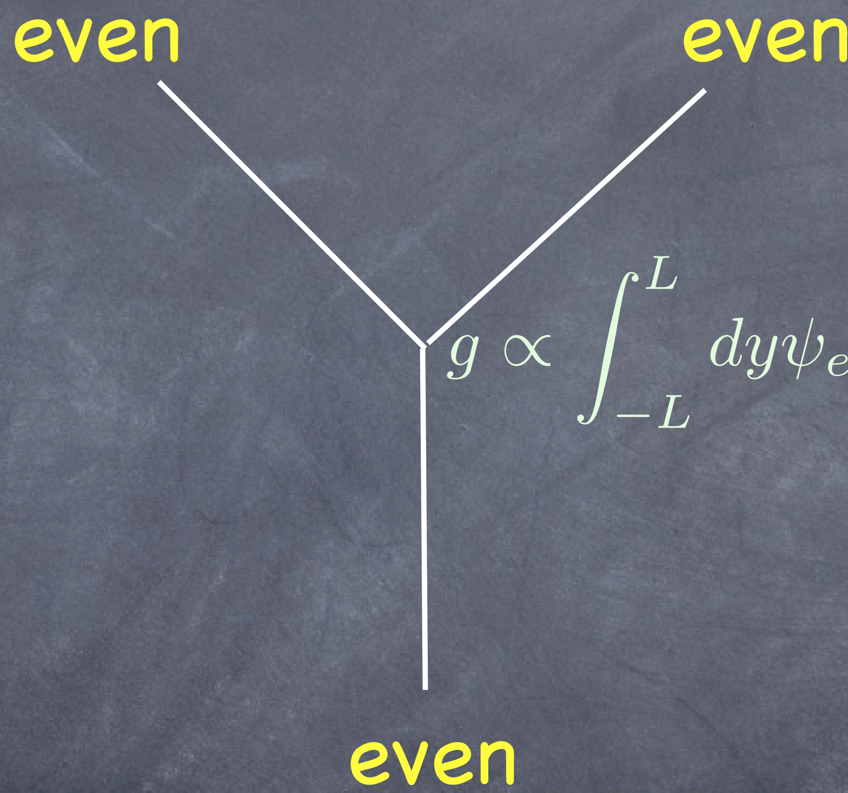
$$\ni \sum_{nlm} g^{eff,nlm} \bar{\psi}^n T^a \gamma_\mu \psi^l G^{ma}_\mu$$

$$g_n^{eff,nlm} = g_5 \int dy f^n_{\bar{\psi}} f^l_\psi f^m_G$$

The integral of the wave function overlap gives the effective coupling.

SM-SM-SM vertex is allowed

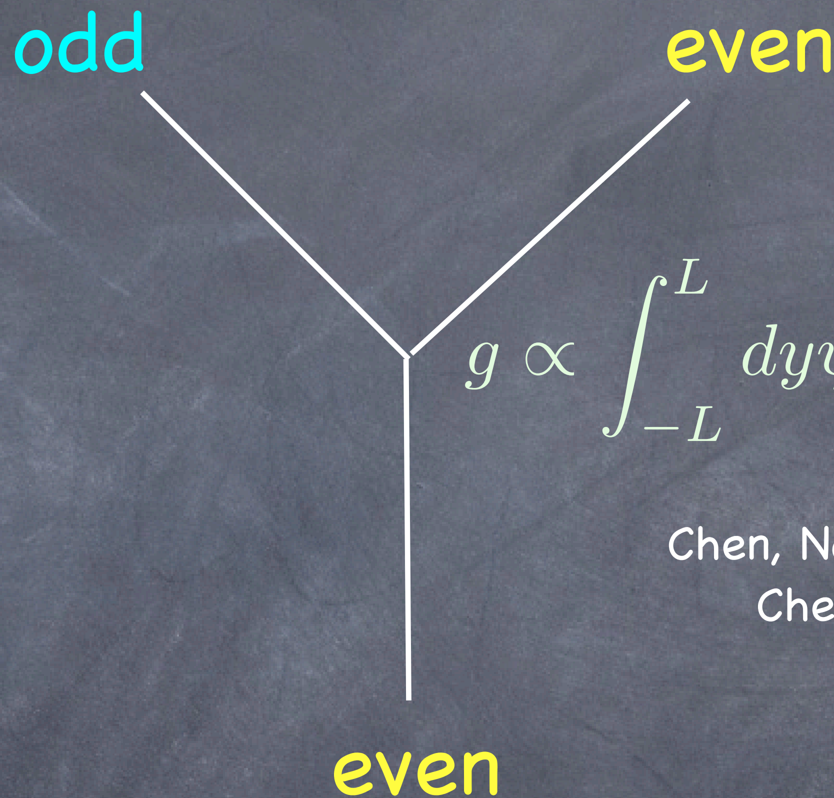
(i.e. even-even-even)



$$g \propto \int_{-L}^{L} dy \psi_{even} \psi_{even} \psi_{even} \neq 0$$

- KK-even particle has a symmetric wave fn.
- SM particles are zero modes (i.e. KK-even)

SM-SM-DM vertex is NOT allowed



$$g \propto \int_{-L}^{L} dy \psi_{odd} \psi_{even} \psi_{even} = 0$$

Chen, Nojiri,Park,Shu,Takeuchi (2009)
Chen, Nojiri, Park, Shu(2009)

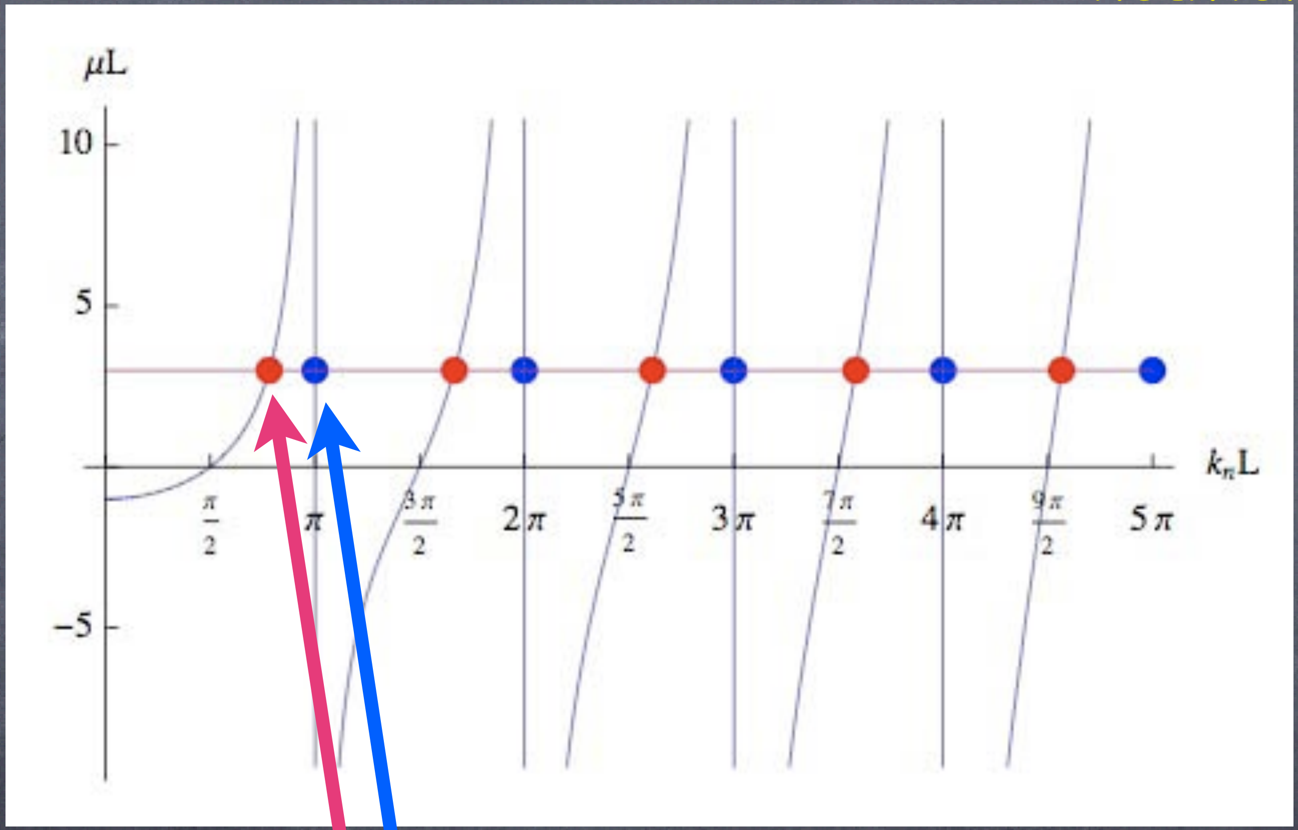
- LKP is stable=> Dark Matter
- Never produced singly

"KK parity mimics R-parity"

Kaluza-Klein spectrum (Tree)

$$m_n^2 = \mu^2 + k_n^2$$

Fermions get heavier with m_5



[Csaki, Hainonen, Hubsiz, Park, Shu (in preparation)]

$\mu = -k_n \cot k_n L$ (odd)

$k_n = n\pi/L$ (even)

KK photon (=B_1) is LKP

$$\delta(m^2_{B^{(n)}}) = \frac{g'^2}{16\pi^2 R^2}\left(\frac{-39}{2}\frac{\zeta(3)}{\pi^2} - \frac{n^2}{3}\ln \Lambda R\right)$$

$$\delta(m^2_{W^{(n)}}) = \frac{g^2}{16\pi^2 R^2}\left(\frac{-5}{2}\frac{\zeta(3)}{\pi^2} + 15 n^2 \ln \Lambda R\right)$$

$$\delta(m^2_{g^{(n)}}) = \frac{g_3^2}{16\pi^2 R^2}\left(\frac{-3}{2}\frac{\zeta(3)}{\pi^2} + 23 n^2 \ln \Lambda R\right)$$

$$\delta(m_{Q^{(n)}}) = \frac{n}{16\pi^2 R}\left(6 g_3^2 + \frac{27}{8} g^2 + \frac{1}{8} g'^2\right)\ln \Lambda R$$

$$\delta(m_{u^{(n)}}) = \frac{n}{16\pi^2 R}\left(6 g_3^2 + 2 g'^2\right)\ln \Lambda R$$

$$\delta(m_{d^{(n)}}) = \frac{n}{16\pi^2 R}\left(6 g_3^2 + \frac{1}{2} g'^2\right)\ln \Lambda R$$

$$\delta(m_{L^{(n)}}) = \frac{n}{16\pi^2 R}\left(\frac{27}{8} g^2 + \frac{9}{8} g'^2\right)\ln \Lambda R$$

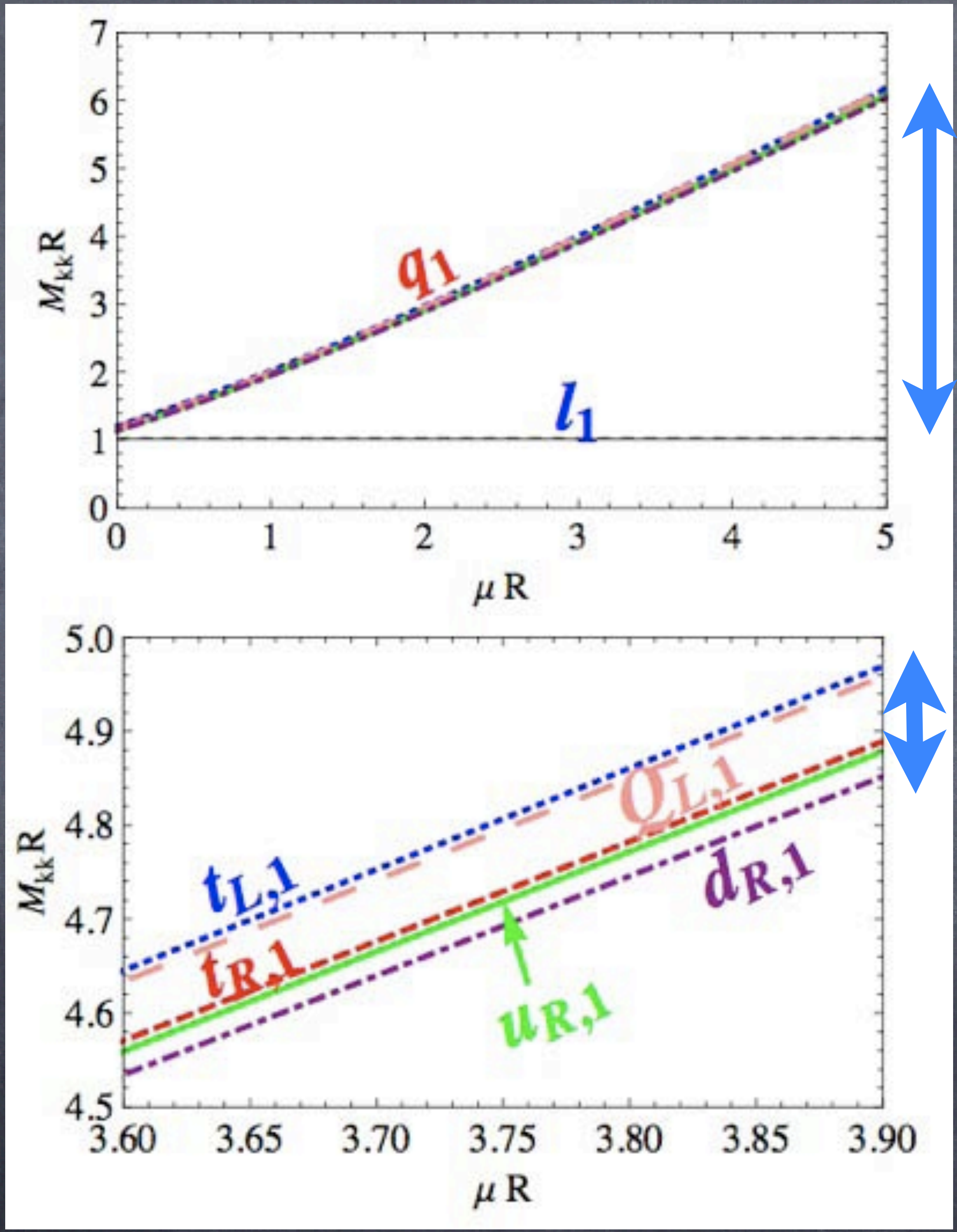
$$\delta(m_{e^{(n)}}) = \frac{n}{16\pi^2 R}\frac{9}{2} g'^2 \ln \Lambda R\,.$$

Bosonic supersymmetry? Getting fooled at the CERN LHC.
Hsin-Chia Cheng, (Chicago U., EFI) , Konstantin T. Matchev, (Florida U. & CERN) , Martin Schmaltz, (Boston U.)
CERN-TH-2002-108, BUHEP-02-21, May 2002. 6pp.
Published in **Phys.Rev.D66:056006,2002.**
e-Print: **hep-ph/0205314**

1-loop RG-running

1. KK photon -0.2%
2. KK gluon +30%
3. KK quarks +14%
4. KK leptons +1%

bulk mass for quarks (1-loop RG-running)

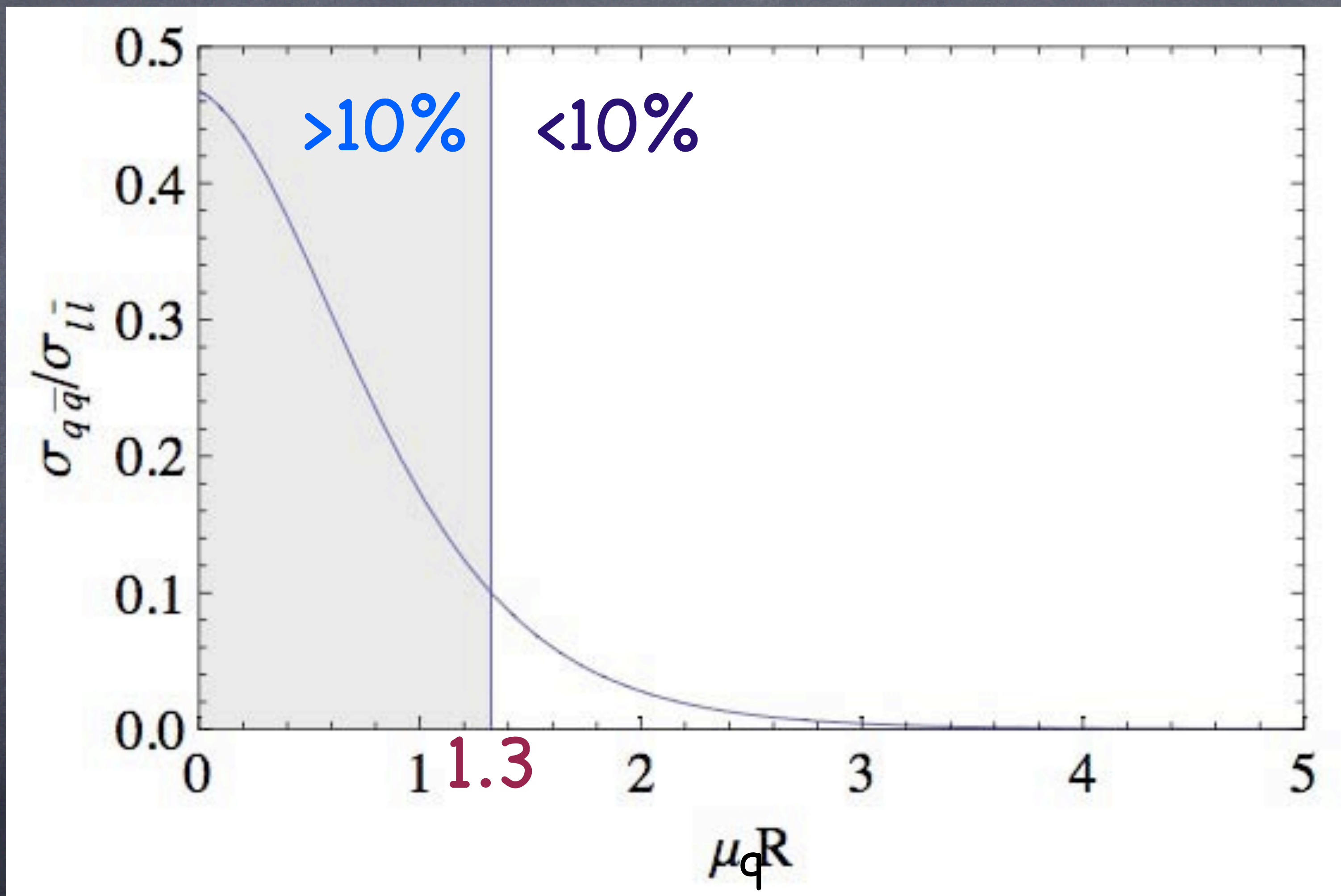


mainly from m_5

1-loop

[Chen, Nojiri, SCP, Shu, Takeuchi JHEP0909.078(2009)]

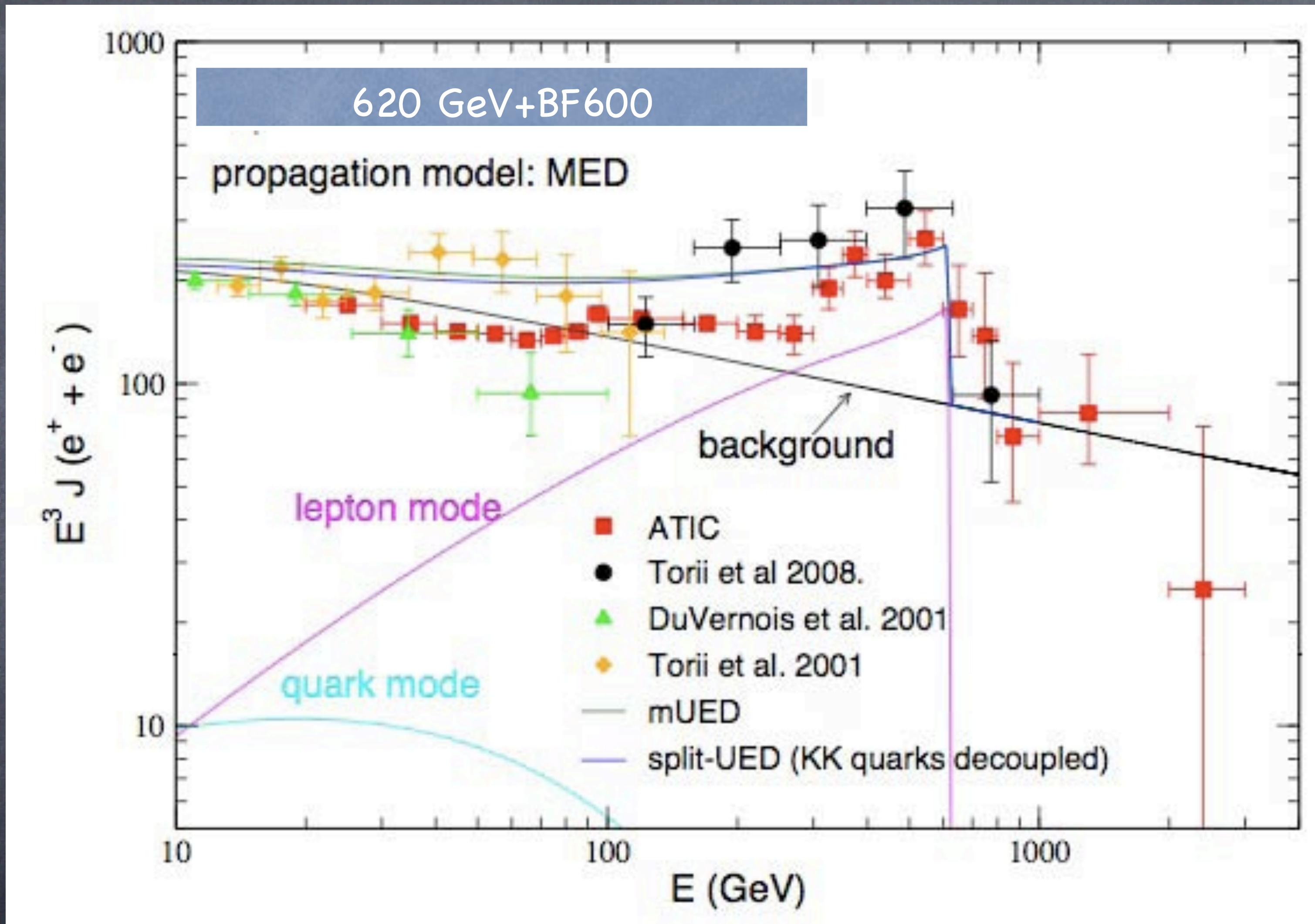
Branching Fraction B_1B_1



[Chen, Nojiri, SCP, Shu, Takeuchi JHEP0909.078(2009)]

Fitting Pamela+ATIC with m=620 GeV

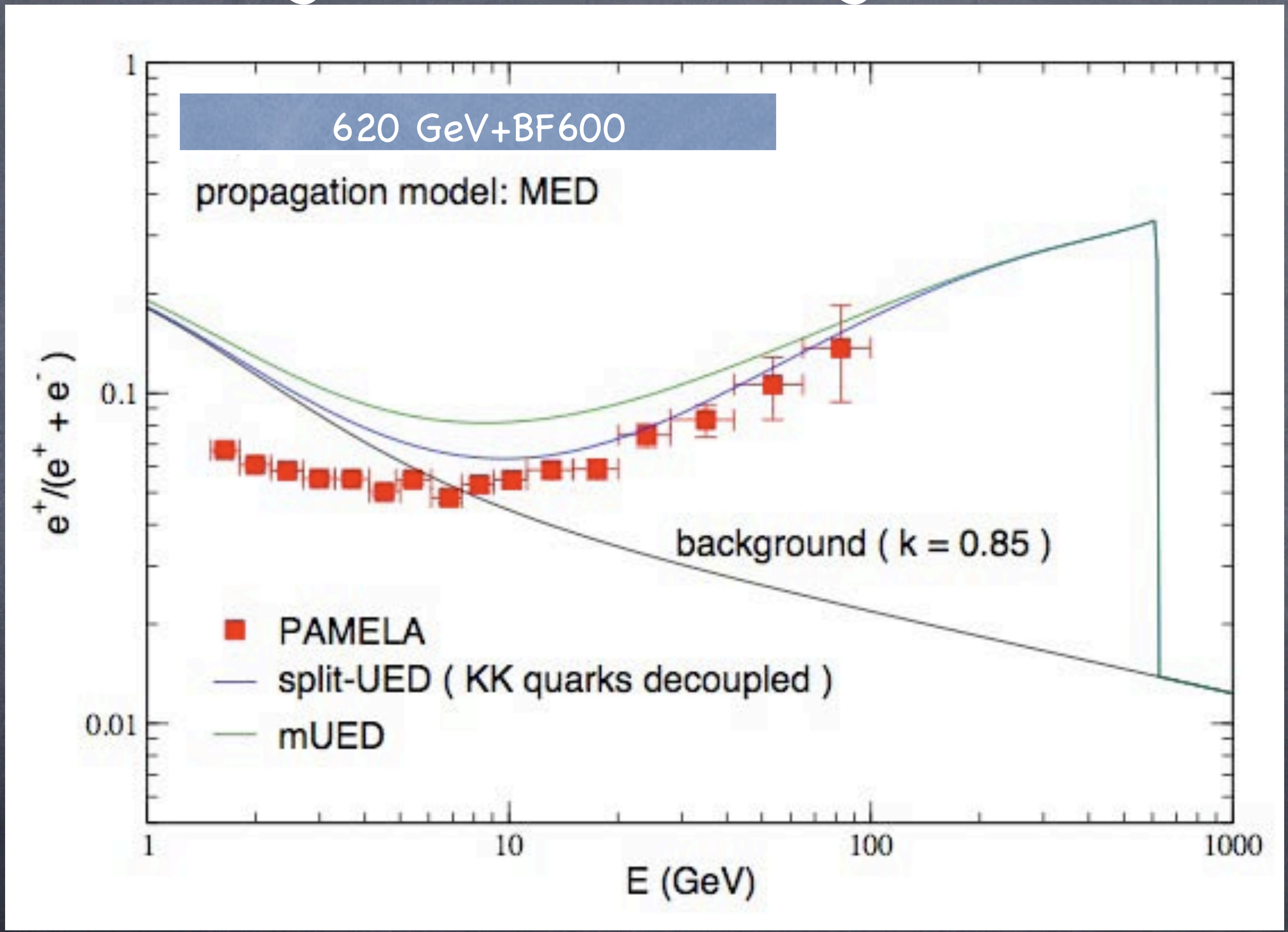
Fitting ATIC (e-e+) with 620 GeV+BF600



[Chen, Nojiri, SCP, Shu, Takeuchi JHEP0909.078(2009)]

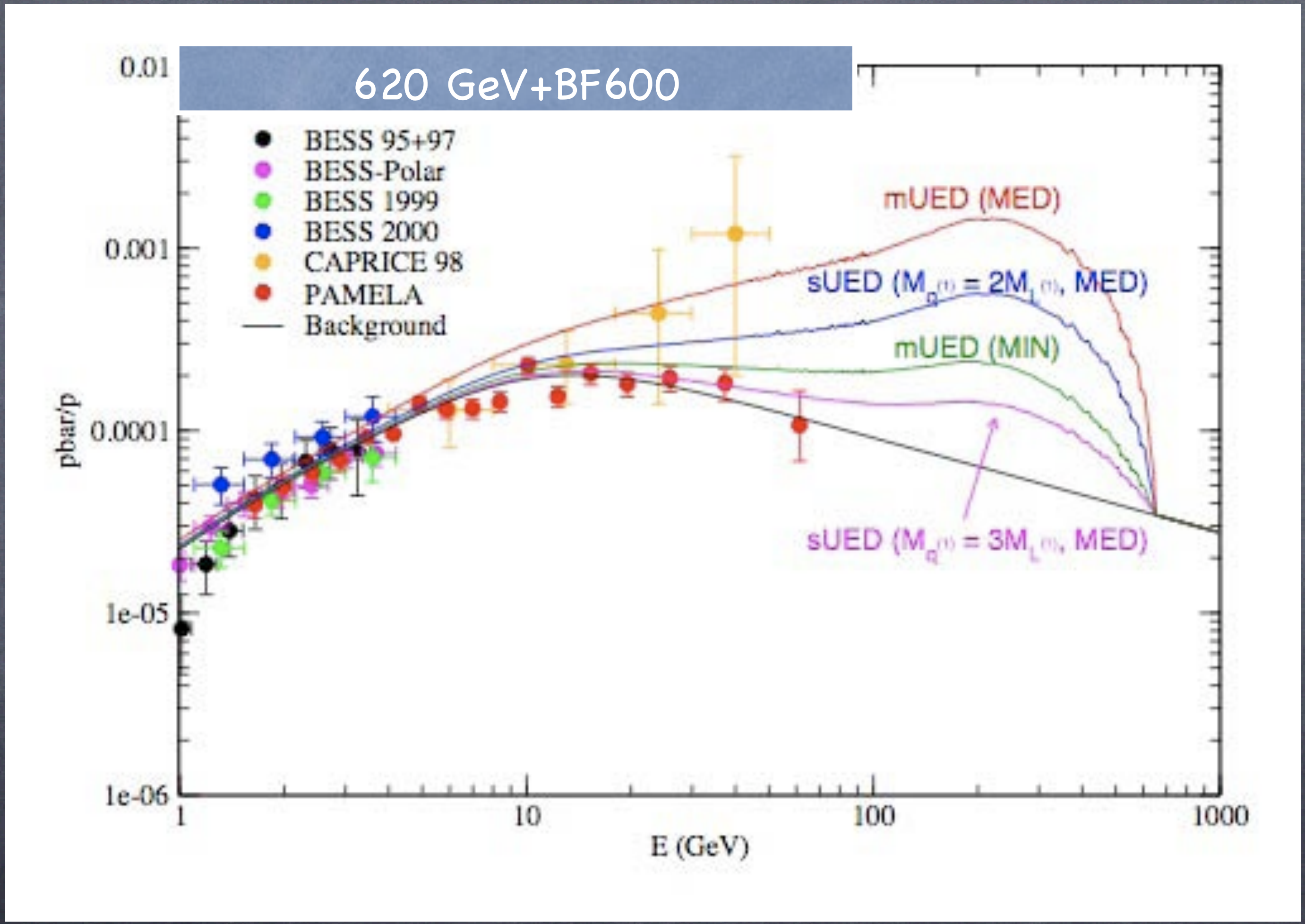
Here the position of peak determines the mass of DM: 620 GeV

With the same mass & BF fitting Pamela is also good!



[Chen, Nojiri, SCP, Shu, Takeuchi JHEP0909.078(2009)]

No Anti-proton excess

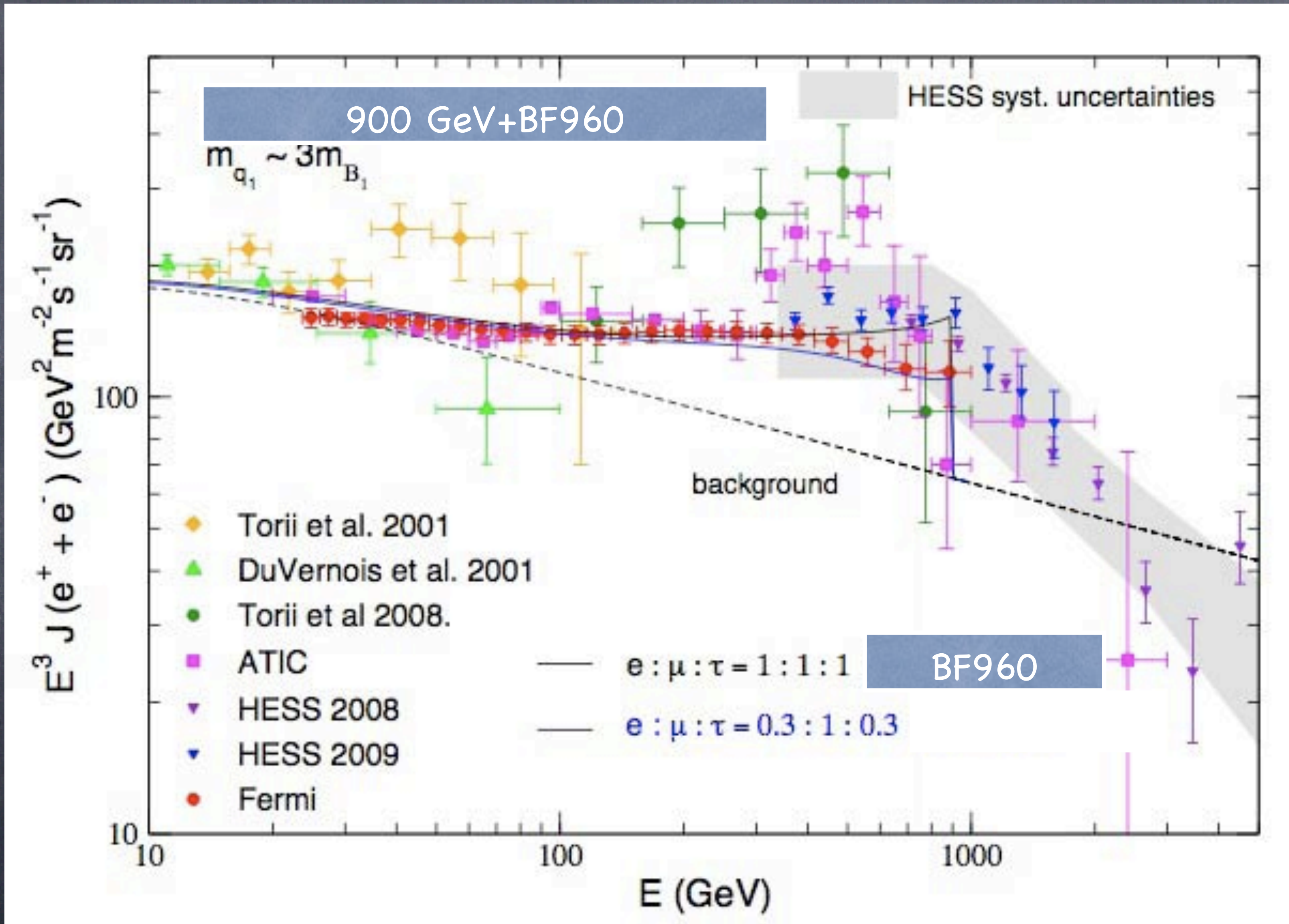


[Chen, Nojiri, SCP, Shu, Takeuchi JHEP0909.078(2009)]

Fitting Pamela+Fermi/LAT with m=900 GeV

Fermi-LAT e+e-

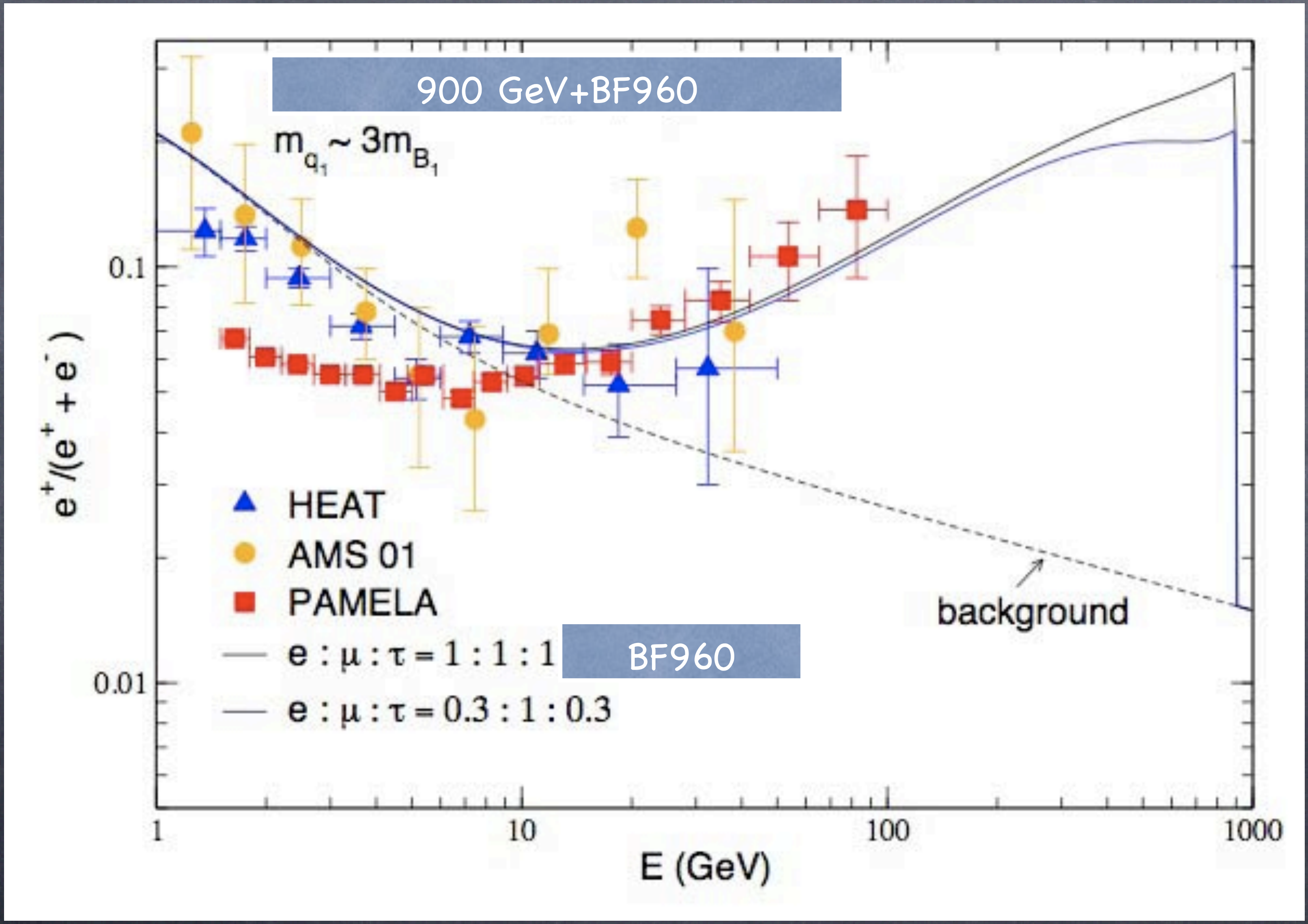
KK DM provides good fit! with 900 GeV



[Chen, Nojiri, SCP, Shu, arXiv:0908.4317]

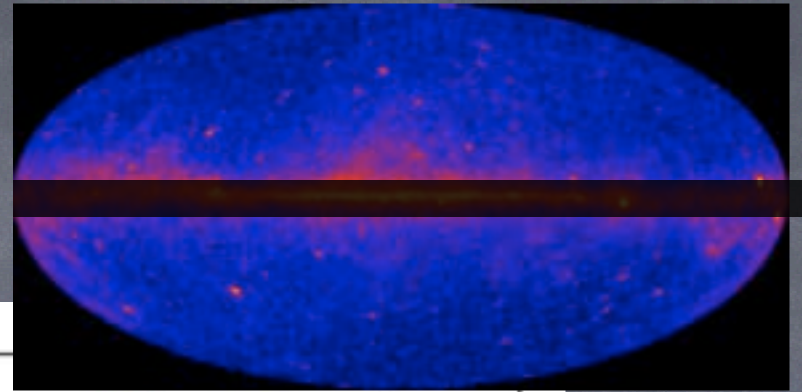
Pamela e+ fraction

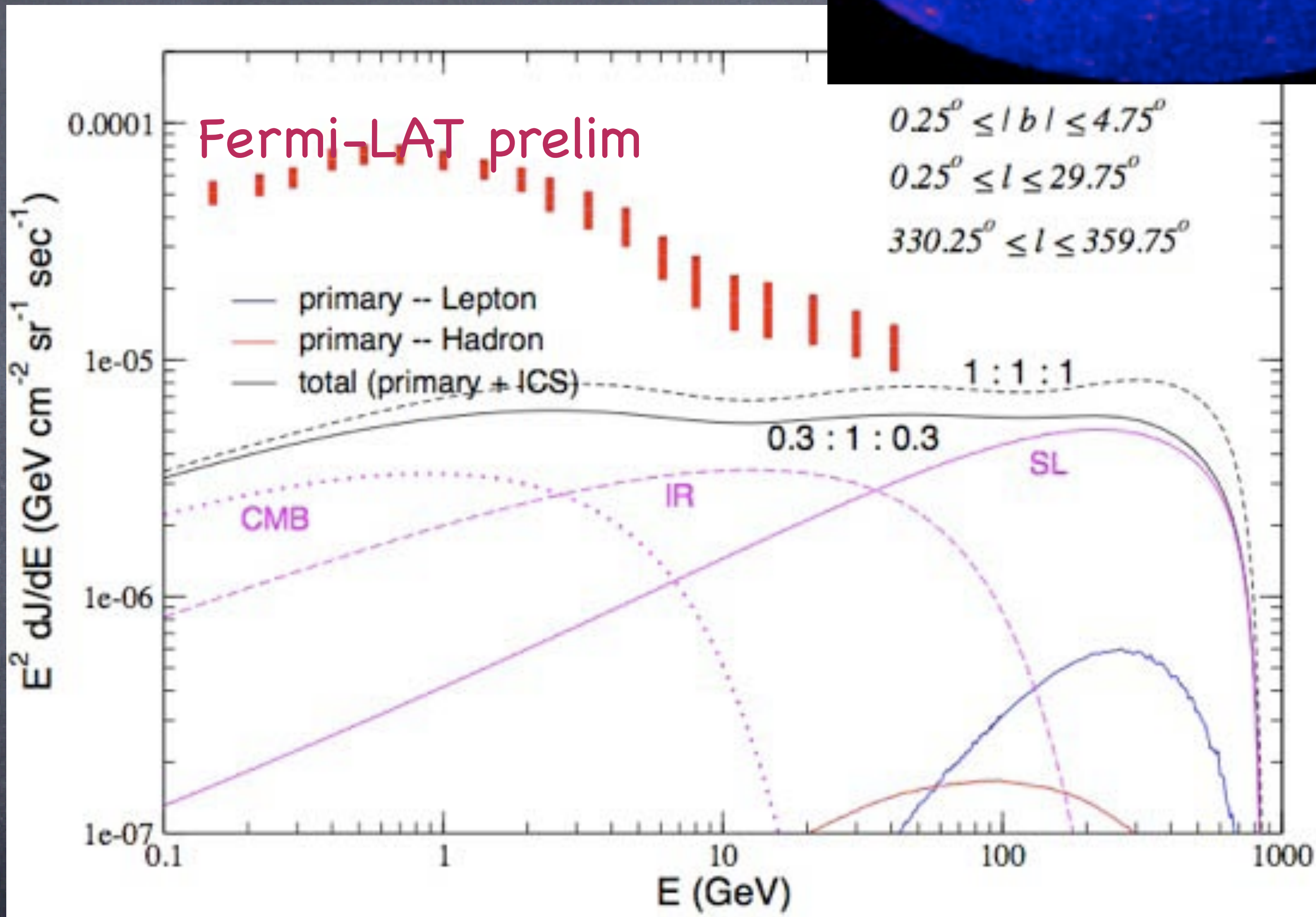
[Chen, Nojiri, SCP, Shu, arXiv:0908.4317]



[Chen, Nojiri, SCP, Shu, arXiv:0908.4317]

Fermi-LAT γ from central region $0.25^o \le |b| \le 4.75^o$





[Chen, Nojiri, SCP, Shu, arXiv:0908.4317]

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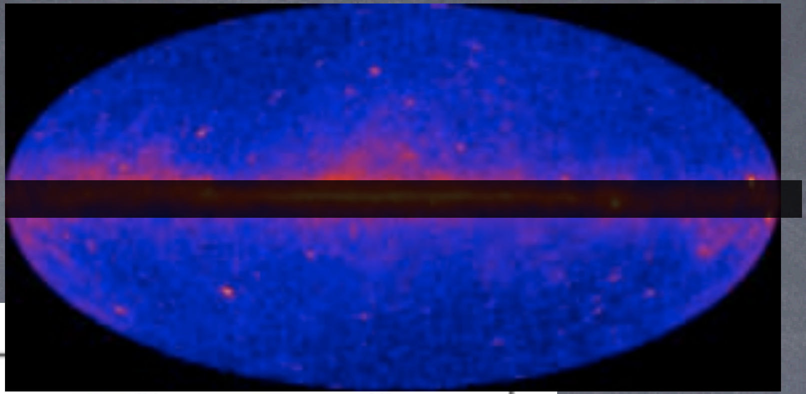
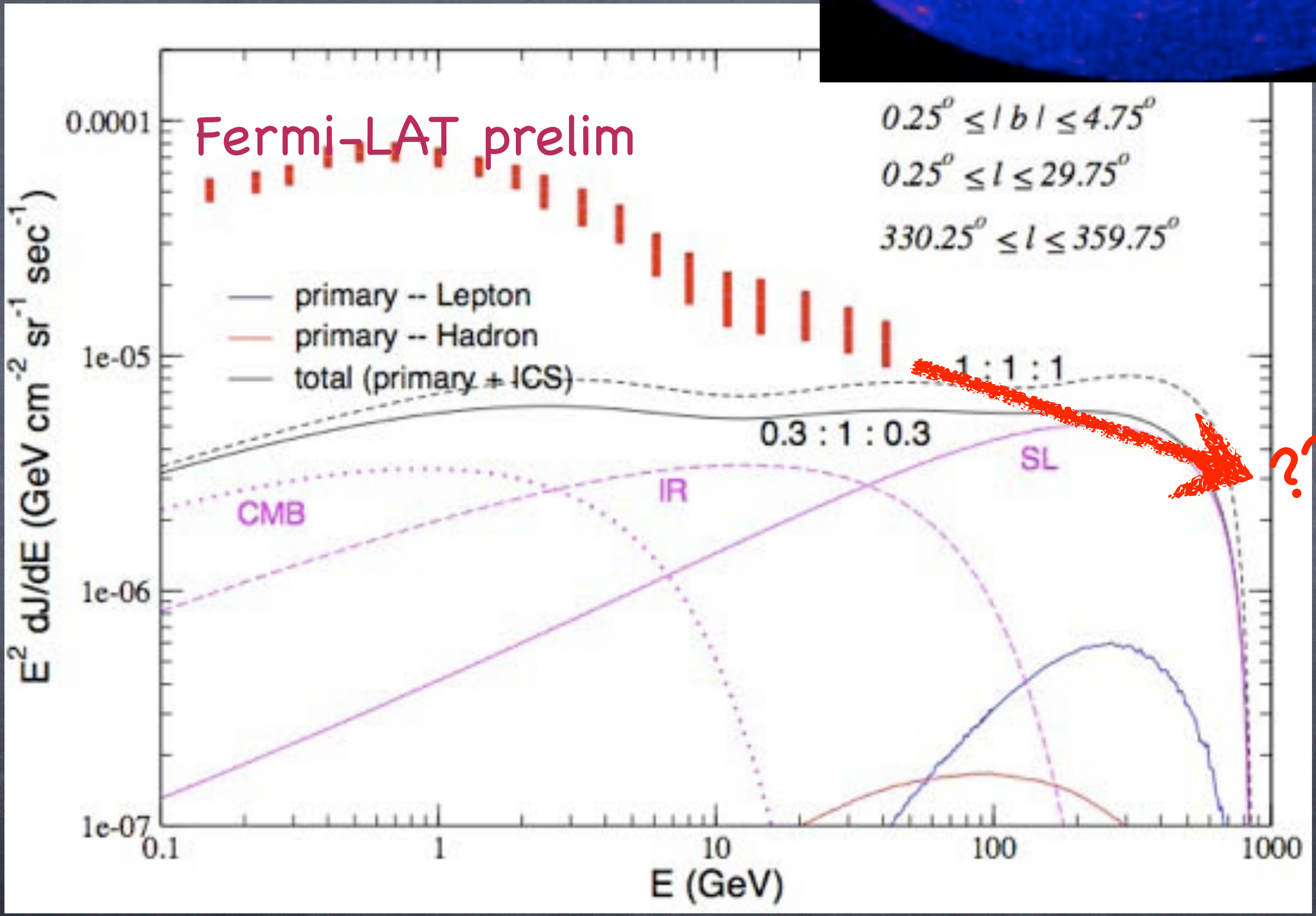
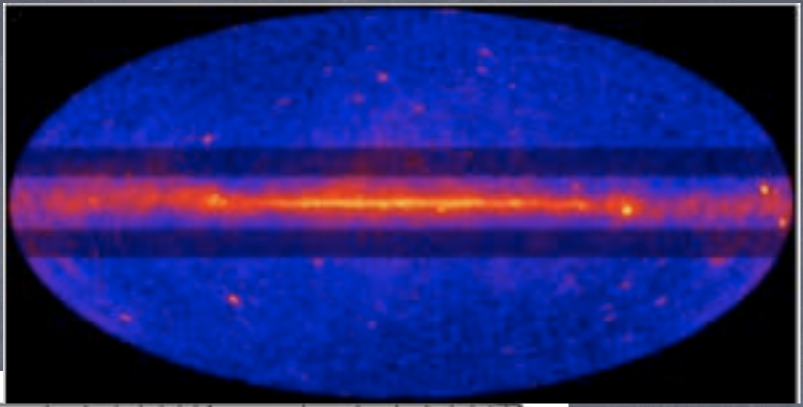
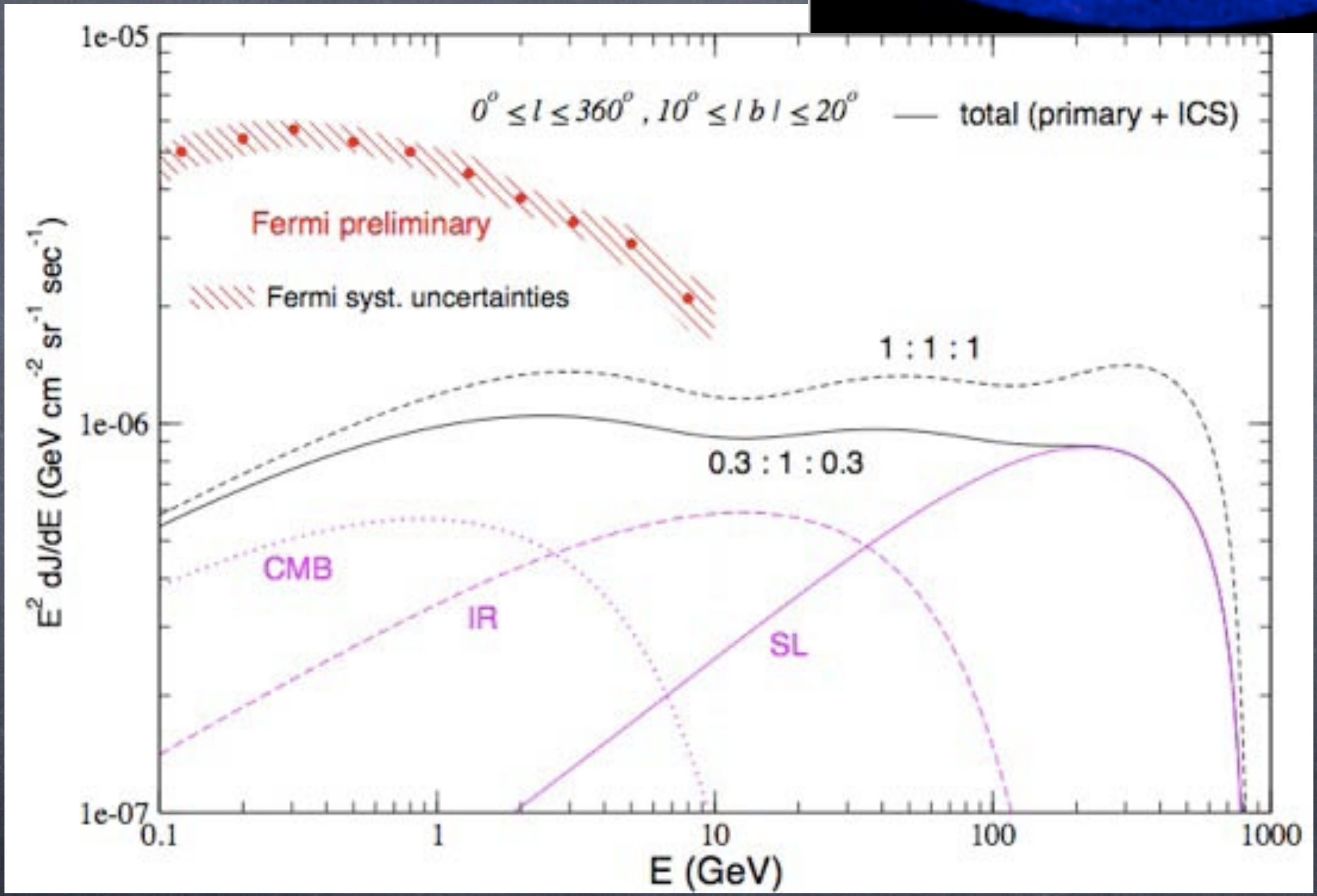




[Chen, Nojiri, SCP, Shu, arXiv:0908.4317]

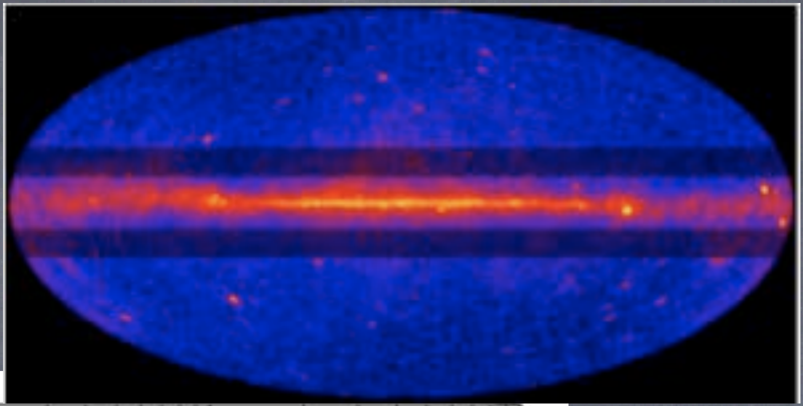
Fermi-LAT γ from intermediate region $10^o \leq |b| \leq 20^o$

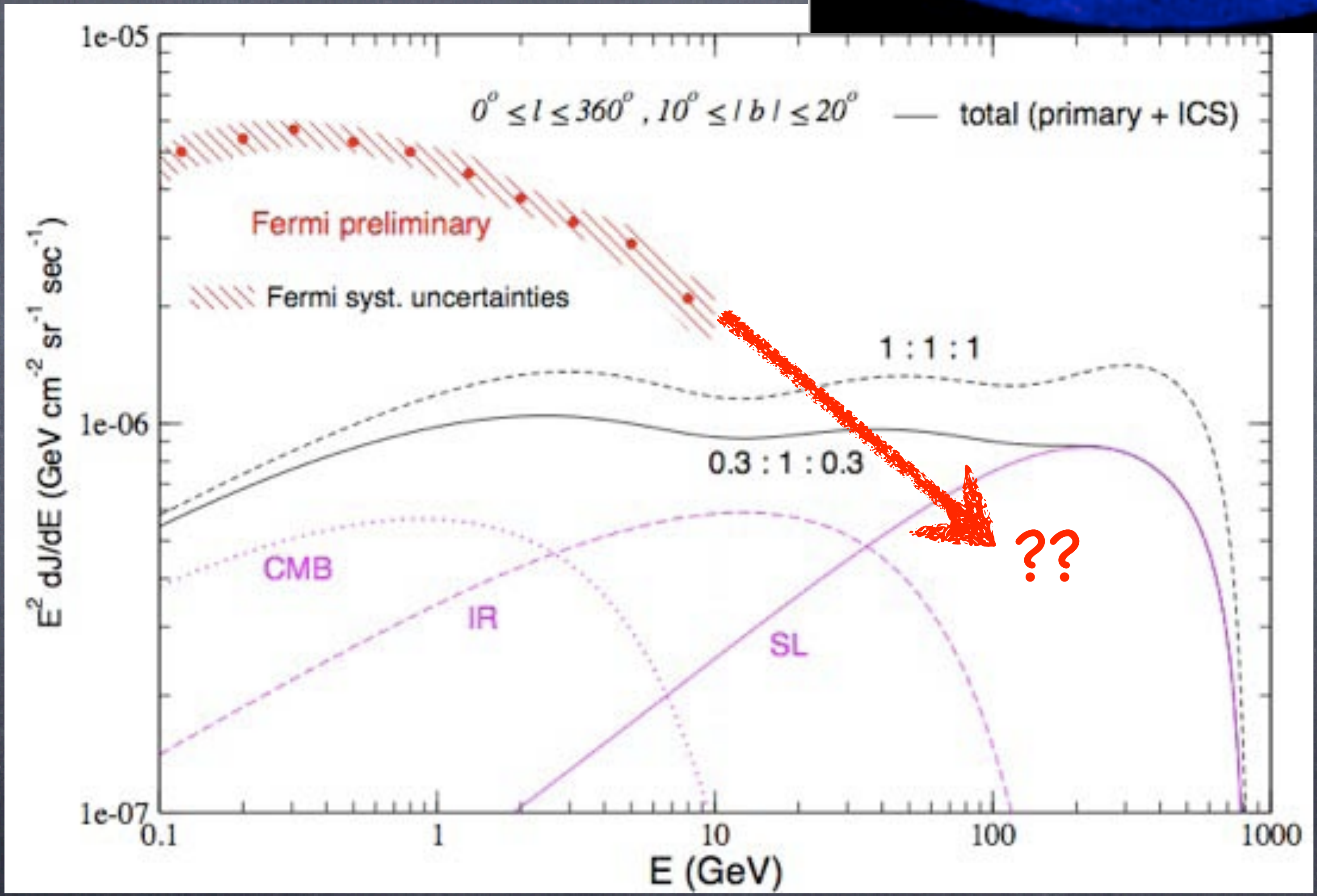




[Chen, Nojiri, SCP, Shu, arXiv:0908.4317]

Fermi-LAT γ from intermediate region $10^o \le |b| \le 20^o$





[Chen, Nojiri, SCP, Shu, arXiv:0908.4317]

Conclusion/Discussion

- In extra dimension models with KK-parity LKP can be a natural WIMP. B_1 is the LKP in UED models.
- Leptophilic B_1 in split-UED can fit PAMELA, FERMI (or ATIC) with 1/R=900 (or 600), which provides the right relic abundance of DM.
- Gamma-ray excess in E_γ>O(100)GeV can be a signal of KK dark matter. The LHC will also prove or disprove this idea.