TECHNION
Israel Institute of Technology
הטכניון
מכון טכנולוגי לישראל

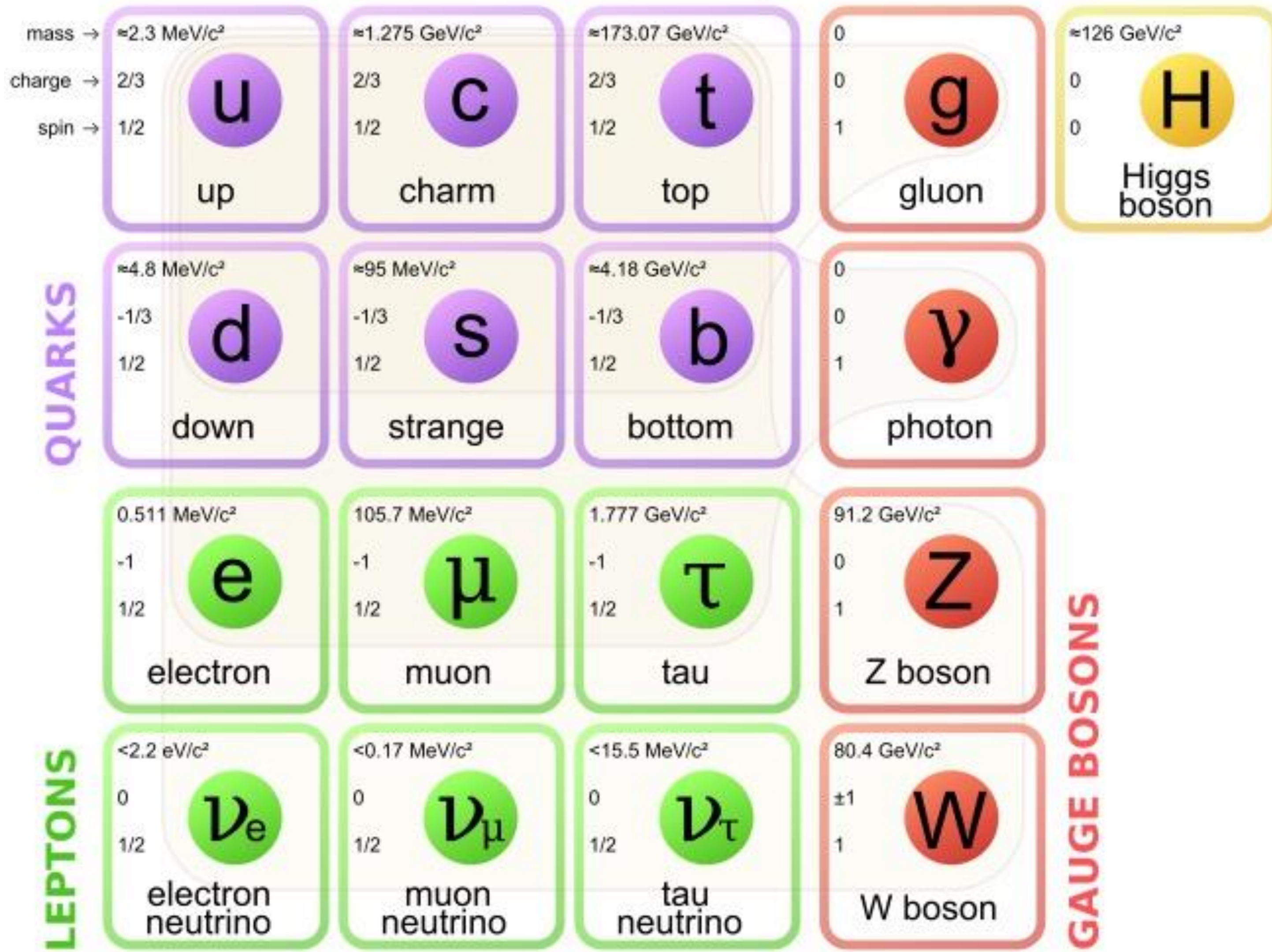
MSSM 4G scenario

Sho IWAMOTO （岩本　祥）

7 Nov. 2016
HEP phenomenology joint Cavendish–DAMTP seminar @ U. Cambridge

Based on [1608.00283] in collaboration with
M. Abdullah, **J. L. Feng**, and **B. Lillard** (UC Irvine)

Universe =



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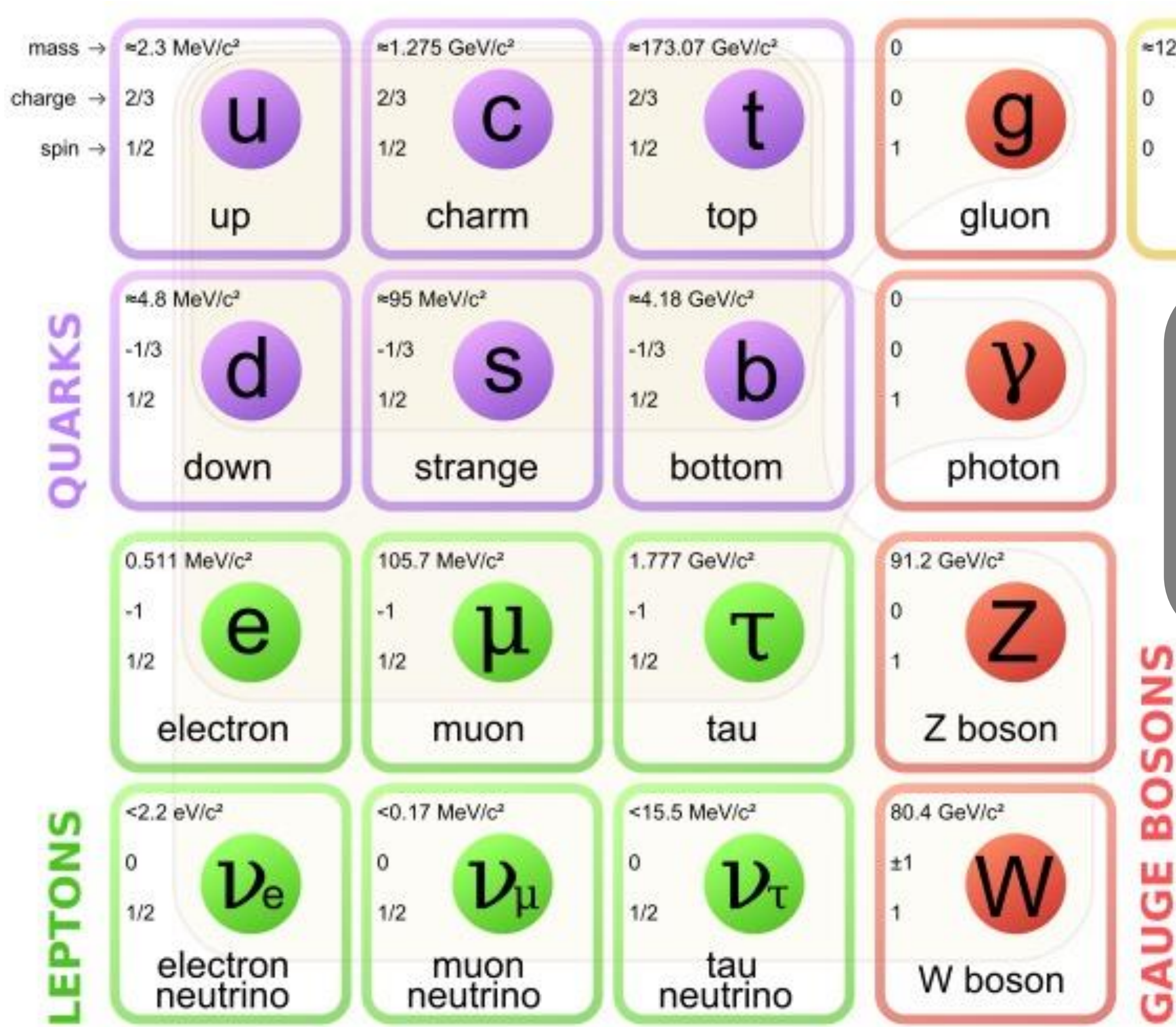
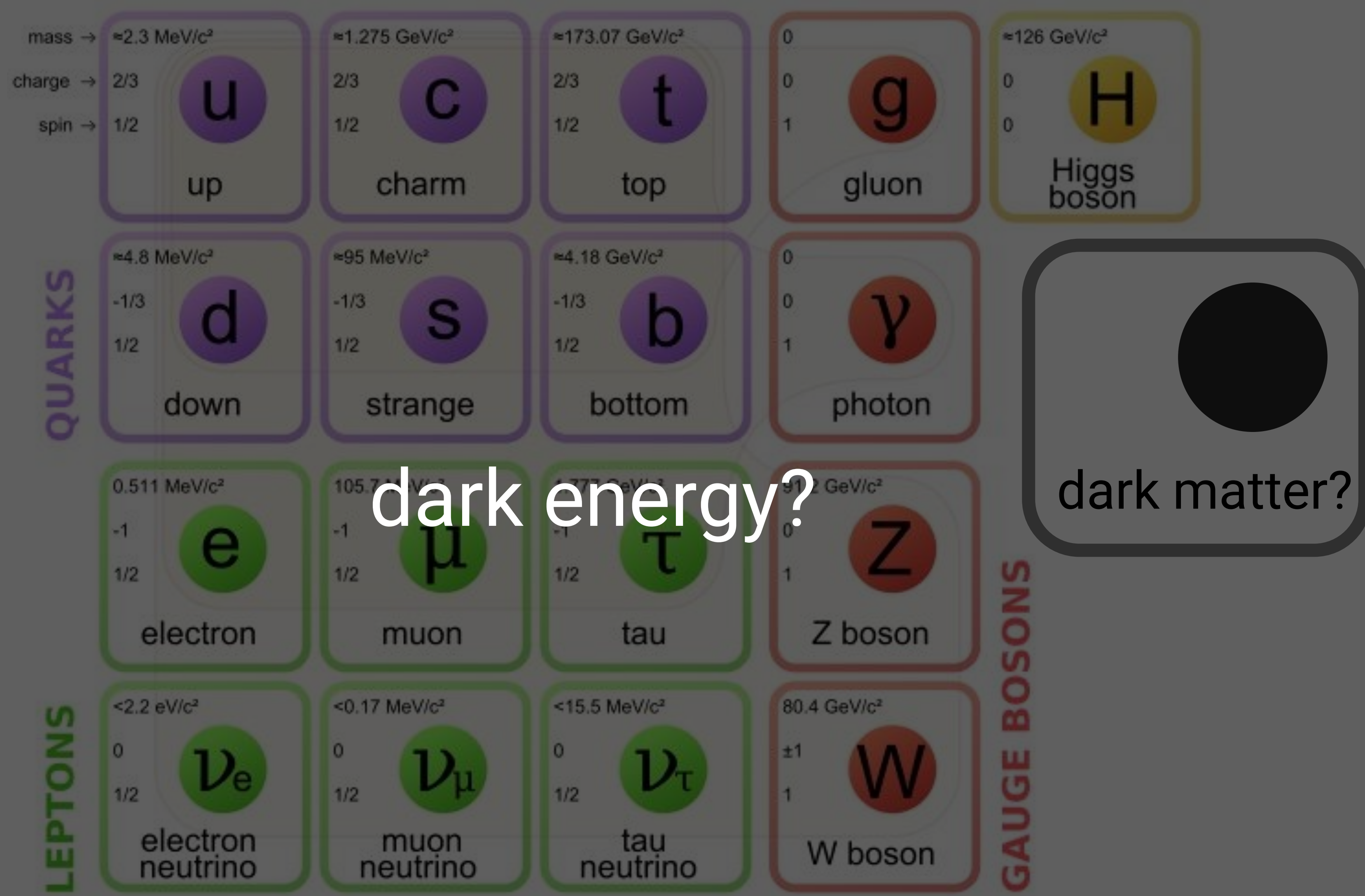

mass →
charge →
spin →
≈2.3 MeV/c²
2/3
1/2
u
up
≈1.275 GeV/c²
2/3
1/2
c
charm
≈173.07 GeV/c²
2/3
1/2
t
top
0
0
1
g
gluon
≈126 GeV/c²
0
0
H
Higgs boson
≈4.8 MeV/c²
-1/3
1/2
d
down
≈95 MeV/c²
-1/3
1/2
s
strange
≈4.18 GeV/c²
-1/3
1/2
b
bottom
0
0
1
γ
photon
0.511 MeV/c²
-1
1/2
e
electron
105.7 MeV/c²
-1
1/2
μ
muon
1.777 GeV/c²
-1
1/2
τ
tau
91.2 GeV/c²
0
1
Z
Z boson
<2.2 eV/c²
0
1/2
νe
electron neutrino
<0.17 MeV/c²
0
1/2
νμ
muon neutrino
<15.5 MeV/c²
0
1/2
ντ
tau neutrino
80.4 GeV/c²
±1
1
W
W boson
QUARKS
LEPTONS
GAUGE BOSONS


dark matter?

Universe =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dark energy?
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Hints of “New Physics”

- Dark matter
- Dark energy
- Neutrino mass
- Gauge coupling unification
- Higgs mass (“naturalness”)
- Muon “$g-2$”
- ...

New Physics Candidates

-
-
-
-

etc...

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- Dark matter
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New Physics Candidates

- SUSY [supersymmetry]
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-
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etc…

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-

Please fill this list with your models / models you like

etc…

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- Gauge-Higgs unification
- Hidden strong SU(N)
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etc…

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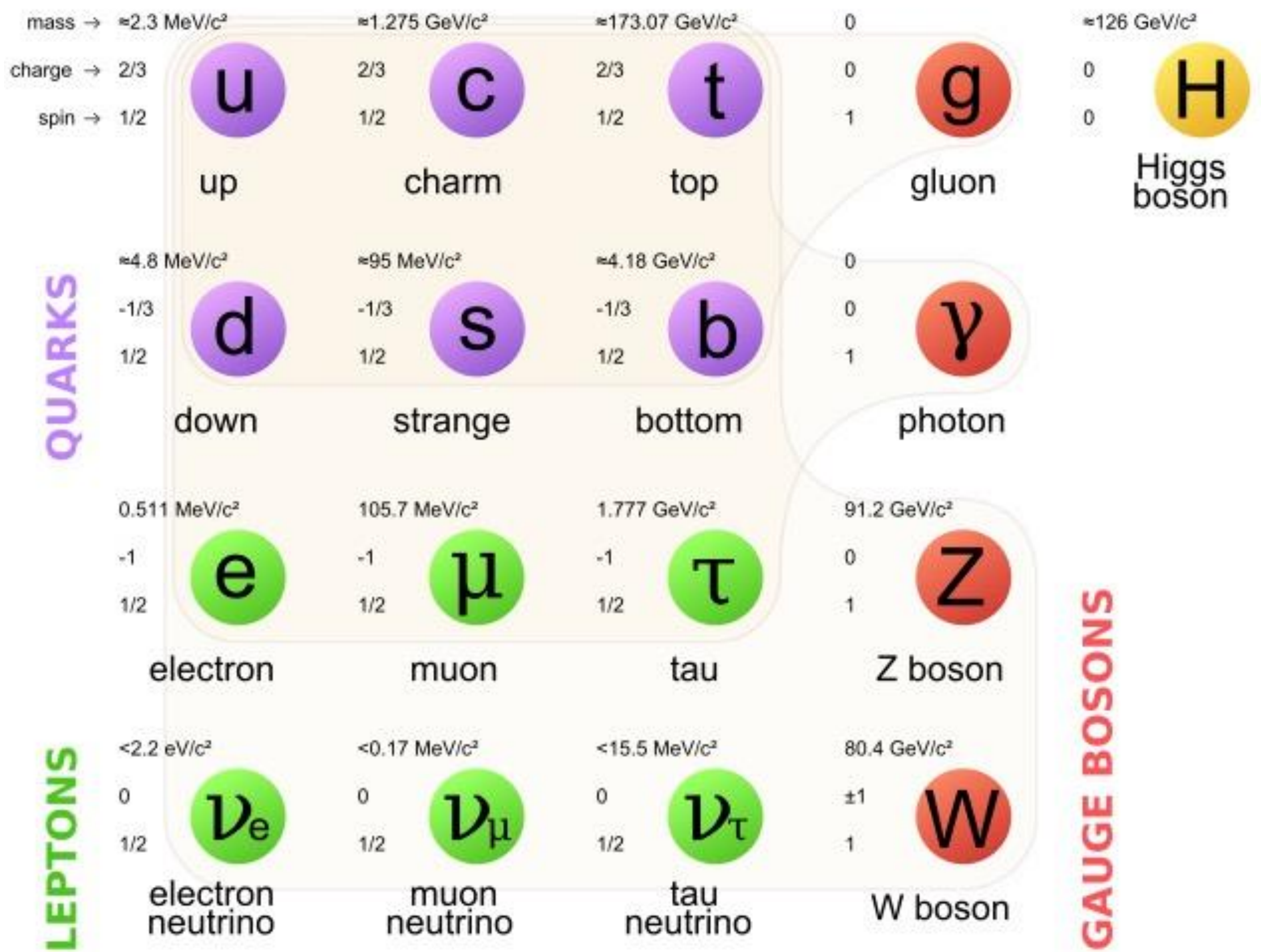
[Standard Model]

- SM =



[Minimal Supersymmetric Standard Model]

- MSSM =

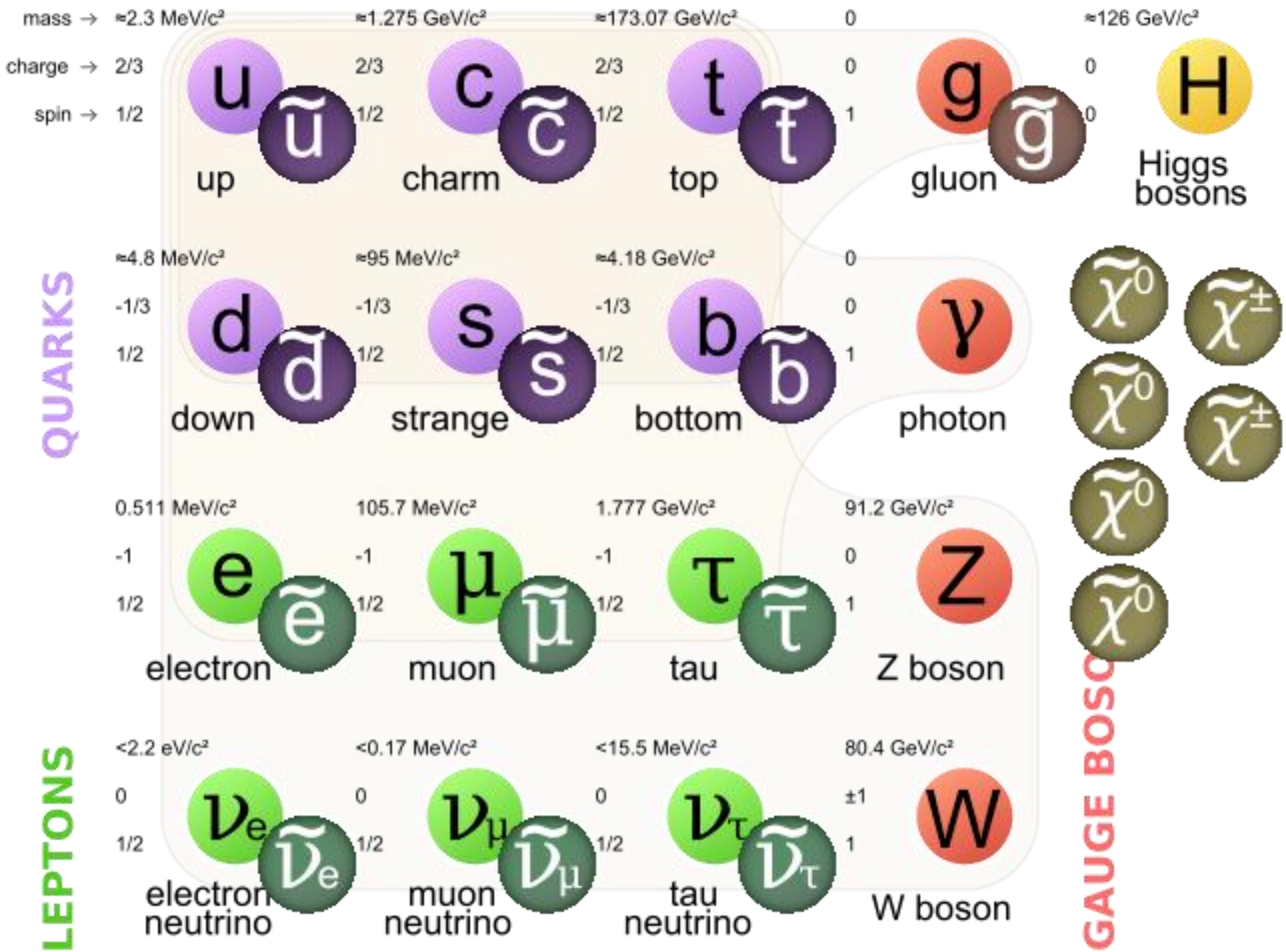


Image by MissBJ [CC BY 3.0], via Wikimedia Commons
(changes were made by S.I)

New Physics Candidates

- SUSY

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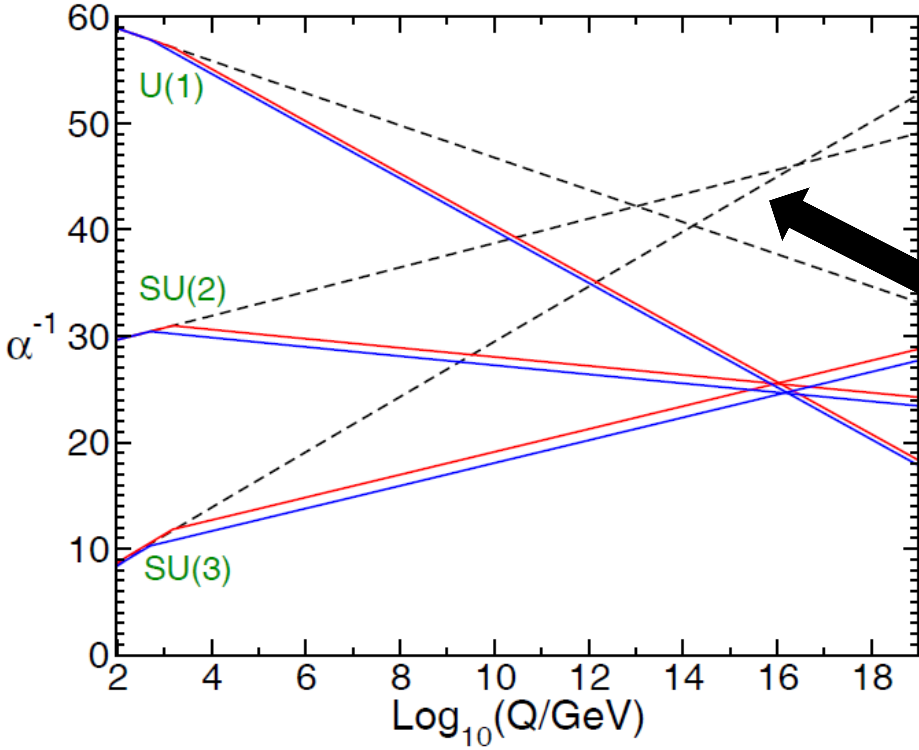
- SM ∋ 3 forces : U(1), SU(2), SU(3) [Why three?]

measured — theoretical prediction



- Gauge coupling unification

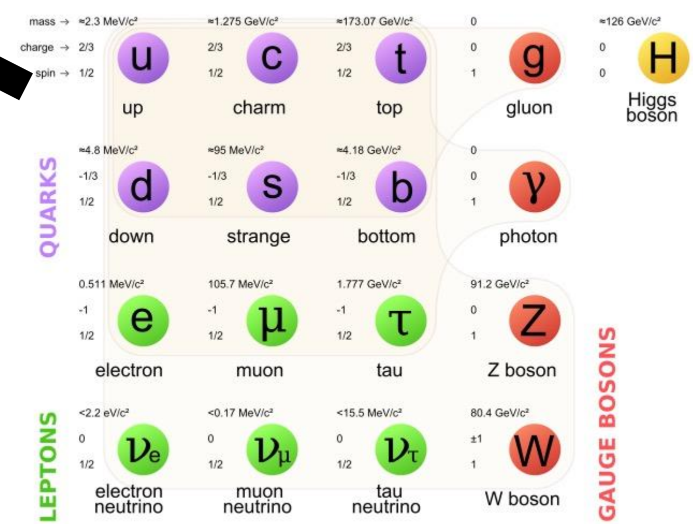


Figure from S. P. Martin, *A Supersymmetry Primer*, hep-ph/9709356

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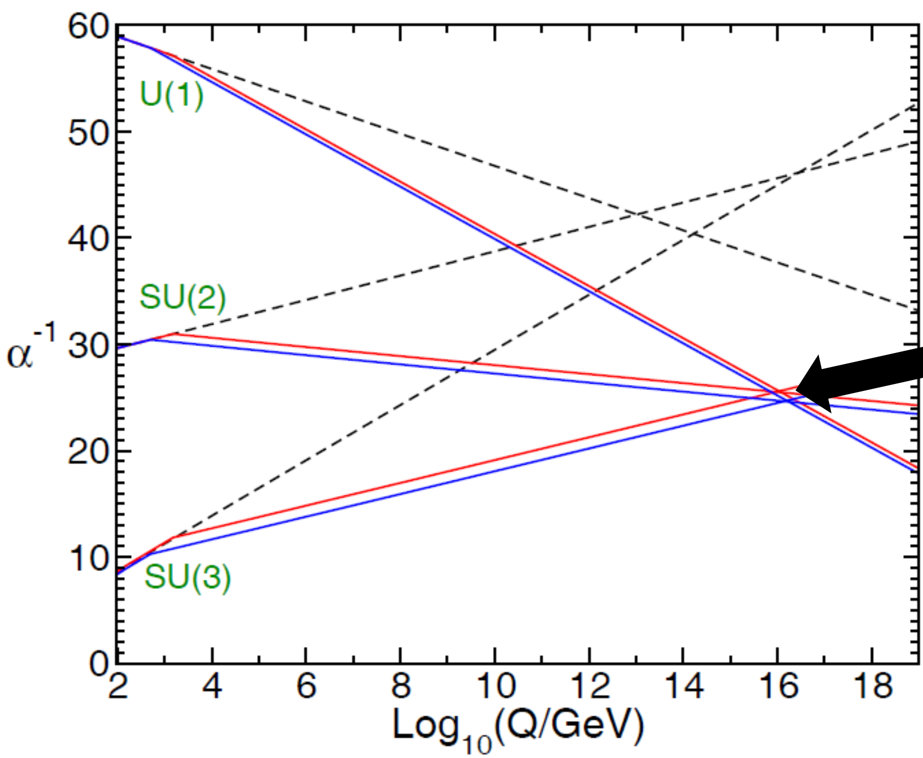

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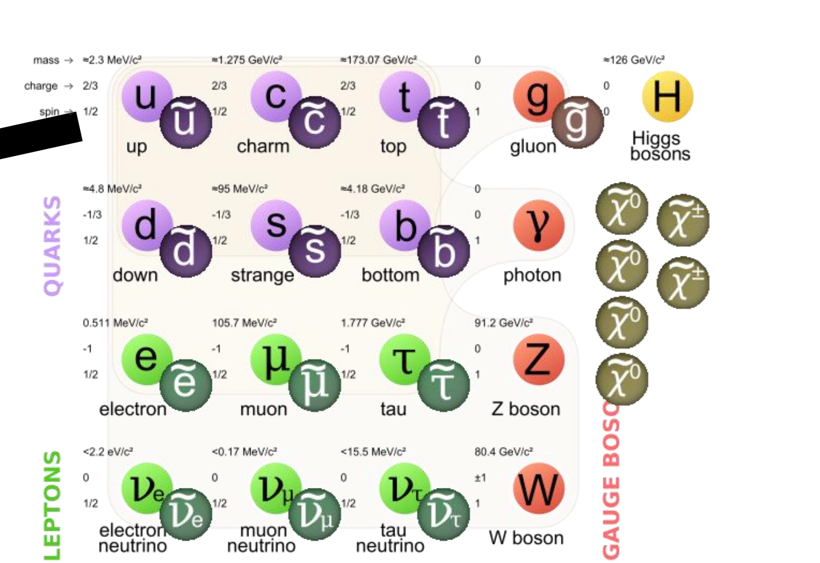

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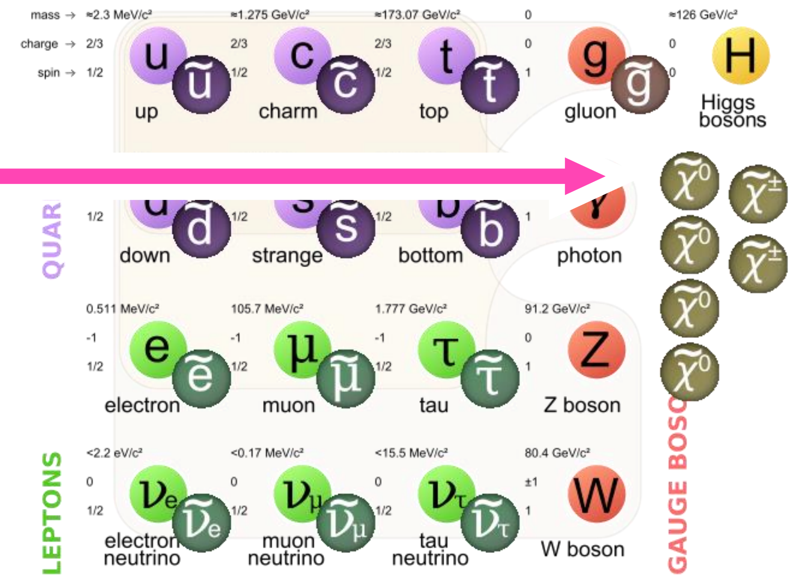
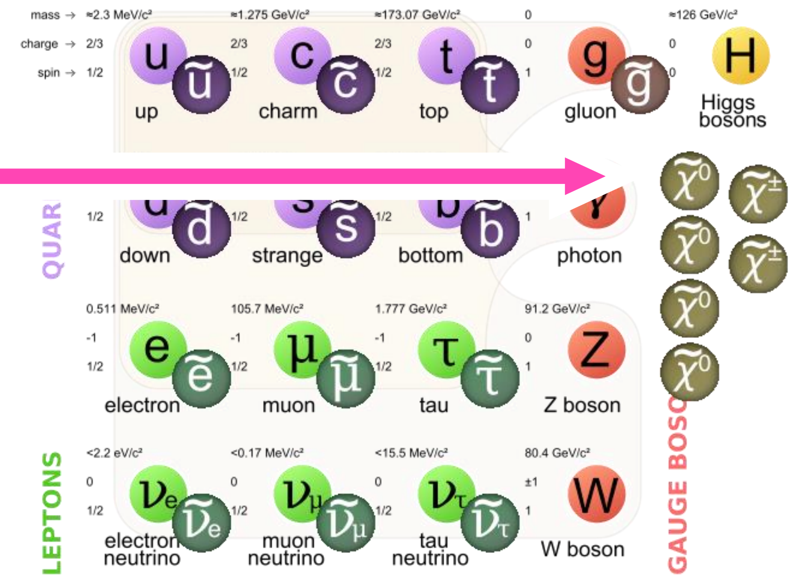
- MSSM ⊃ Dark matter candidate



- Dark matter?
  - stable (at least 10^{10} yr)
  - charge neutral ✓
  - density $\Omega h^2 = 0.12$
  - not detected by astrophysics / direct search / LHC

- MSSM $\ni$ Dark matter candidate



- Dark matter?

if we introduce R-parity

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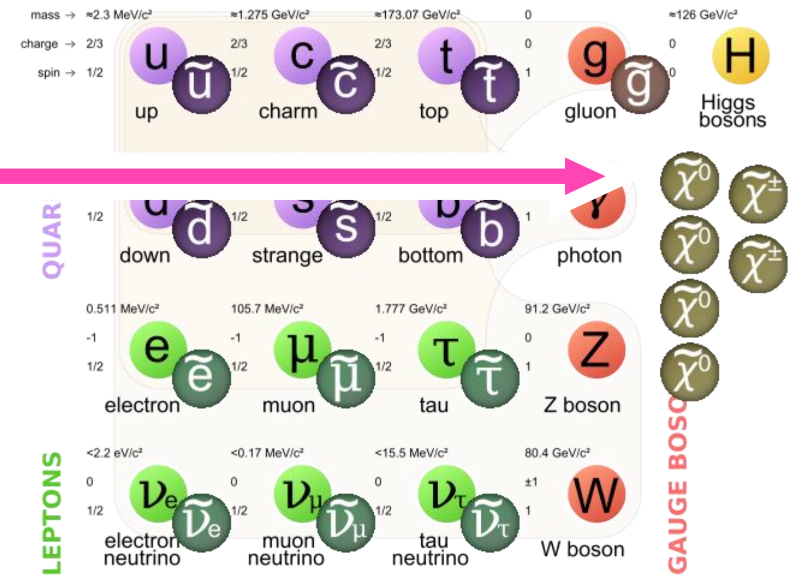
- MSSM ∋ Dark matter candidate



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$$\tilde{\chi}^0 = \tilde{B} \oplus \widetilde{W}^0 \oplus \tilde{H}_d^0 \oplus \tilde{H}_u^0$$

- $\tilde{B}$-like? → "overabundant" problem
- $\widetilde{W}$-like?
- $\tilde{H}$-like?

$$\Omega h^2 \gg 0.12$$

Neutralino relic density

$$\tilde{\chi}^0 = \tilde{B} \oplus \widetilde{W}^0 \oplus \tilde{H}^0_{\mathrm{d}} \oplus \tilde{H}^0_{\mathrm{u}}$$

- $\tilde{B}$-like? → "overabundant" problem
- $\widetilde{W}$-like?
- $\tilde{H}$-like?

$$\Omega h^2 \gg 0.12$$

⇒ **MSSM 4G model**

Introduction: why overabundant?

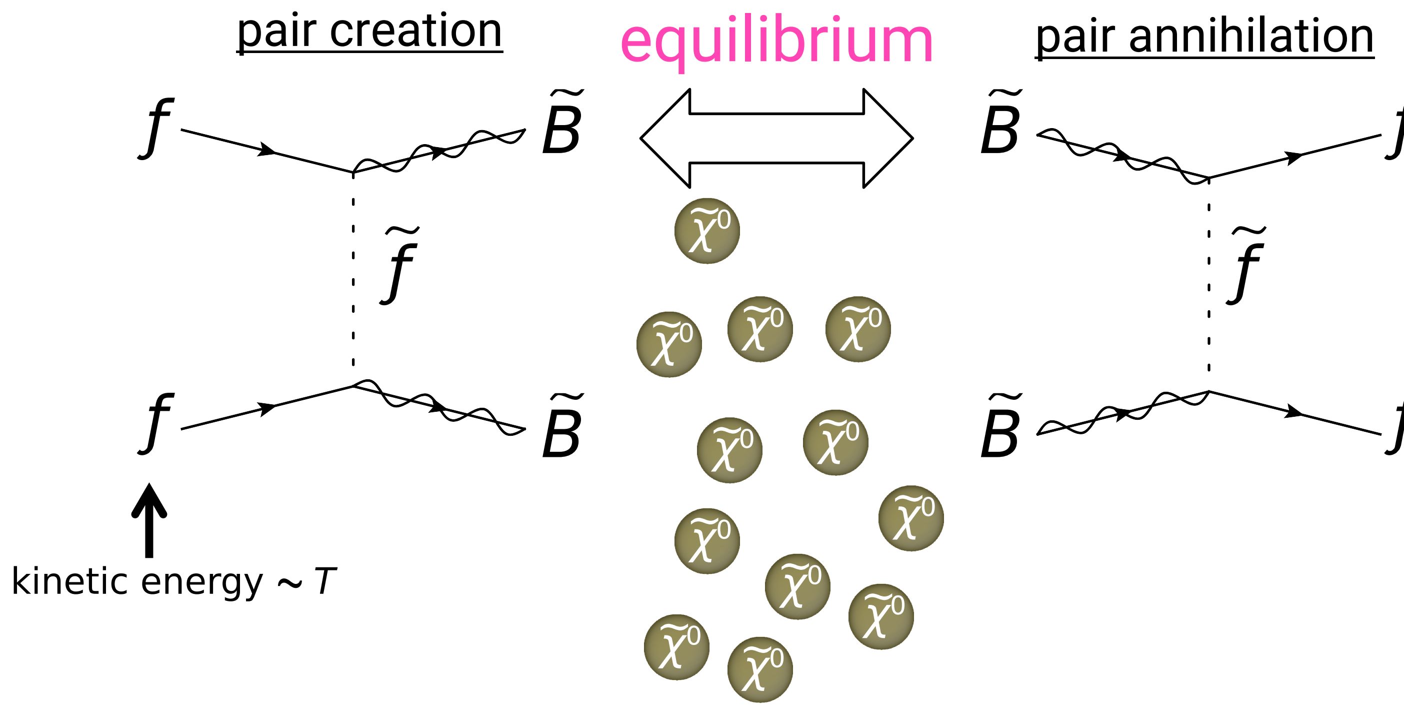
Model: **MSSM4G** solves overabundance.

Analysis:

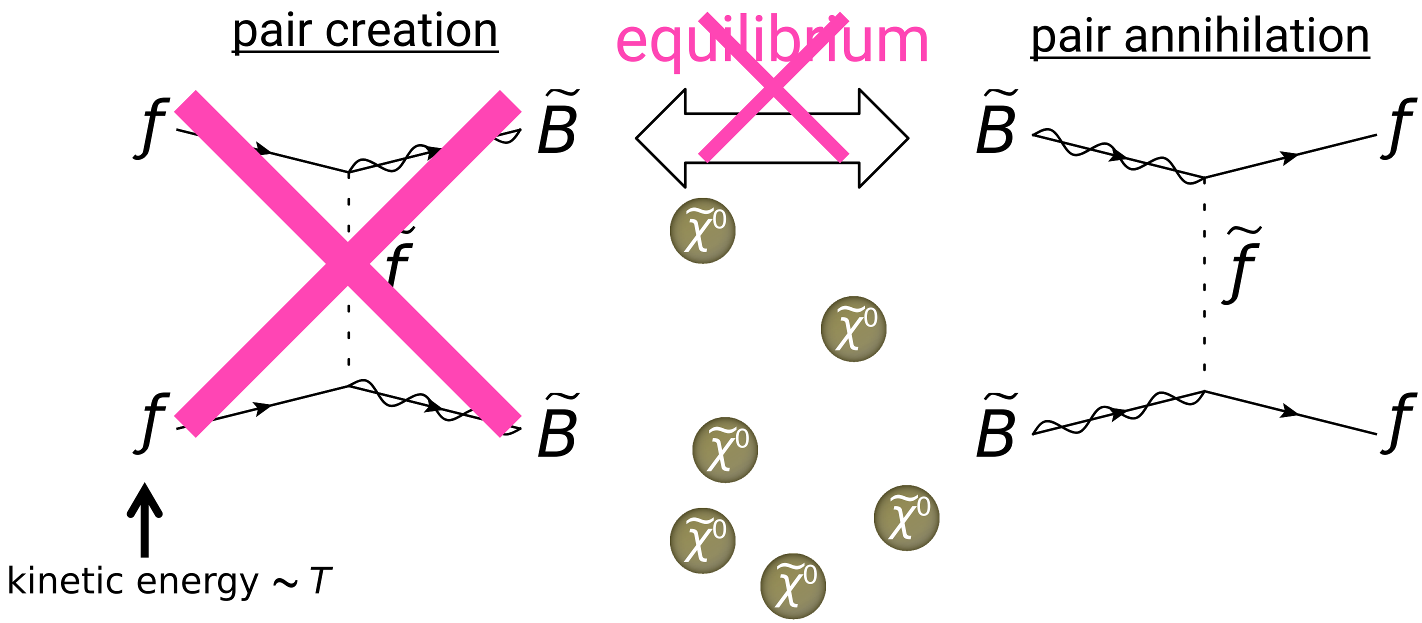
- cosmic rays (CTA, Fermi, MAGIC)
- colliders (LHC)
- direct detection (LUX)

Summary with discussion seeds

- Early Universe with $T > m_{\tilde{B}}$



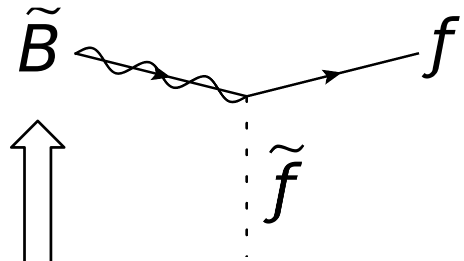
- Early Universe with $T \lesssim m_{\tilde{B}}$

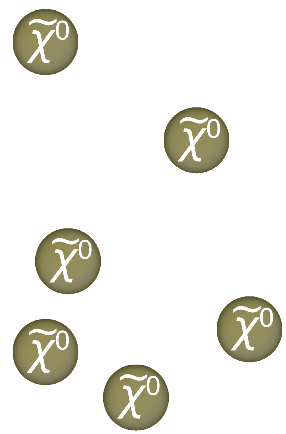


- Early Universe with $T \lesssim m_{\tilde{B}}/20$

pair creation

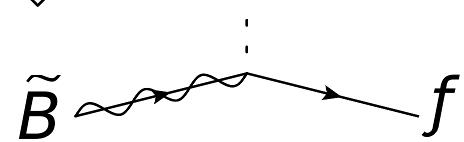
pair annihilation





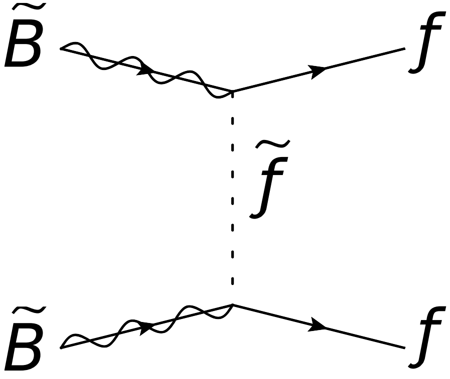
"relic density"

far apart due to
- pair annihilation
- Universe's expansion



- "observed" relic density Ωh^2

⇦ "proper" crosssection $\langle \sigma v \rangle$ of (DM)(DM)→SM



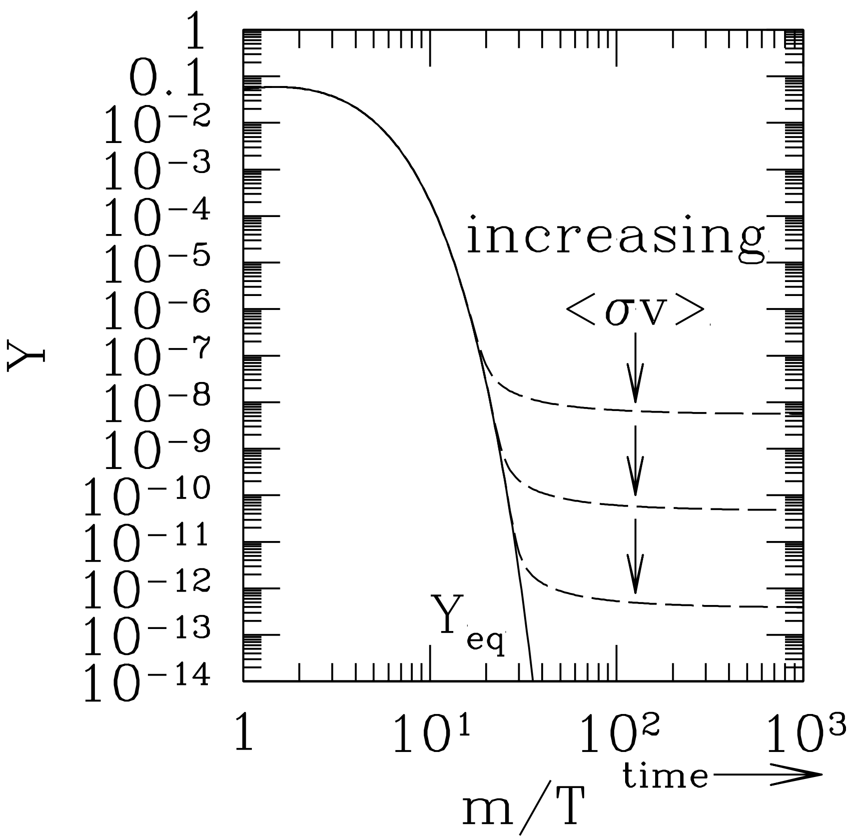
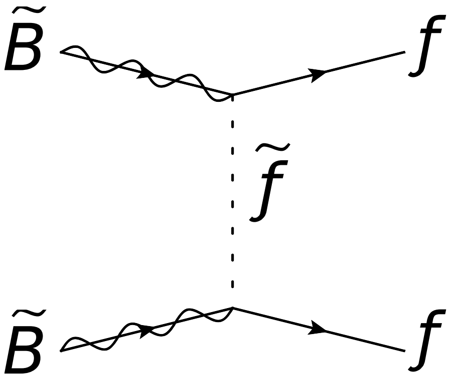


Figure from Gelmini and Gondolo, [1009.3690]

- "observed" relic density Ωh^2

⟸ "proper" crosssection $\langle \sigma v \rangle$ of (DM)(DM)→SM



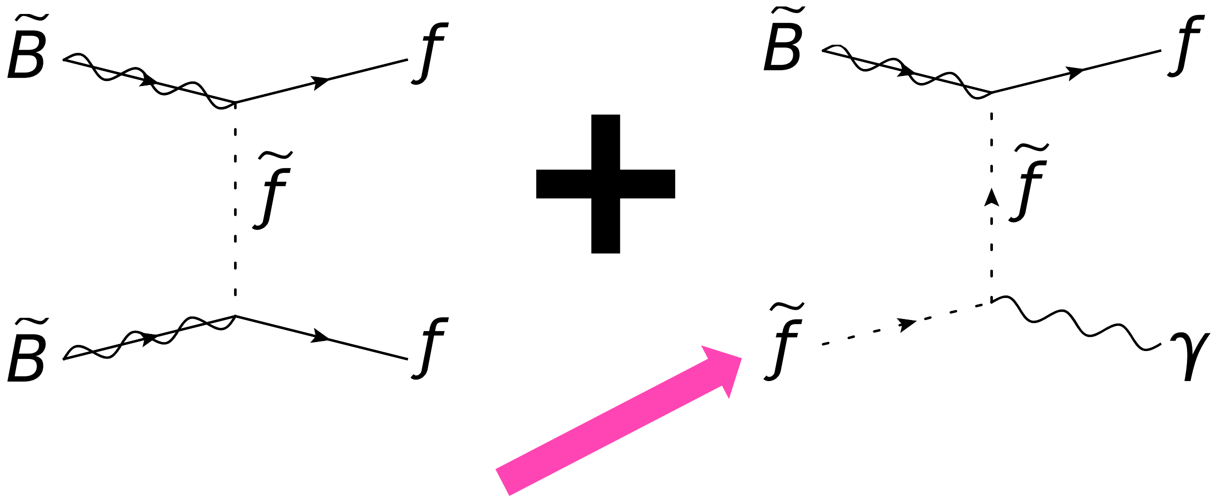
- pure $\tilde{B}$-DM (i.e., LSP $\tilde{\chi}^0$ is $\tilde{B}$-like)
  - $\langle \sigma v \rangle$ strongly depends on $m_{\tilde{f}}$

↳ $m_{\tilde{f}} \sim 100$ GeV

$$m_{\tilde{f}} \gg 100 \text{ GeV} \Longrightarrow \langle \sigma v \rangle \text{ too small}$$

$\Longrightarrow$ "overabundant" problem

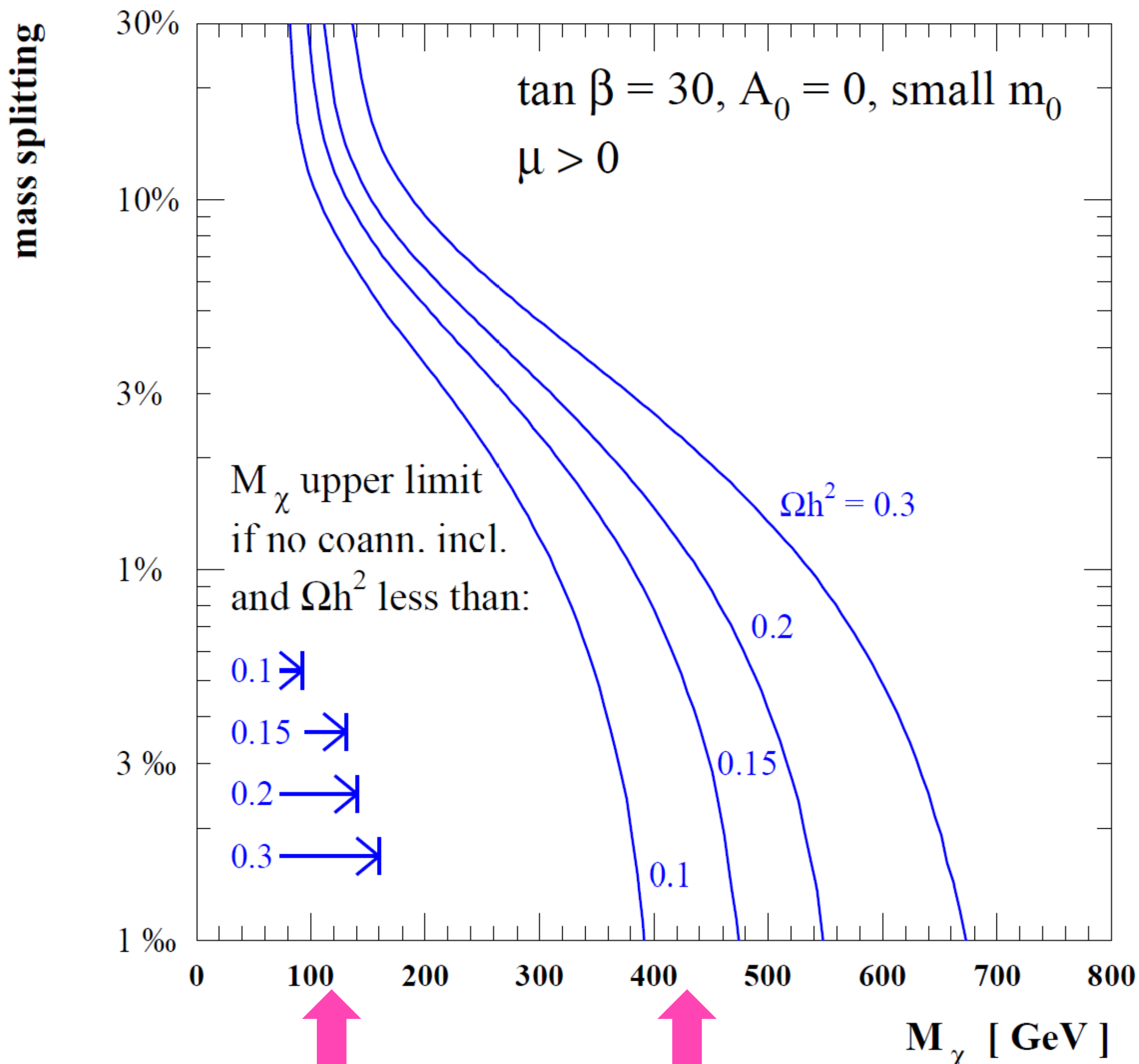
- An old solution to increase $\langle \sigma v \rangle$: "co-annihilation"



mass splitting $\dfrac{m_{\tilde{f}} - m_{\tilde{B}}}{m_{\tilde{B}}} \ll 1$

- An c … on"

An example in CMSSM with $\tilde{\tau}$-coann.:



f

γ

Figure from Ed…ö, Schelke, Ullio, Gondolo, hep-ph/0301106

Introduction: why overabundant?

Model: MSSM4G solves overabundance.

Analysis:

- cosmic rays (CTA, Fermi, MAGIC)
- colliders (LHC)
- direct detection (LUX)

Summary with discussion seeds

- MSSM = **3G**enerations

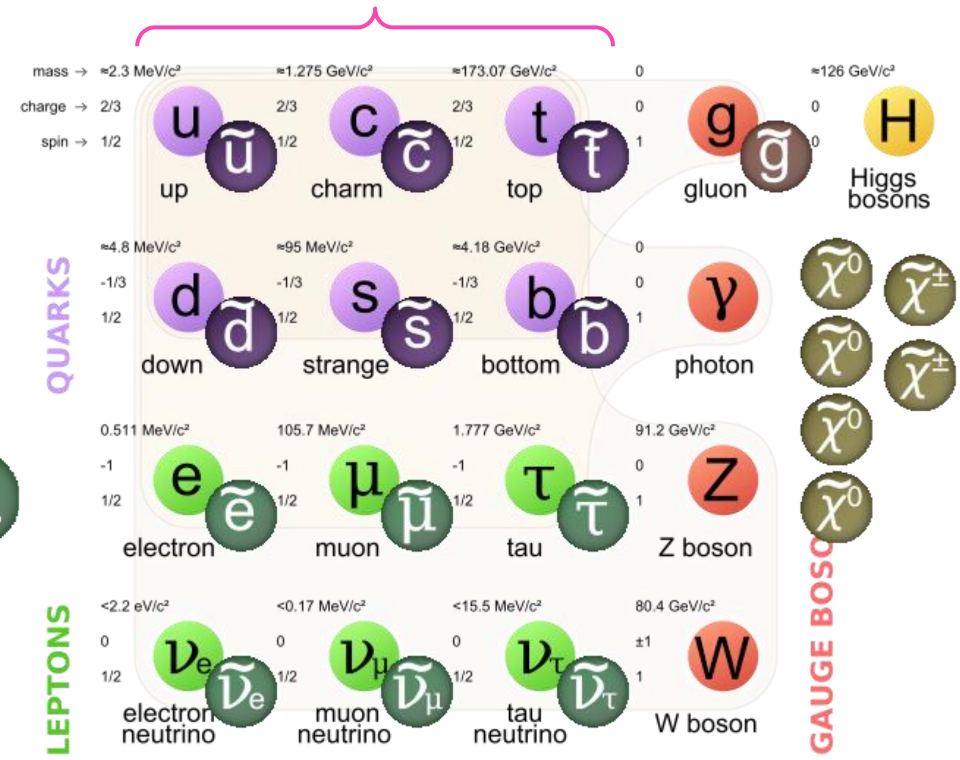
+

extra vector-like

4^th^-Generation lepton

=

MSSM4G



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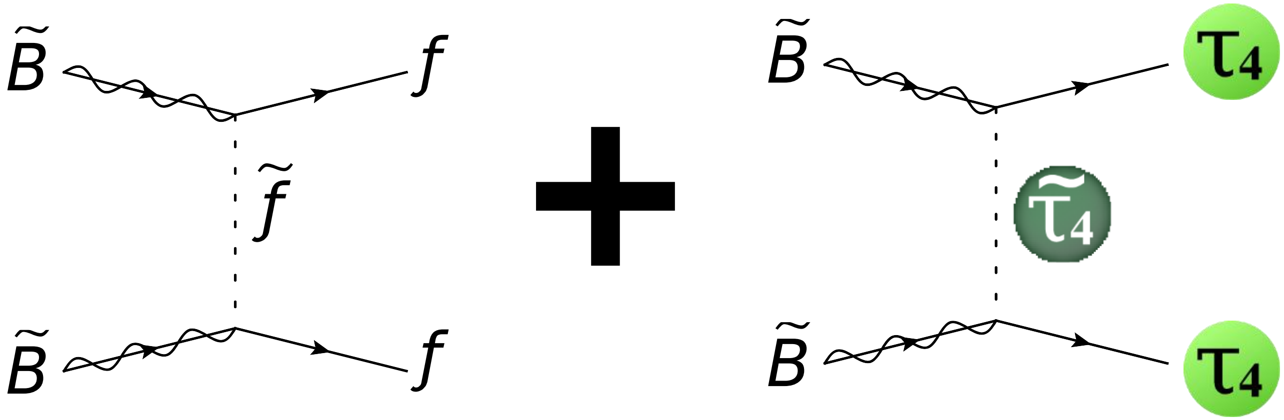
(changes were made by S.I)

- A new solution to increase $\langle \sigma v \rangle$: MSSM4G



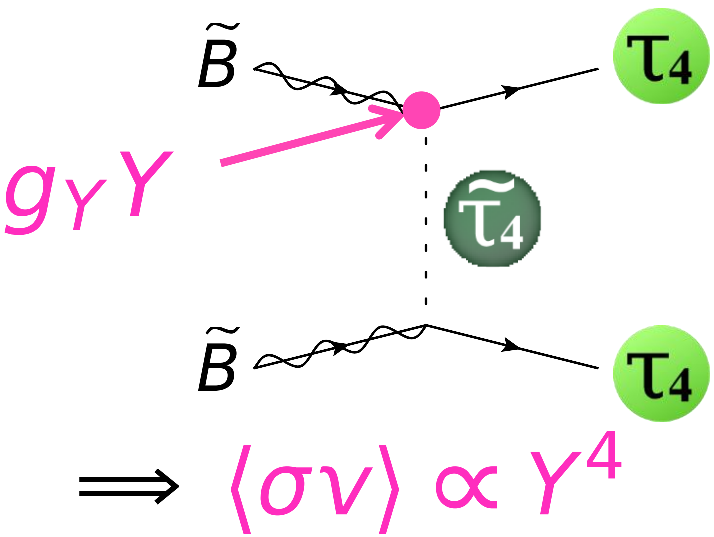
extra annihilation channel
→ larger $\langle \sigma v \rangle$
→ "proper" Ωh^2

if $\tilde{\tau}_4 \gtrsim \tilde{B} > \tau_4$

$$(Q_i, \bar{U}_i, \bar{D}_i, L_i, \bar{E}_i) + (H_u, H_d) \quad \text{[MSSM]}$$

$(i = 1 \ldots 3)$

$$+(E_4, \bar{E}_4) \quad \text{[MSSM4G]}$$

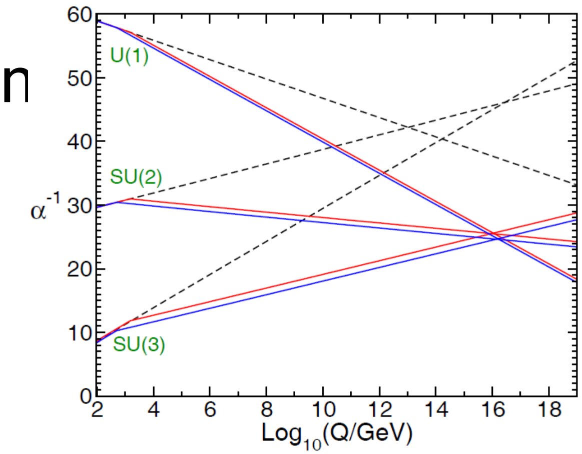


	$SU(3)_{color}$	$SU(2)_{weak}$	$U(1)_Y$
Q_i	$\mathbf{3}$	$\mathbf{2}$	$1/6$
$\bar{U}_i$	$\bar{\mathbf{3}}$	$\mathbf{1}$	$-2/3$
$\bar{E}_i$	$\mathbf{1}$	$\mathbf{1}$	1
$\bar{D}_i$	$\bar{\mathbf{3}}$	$\mathbf{1}$	$1/3$
L_i	$\mathbf{1}$	$\mathbf{2}$	$-1/2$
H_u	$\mathbf{1}$	$\mathbf{2}$	$1/2$
H_d	$\mathbf{1}$	$\mathbf{2}$	$-1/2$
$\bar{E}_4$	$\mathbf{1}$	$\mathbf{1}$	1
E_4	$\mathbf{1}$	$\mathbf{1}$	-1

$$W = Y_u H_u Q \bar{U} + Y_d H_d Q \bar{D} + Y_e H_d L \bar{E}$$

$$+ M_{E_4} E_4 \bar{E}_4 + \epsilon_i H_d L_i \bar{E}_4$$

[vector-like mass] [mixing with SM leptons]



- MSSM + $E\bar{E}$ → breaks coupling unification

- QUE model : MSSM + $Q\bar{Q}U\bar{U}E\bar{E}$
  - ✓ gauge coupling unification
  - ✓ SU(5) GUT
  - ➢ extra $H_u Q_4 \bar{U}_4$ interaction → m_h UP

- QDEE model : MSSM + $Q\bar{Q}D\bar{D}E\bar{E}E\bar{E}$
  - ✓ gauge coupling unification
  - ✗ SU(5) GUT
  - ➢ extra $H_d Q_4 \bar{D}_4$ coupling → m_h slightly UP

- MSSM + $E\bar{E}$ → breaks coupling unification

- QUE model : MSSM + $Q\bar{Q}U\bar{U}E\bar{E}$

⇨ MSSM + $T_4, B_4, t_4, \tau_4,$

$\tilde{T}_{4L}, \tilde{T}_{4R}, \tilde{B}_{4L}, \tilde{B}_{4R}, \tilde{t}_{4L}, \tilde{t}_{4R}, \tilde{\tau}_{4L}, \tilde{\tau}_{4R}$

- QDEE model : MSSM + $Q\bar{Q}D\bar{D}E\bar{E}E\bar{E}$

⇨ MSSM + $T_4, B_4, b_4, \tau_4, \tau_5,$

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- MSSM + $E\bar{E}$ → breaks coupling

Other working assumptions

- $M_1 \ll \mu \ll M_2$
  → LSP $\tilde{\chi}_1^0$ is $\tilde{B}$-like
- All the other SUSY particles & extra Higgses are decoupled.

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⇨ MSSM + ~~$T_4, B_4, t_4,$~~ $\tau_4,$

~~$\tilde{T}_{4L}, \tilde{T}_{4R}, \tilde{B}_{4L}, \tilde{B}_{4R}, \tilde{t}_{4L}, \tilde{t}_{4R},$~~ $\tilde{\tau}_{4L}, \tilde{\tau}_{4R}$

assumed to be “decoupled” (very heavy) and we will ignore them.

- QDEE model : MSSM + $Q\bar{Q}D\bar{D}E\bar{E}E\bar{E}$

⇨ MSSM + ~~$T_4, B_4, b_4,$~~ $\tau_4, \tau_5,$

~~$\tilde{T}_{4L}, \tilde{T}_{4R}, \tilde{B}_{4L}, \tilde{B}_{4R}, \tilde{b}_{4L}, \tilde{b}_{4R},$~~ $\tilde{\tau}_{4L}, \tilde{\tau}_{4R}, \tilde{\tau}_{5L}, \tilde{\tau}_{5R}$

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⇨ SM + $\tilde{\chi}_1^0(\approx \tilde{B})$, τ_4,

$\tilde{\tau}_{4L}, \tilde{\tau}_{4R}$ (assumed to be equal-mass)

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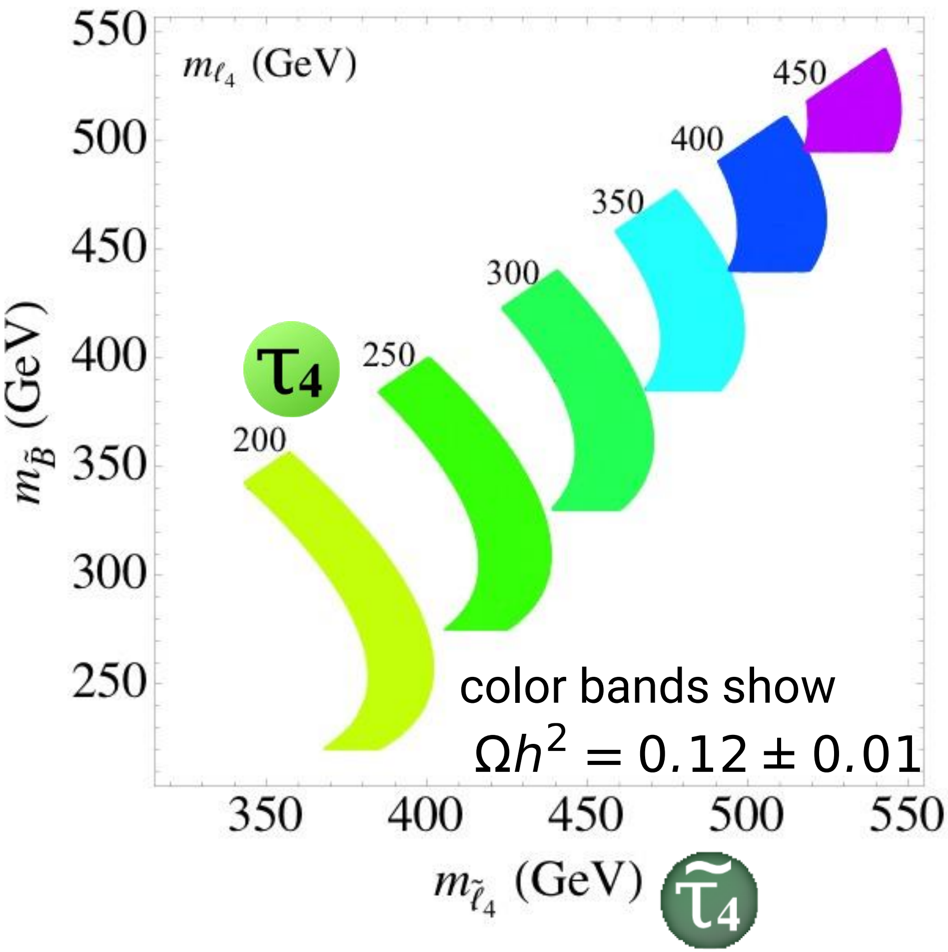
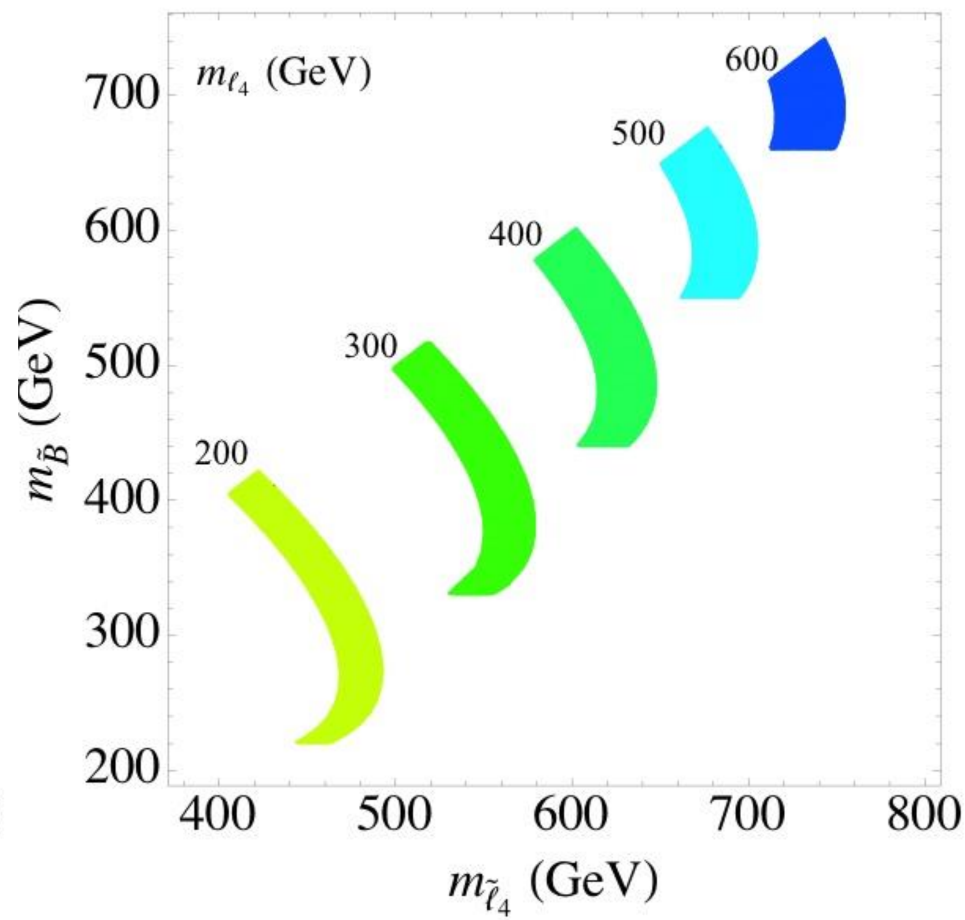
$\tilde{\tau}_{4L}, \tilde{\tau}_{4R}, \tilde{\tau}_{5L}, \tilde{\tau}_{5R}$ (assumed to be equal-mass)

QUE model

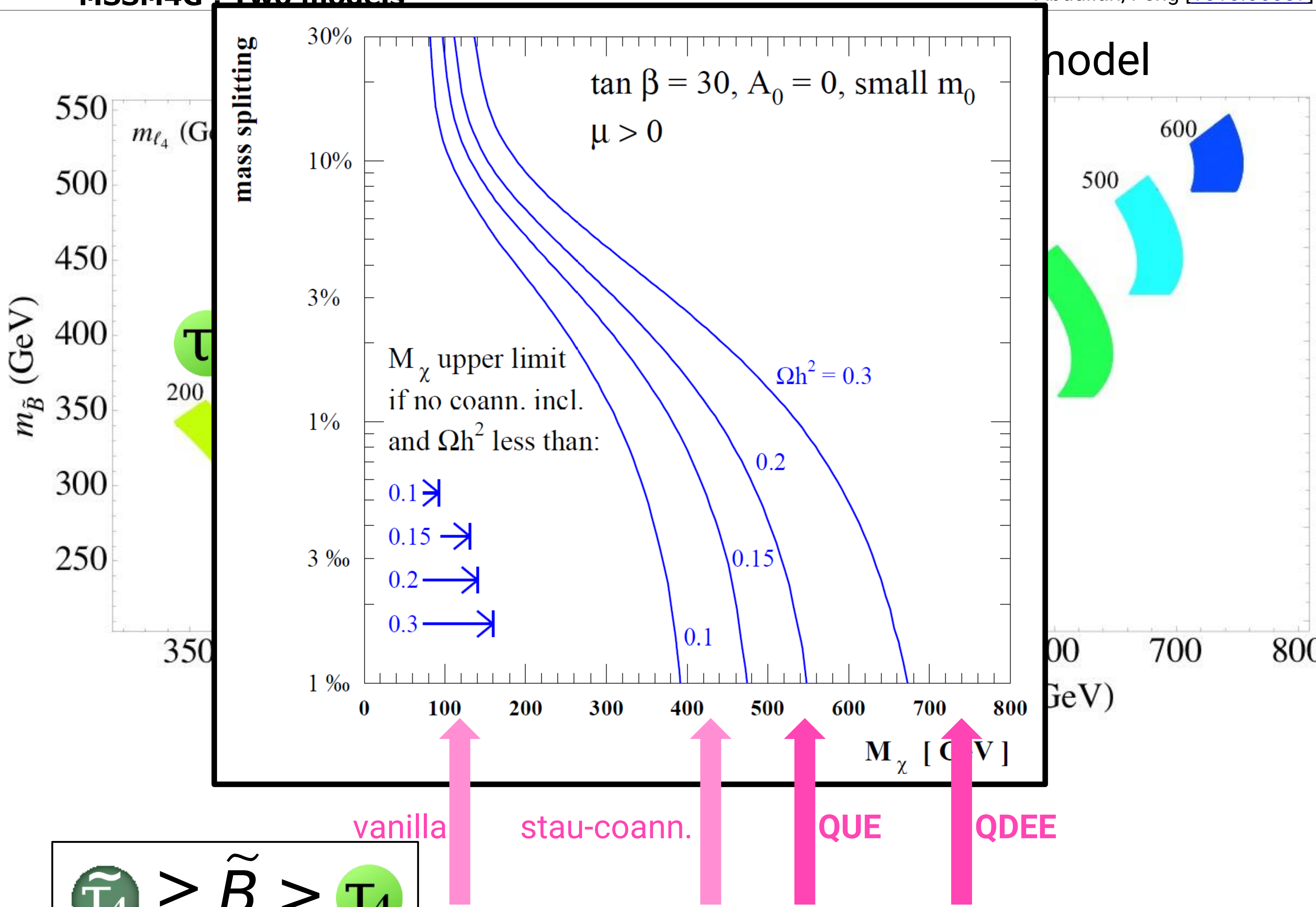


QDEE model



$$\tilde{\tau}_4 \gtrsim \tilde{B} > \tau_4$$

Abdullah, Feng [1510.06089]



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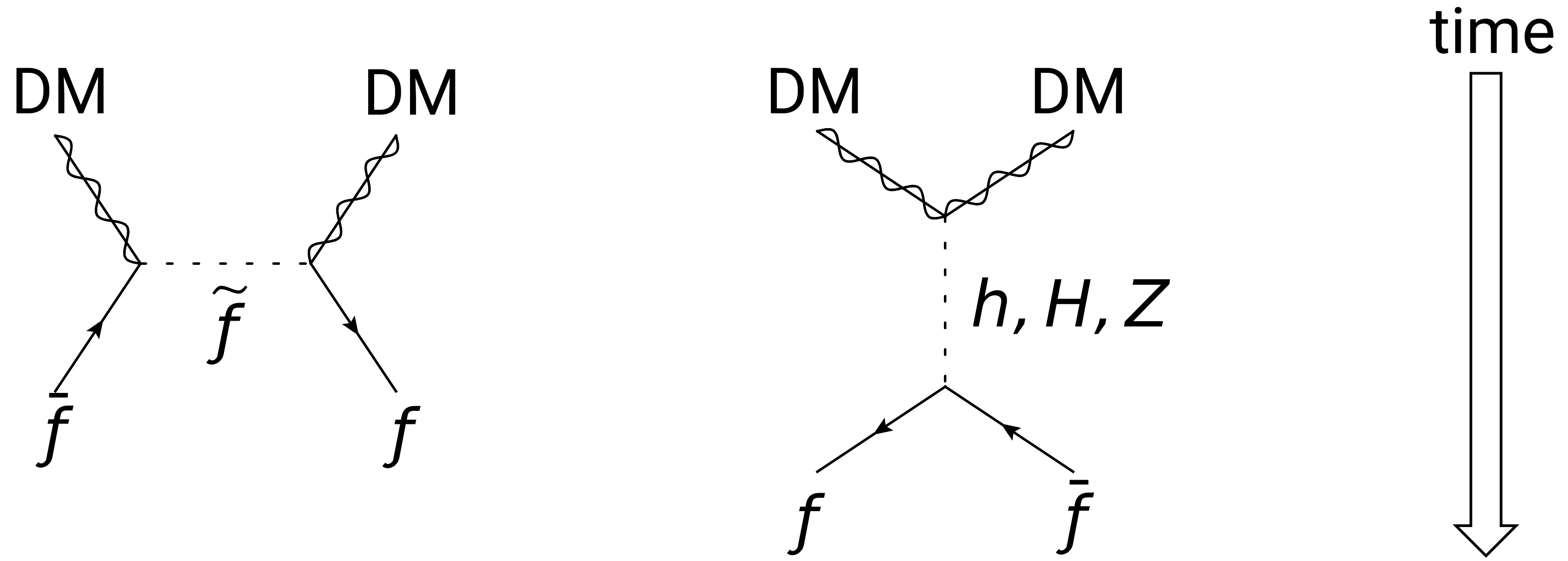

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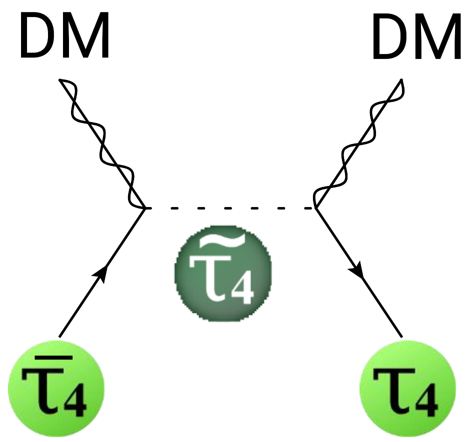
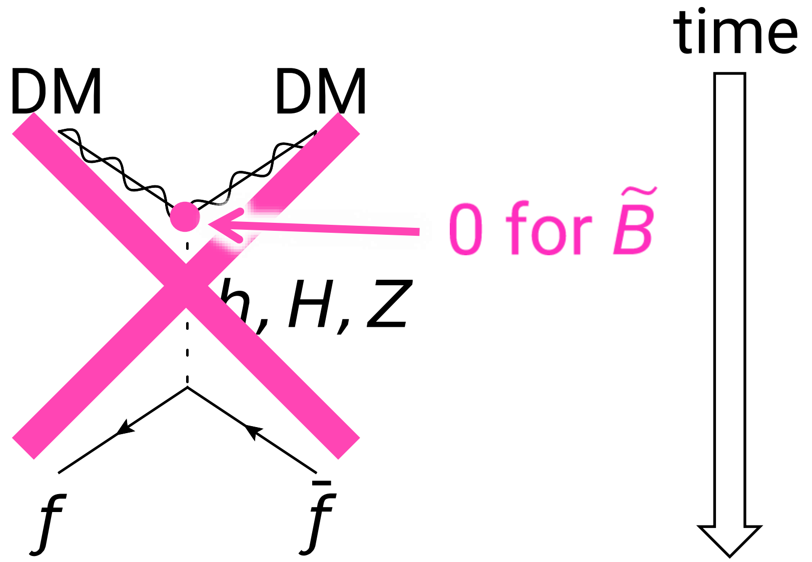
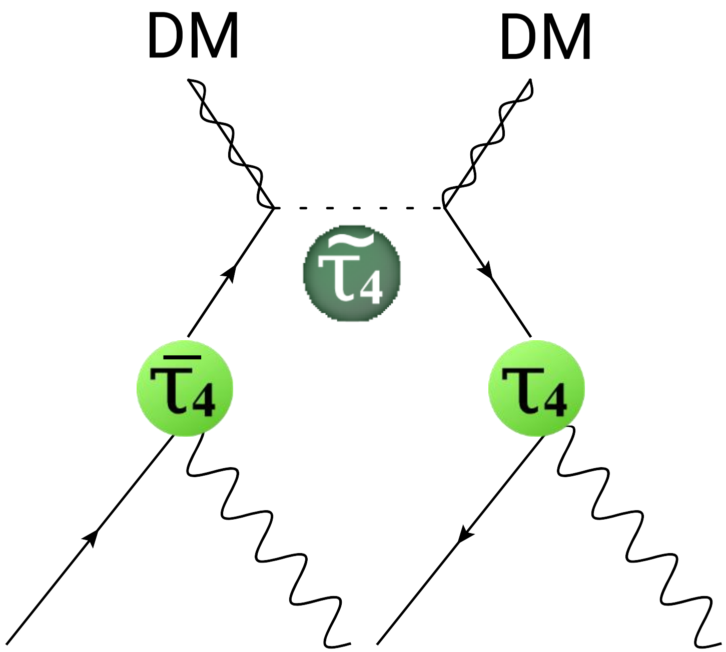




- DM indirect detection (= searches for DM DM $\to \tau_4 \bar{\tau}_4$)



$$\tau_4 \longrightarrow \begin{cases} W + \nu \\ Z + l \\ h + l \end{cases} \quad \left(\begin{array}{l} \nu = \nu_e, \nu_\mu, \nu_\tau \\ l = e, \mu, \tau \end{array} \right)$$

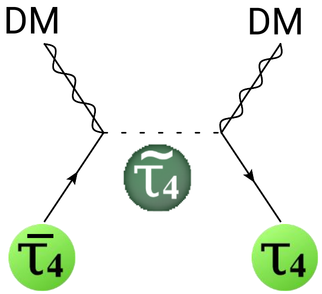
$$W\nu : Zl : hl \sim 2 : 1 : 1$$

$$W \ni Y_{\mathrm{e}} H_{\mathrm{d}} L \bar{E} + M_{E_4} E_4 \bar{E}_4 + \epsilon_i H_{\mathrm{d}} L_i \bar{E}_4$$

[vector-like mass] [mixing with SM leptons]

- DM indirect detection

$$W \ni Y_{\mathrm{e}} H_{\mathrm{d}} L \bar{E} + M_{E_4} E_4 \bar{E}_4 + \epsilon_i H_{\mathrm{d}} L_i \bar{E}_4$$



$W\nu : Zl : hl \sim 2:1:1$

	DM DM→
$\tau_{4(5)}$ mixes with e	W^+W^- ZZ hh $\nu\bar{\nu}$ e^+e^-
$\tau_{4(5)}$ mixes with μ	W^+W^- ZZ hh $\nu\bar{\nu}$ $\mu^+\mu^-$
$\tau_{4(5)}$ mixes with τ	W^+W^- ZZ hh $\nu\bar{\nu}$ $\tau^+\tau^-$

- DM indirect detection

$$W \ni Y_e H_d L \bar{E} + M_{E_4} E_4 \bar{E}_4 + \epsilon_i H_d L_i \bar{E}_4$$

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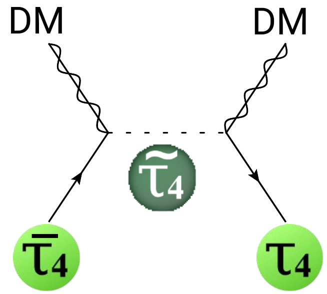


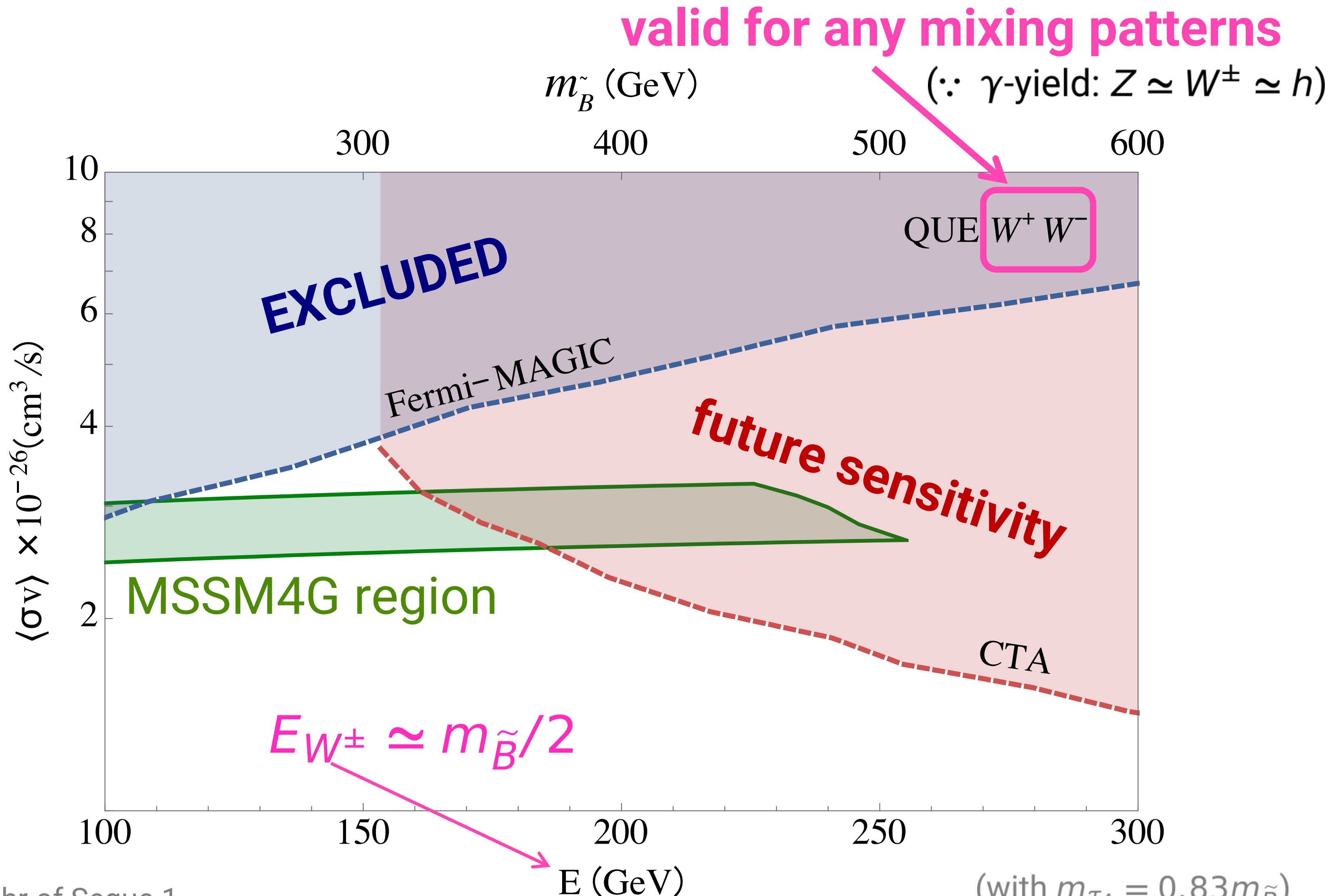
insensitive (IceCube)

less sensitive / large BKG uncertainty

	DM DM→				
$\tau_{4(5)}$ mixes with e	W^+W^-	ZZ	hh	$\nu\bar{\nu}$	e^+e^-
$\tau_{4(5)}$ mixes with μ	W^+W^-	ZZ	hh	$\nu\bar{\nu}$	$\mu^+\mu^-$
$\tau_{4(5)}$ mixes with τ	W^+W^-	ZZ	hh	$\nu\bar{\nu}$	$\tau^+\tau^-$

$\rightarrow \pi^0 \rightarrow \gamma$

$\rightarrow \cdots \rightarrow \gamma$



(with $m_{\tau_4} = 0.83 m_{\tilde{B}}$)

MAGIC: 158 hr of Segue 1

Fermi-LAT: 6 yr of 15 dSph (incl. Segue 1)

DM profile: NFW

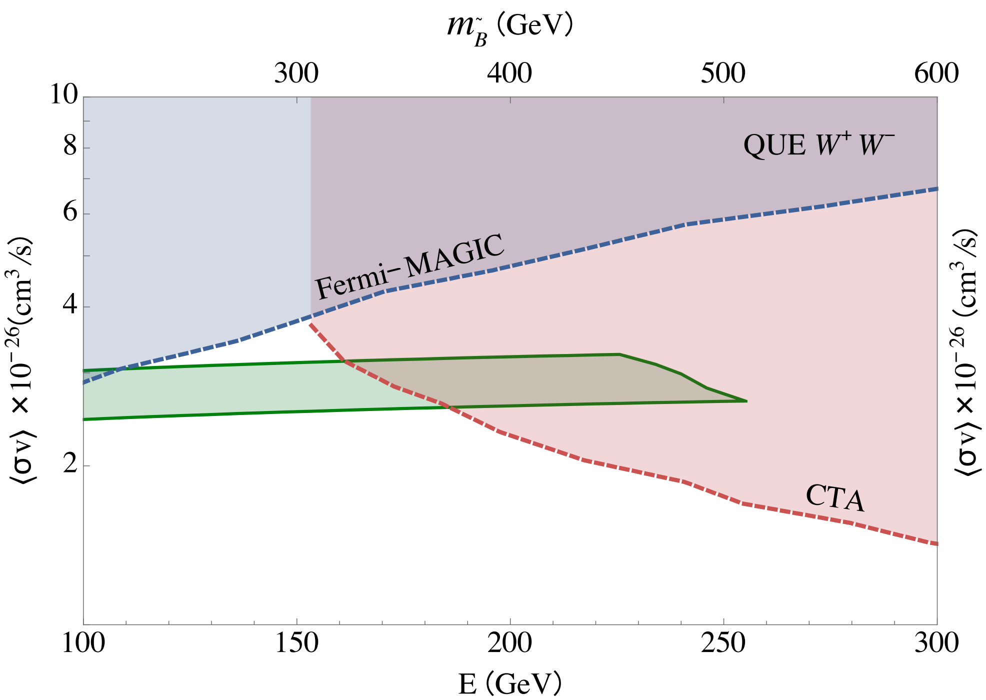
Fermi-LAT dominates MAGIC in almost all *E*-range.

CTA prospect : 500hr of Milky Way

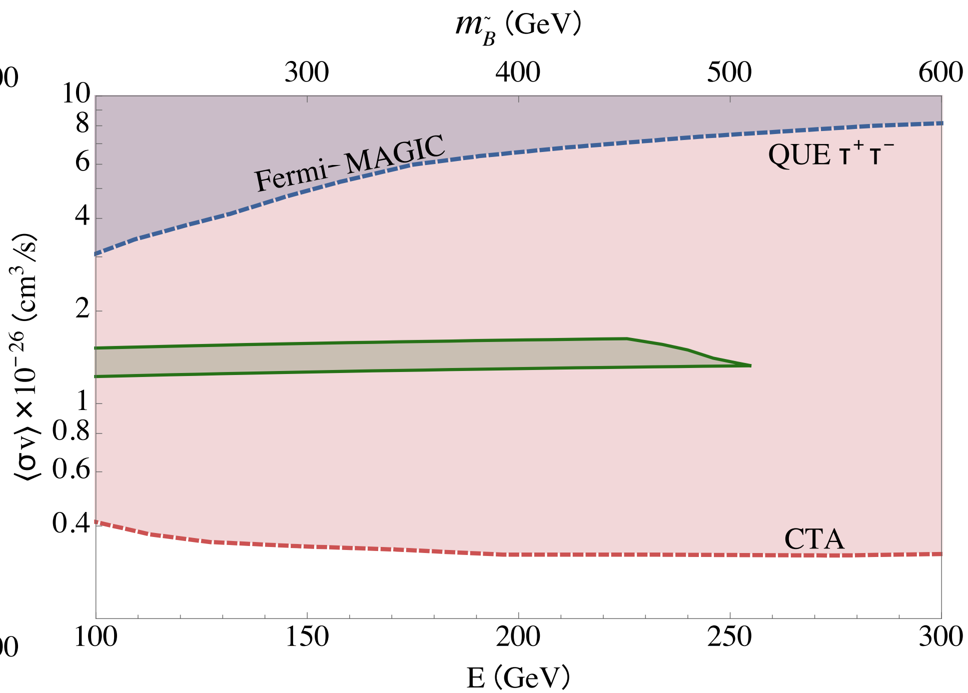
DM profile: Einasto

No syst. unc. (stat only)

WW (any mixing pattern)



ττ (only for τ-mixing cases)



✓ τ-mixing fully covered

✓ e/μ-mixing with $m_{\tilde{B}} > 340{-}380$ GeV covered

(with $m_{\tau 4} = 0.83 m_{\tilde{B}}$)

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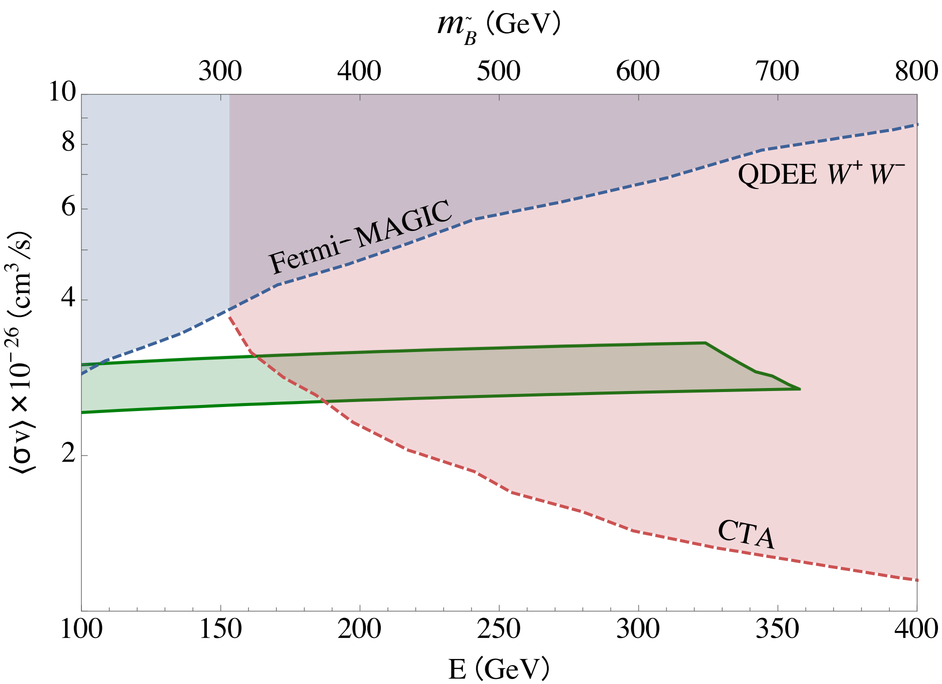

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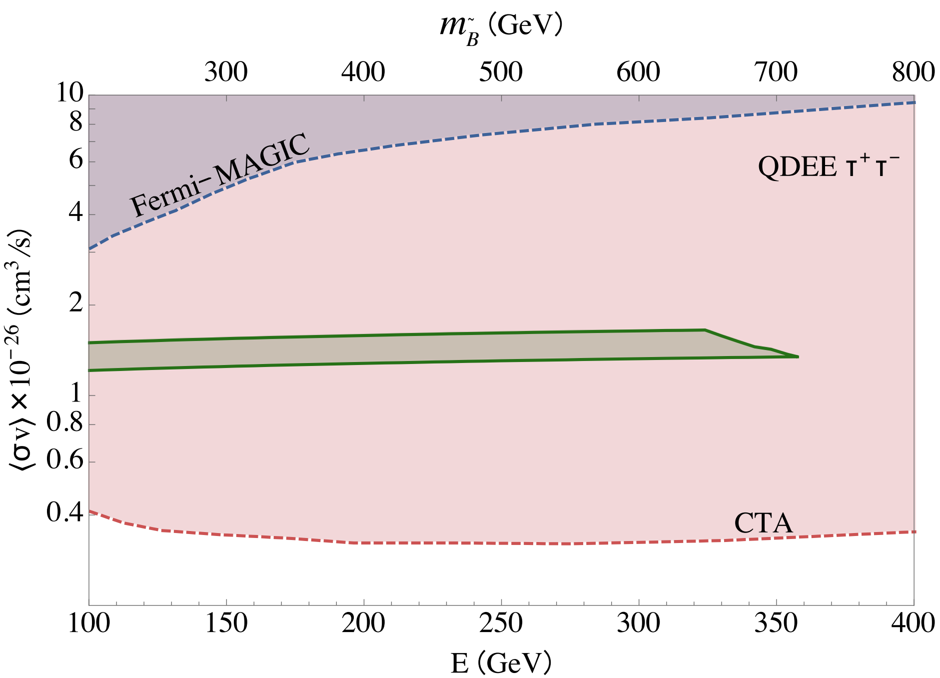

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(with $m_{\tau_4} = 0.83 m_{\tilde{B}}$)

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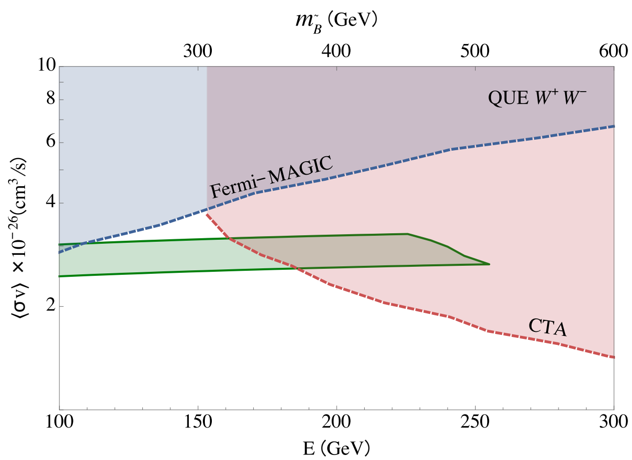
DM profile: Einasto

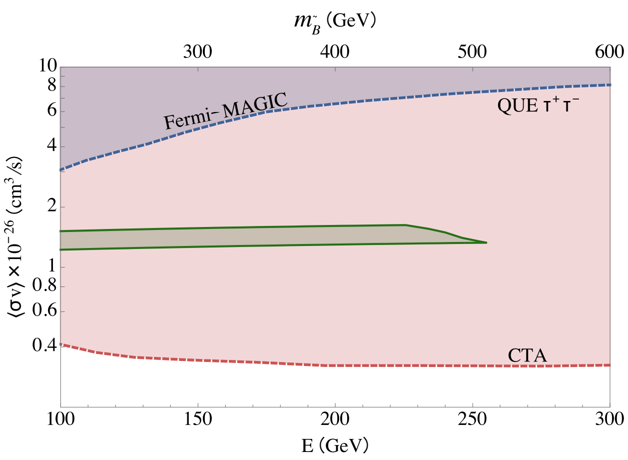
No syst. unc. (stat only)

	e-mixing	μ-mixing	τ-mixing
CTA 500hr	covers $m_{\tilde{B}}$ > 340−380 GeV		**full coverage**
HL-LHC			

e/μ-mixing, QUE



τ/μ-mixing, QUE



Introduction: why overabundant?

Model: **MSSM4G** solves overabundance.

Analysis:

- cosmic rays (CTA, Fermi, MAGIC)
- colliders (LHC)
- direct detection (LUX)

Summary with discussion seeds

- MSSM + $E\bar{E}$ → breaks coupling unification

- QUE model : MSSM + $Q\bar{Q}U\bar{U}E\bar{E}$

⇨ SM + $\tilde{\chi}_1^0(\approx \tilde{B})$, τ_4,

$\tilde{\tau}_{4L}, \tilde{\tau}_{4R}$

assumed to be equal-mass

- QDEE model : MSSM + $Q\bar{Q}D\bar{D}E\bar{E}E\bar{E}$

⇨ SM + $\tilde{\chi}_1^0(\approx \tilde{B})$, τ_4, τ_5, (assumed to be equal-mass)

$\tilde{\tau}_{4L}, \tilde{\tau}_{4R}, \tilde{\tau}_{5L}, \tilde{\tau}_{5R}$

assumed to be equal-mass

- MSSM + $E\bar{E}$ → breaks coupling unification

- QUE model : MSSM + $Q\bar{Q}U\bar{U}E\bar{E}$

⇨ SM + $\tilde{\chi}_1^0(\approx \tilde{B})$, τ_4, $\tilde{\tau}_{4L}, \tilde{\tau}_{4R}$

($\tilde{\tau}_{4L}, \tilde{\tau}_{4R}$: assumed to be equal-mass)

slepton search

extra lepton search

- QDEE model : MSSM + $Q\bar{Q}D\bar{D}E\bar{E}E\bar{E}$

⇨ SM + $\tilde{\chi}_1^0(\approx \tilde{B})$, τ_4, τ_5, $\tilde{\tau}_{4L}, \tilde{\tau}_{4R}, \tilde{\tau}_{5L}, \tilde{\tau}_{5R}$

(τ_4, τ_5: assumed to be equal-mass)

($\tilde{\tau}_{4L}, \tilde{\tau}_{4R}, \tilde{\tau}_{5L}, \tilde{\tau}_{5R}$: assumed to be equal-mass)

- MSSM + $E\bar{E}$ → breaks coupling unification

- QUE model : MSSM + $Q\bar{Q}U\bar{U}E\bar{E}$

⇨ SM + $\tilde{\chi}_1^0(\approx \tilde{B})$, τ_4, $\tilde{\tau}_{4L}, \tilde{\tau}_{4R}$

assumed to be equal-mass

+ $Q\bar{Q}D\bar{D}E\bar{E}E\bar{E}$

τ_4, τ_5, $\tilde{\tau}_{4L}, \tilde{\tau}_{4R}, \tilde{\tau}_{5L}, \tilde{\tau}_{5R}$

assumed to be equal-mass

assumed to be equal-mass

extra lepton search

$\tau_4 \to W\nu, Zl, hl$

(as discussed before)

standard searches
for vectorlike leptons
(but 2x in QDEE)

slepton search

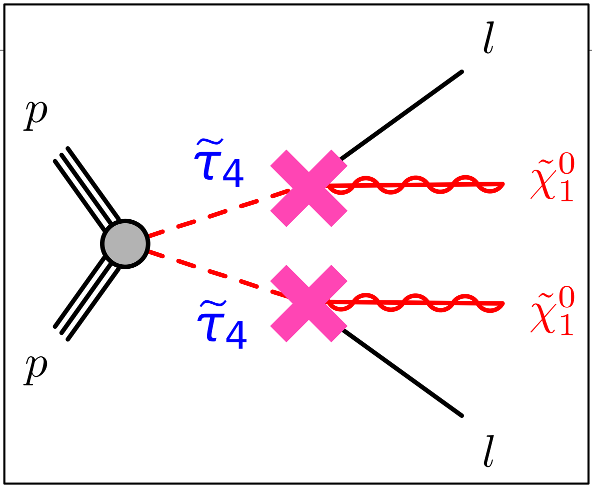
$\tilde{\tau}_4 \not\to \tau_4 + \tilde{B}$

$\longrightarrow (e, \mu, \tau) + \tilde{B}$

$\equiv 2(4) \times \tilde{l}_R$

$$pp \to \tilde{\tau}_{4(,5)}\tilde{\tau}^*_{4,(5)} \equiv pp \to \tilde{l}_R \tilde{l}^*_R$$

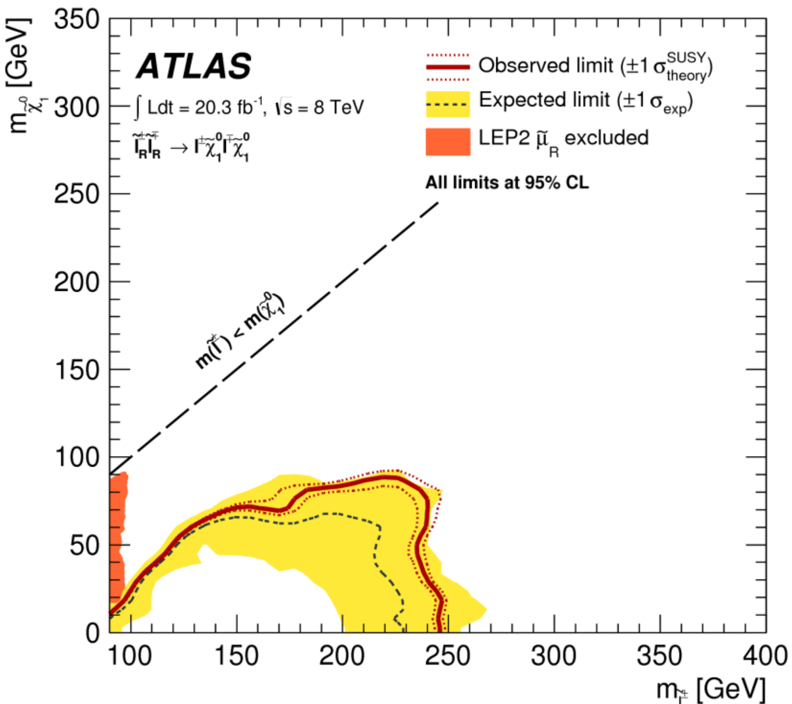
determined by mixing parameters



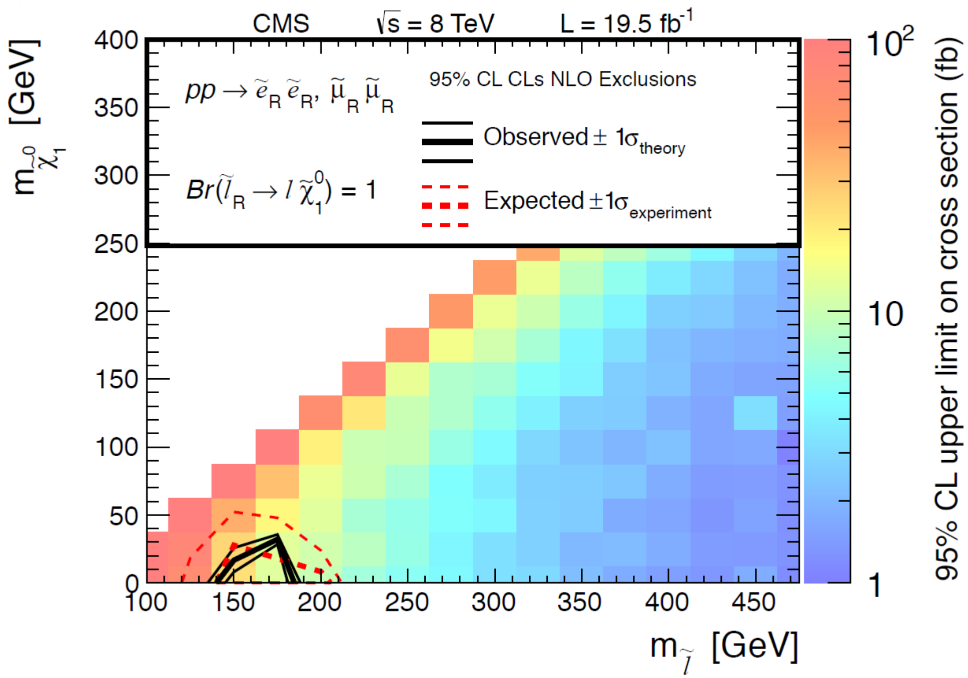
e/μ-mixing → slepton searches × 2 (4)
$(\tilde{e}_R, \tilde{\mu}_R)$

14 TeV prospects studied in 1408.2841 (Eckel, Ramsey-Musolf, Shepherd, Su)

→ re-interpreted



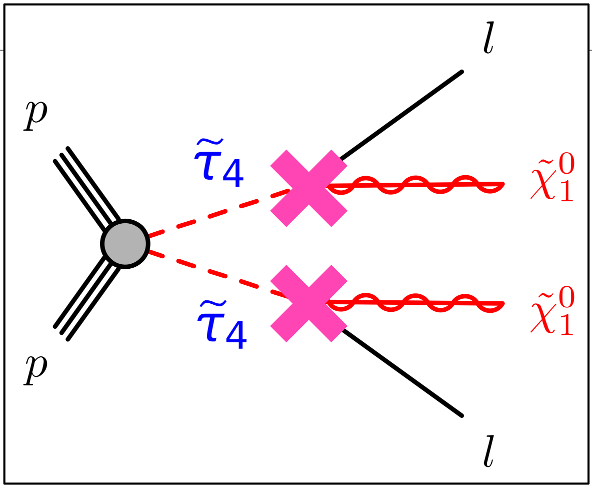
ATLAS (8TeV full) [1403.5294]



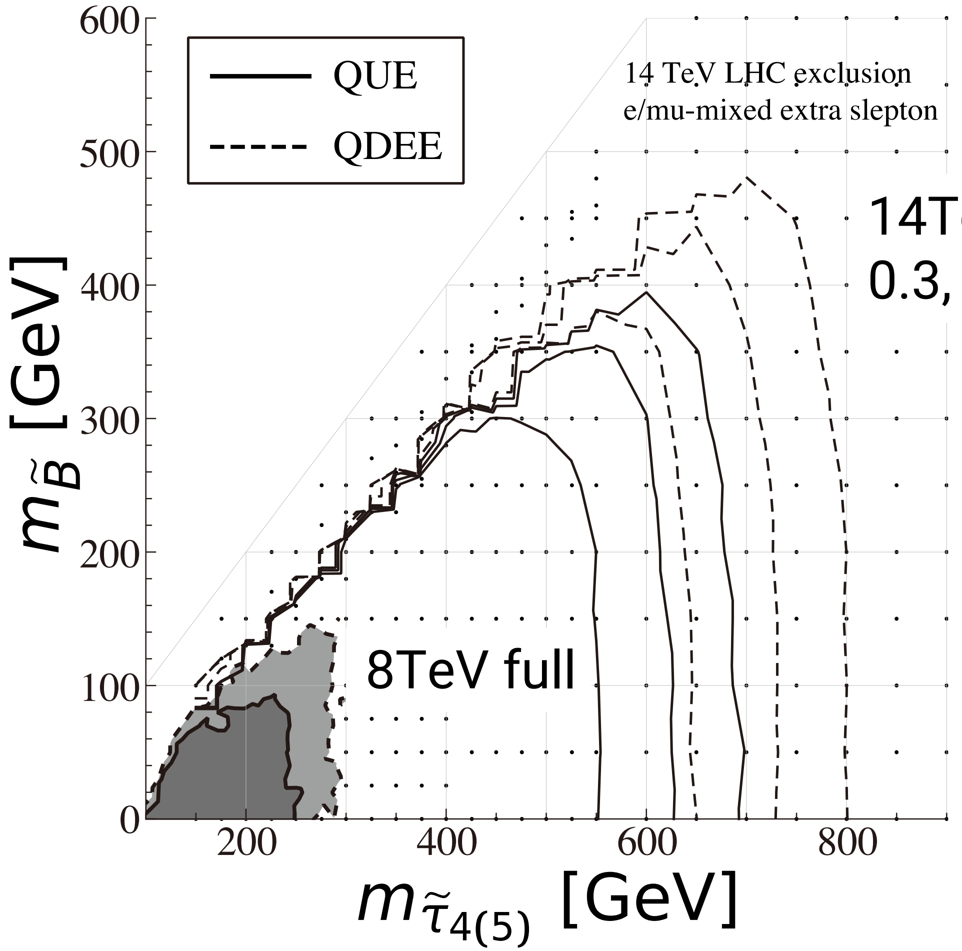
CMS (8TeV full) [1405.7570]

$$pp \to \tilde{\tau}_{4(,5)} \tilde{\tau}^*_{4,(5)} \equiv pp \to \tilde{l}_R \tilde{l}^*_R$$

determined by mixing parameters



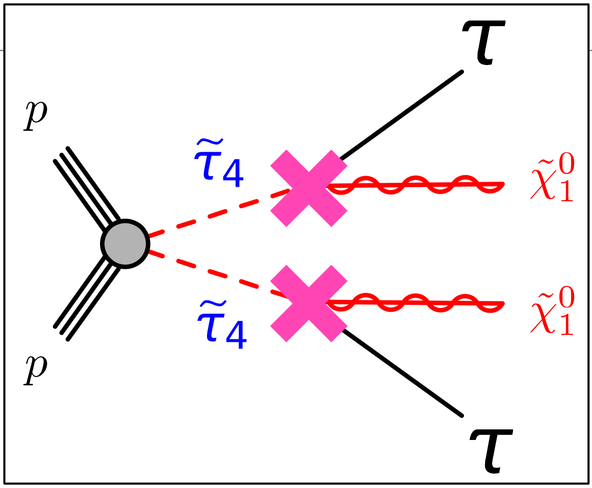
e/μ-mixing → slepton searches × 2 (4)
$(\tilde{e}_R, \tilde{\mu}_R)$



- 2 lepton + MET + mT2 + jet-veto
- BKG taken from 1408.2841
  - MG5−Pythia−Delphes (also for signal)
  - rescaled by NLO *K*-factor
  - di-boson dominates
- Signal events at LO level
- Uncertainties = stat. + 5% syst.

$$pp \to \tilde{\tau}_{4(,5)} \tilde{\tau}^*_{4,(5)} \equiv pp \to \tilde{l}_R \tilde{l}^*_R$$

↑ determined by mixing parameters



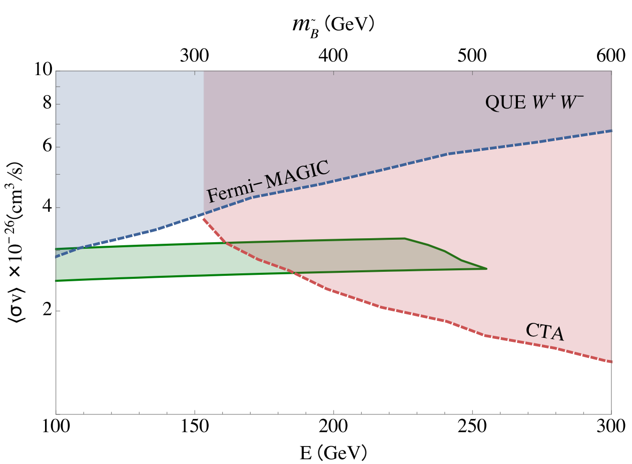
τ-mixing → stau searches × 2 (4)

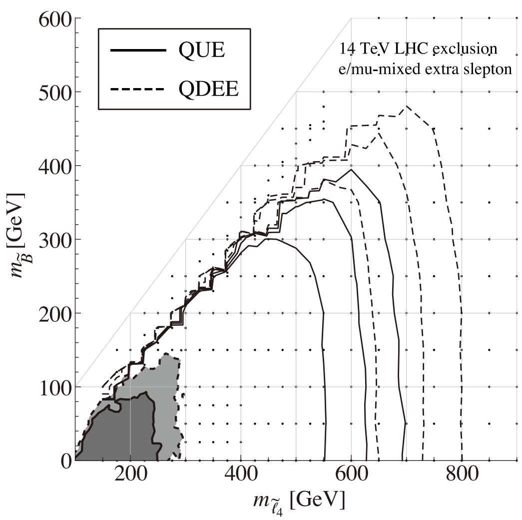
→ No constraint expected.

- LHC Run 1 provided no limit on MSSM stau mass.
- 14TeV, 3/ab LHC will not exclude MSSM4G parameter region.

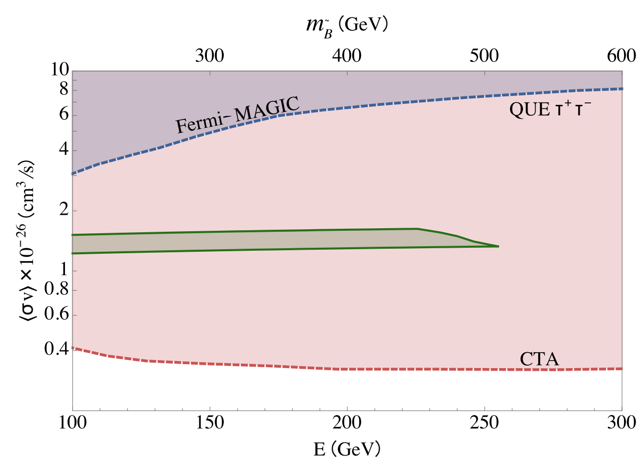
	e-mixing	μ-mixing	τ-mixing
CTA 500hr	covers $m_{\tilde{B}}$ > 340–380 GeV		**full coverage**
HL-LHC (slepton)	covers $m_{\tilde{B}}$ < 400 (480) GeV (but not "degenerate" region)		–
HL-LHC (lepton)			

e/μ-mixing

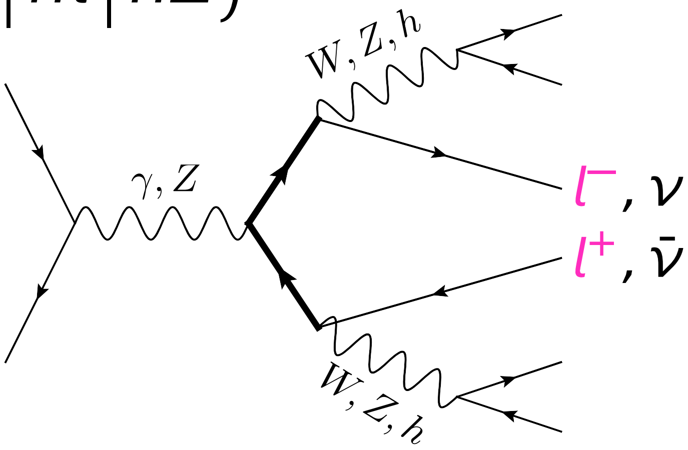




τ/μ-mixing, QUE



$$pp \to \tau^{+}_{4(,5)}\tau^{-}_{4,(5)} \to (W\nu|hl|Zl)(W\nu|hl|hZ)$$



e/μ-mixing case

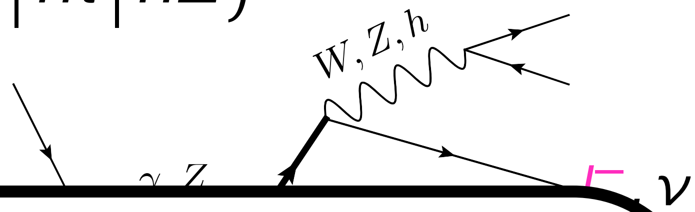
"vectorlike lepton searches" by multi-$\ell^{\pm}$ signature ($3-5\ell^{\pm}$)

[Cf. ATLAS collaboration, 1506.01291]

$$\begin{cases} W\nu Z\ell \to 3\ell\ (1.3\%) \\ W\nu h\ell \to 3\ell\ (0.6\%) \\ h\ell Z\ell \to 3\ell\ (0.8\%) \\ h\ell h\ell \to 3\ell\ (0.8\%) \end{cases} \quad \begin{cases} W\nu Z\ell \to 4^{+}\ell\ (0.4\%) \\ h\ell Z\ell \to 4^{+}\ell\ (1.0\%) \\ Z\ell Z\ell \to 4^{+}\ell\ (0.8\%) \\ h\ell h\ell \to 4^{+}\ell\ (0.2\%) \end{cases}$$

→ Monte Carlo simulation

$$pp \to \tau^{+}_{4(,5)}\tau^{-}_{4,(5)} \to (W\nu|hl|Zl)(W\nu|hl|hZ)$$



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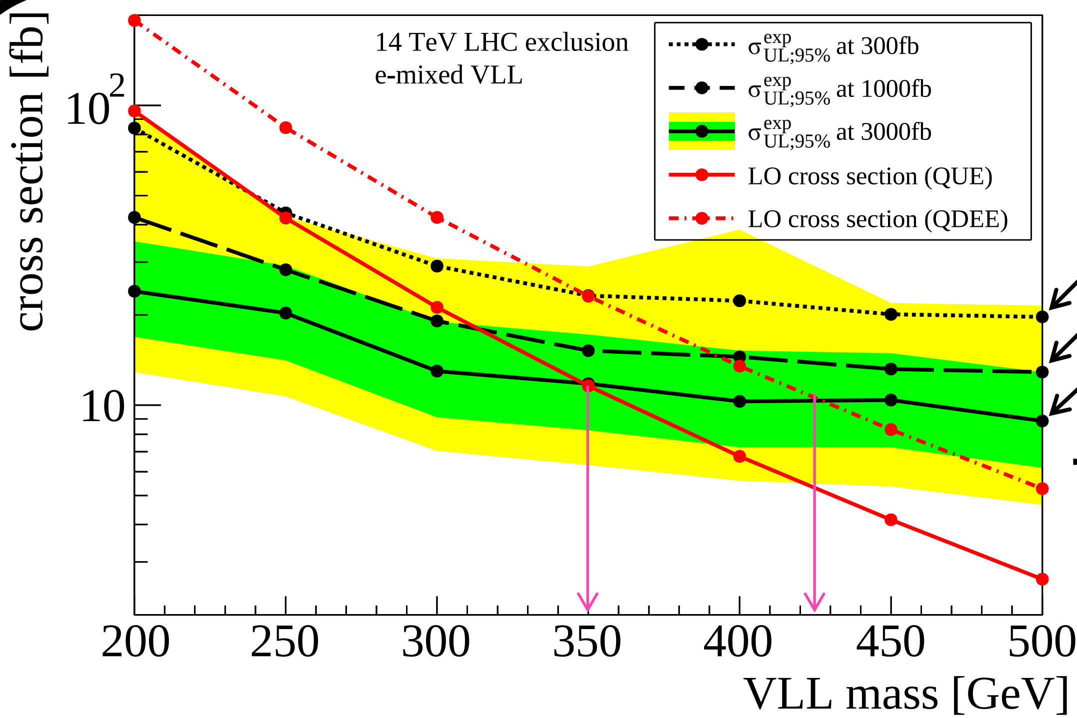
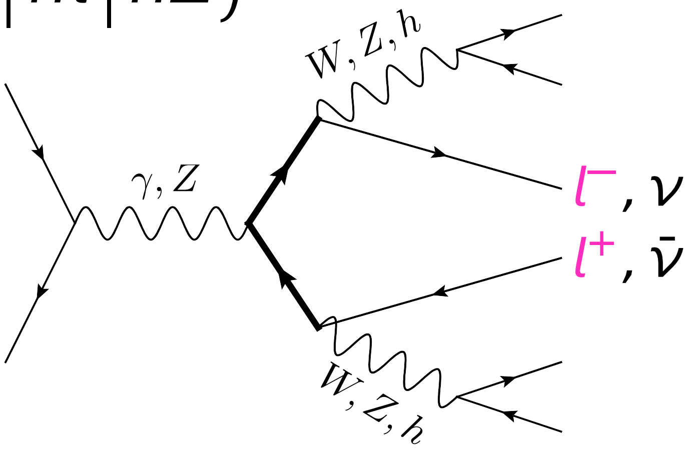


0.3/ab
1/ab
3/ab (with 1&2σ band)

→ 14TeV, 3/ab covers m_{τ_4} < 350 (425) GeV
QUE QDEE

- Snowmass BKG set is used.
  - MG5−Pythia−Delphes + NLO *K*-factor
  - di-boson + *tt* dominated
- Signal by FR−MG5aMC−Pythia−Delphes (LO)
- SR dedicated for WZ / ZZ + leptons
  - 3L, 4L for WZ, and 4L, 5L for ZZ
  - tau-tag / b-tag not used (avoided)
- Uncertainties = stat. + 20% syst.

$$pp \to \tau^{+}_{4(,5)}\tau^{-}_{4,(5)} \to (W\nu|hl|Zl)(W\nu|hl|hZ)$$



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→ 14TeV, 3/ab covers $m_{\tau_4} < 350\ (425)$ GeV
QUE QDEE

τ-mixing case

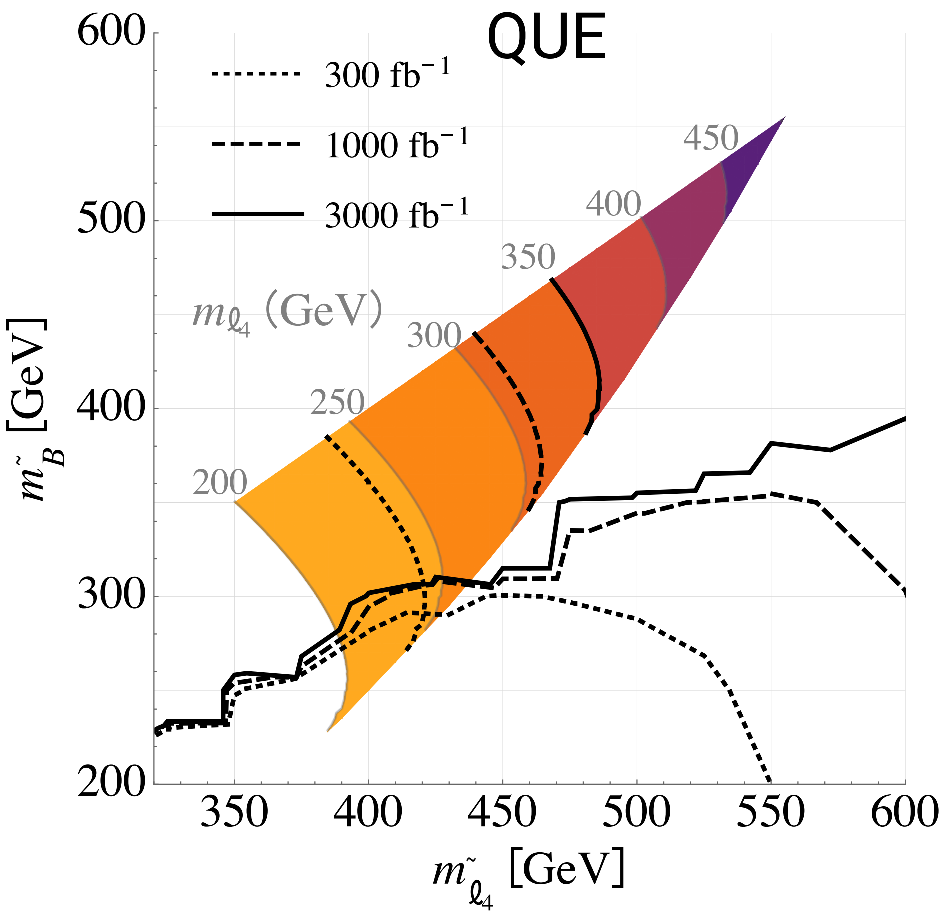
✓ 1510.03456 (Kumar and Matrin)

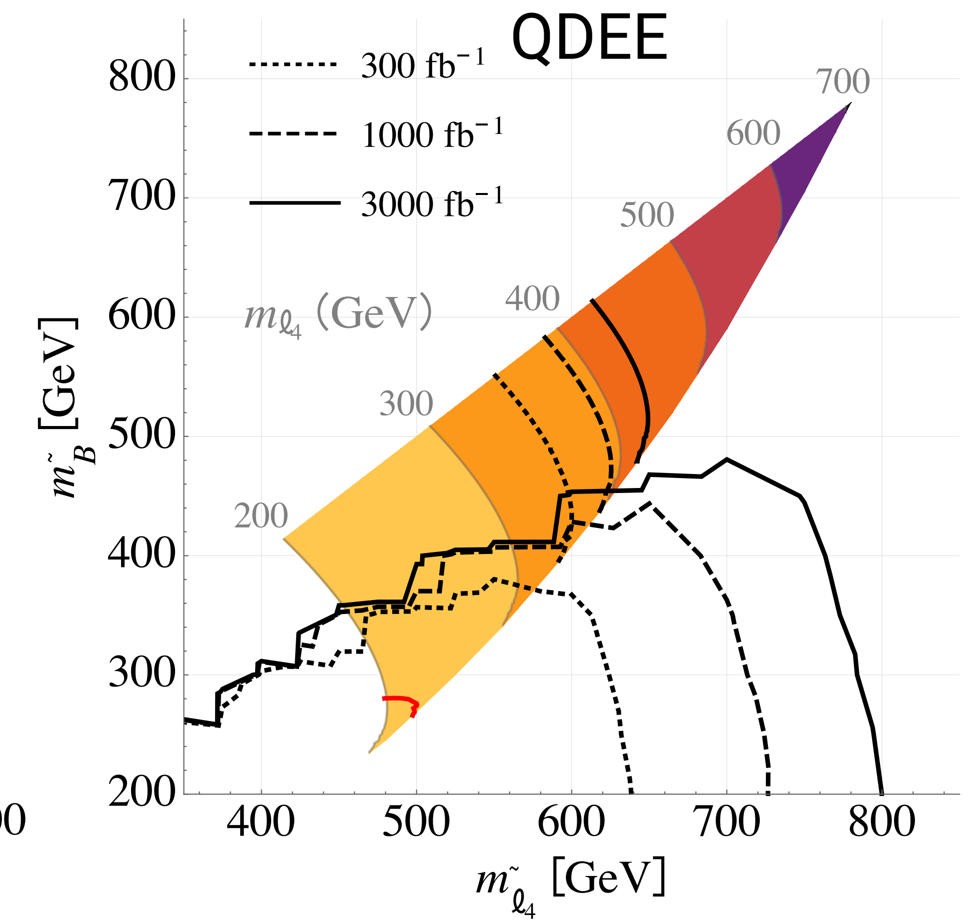
- SRs: 4(e, mu, had-tau)
- Signal and BKG by their MC (FR–MG5–Pythia–Delphes)
- no prospects for exclusion if BKG syst. unc. > 10%

→ 13 TeV, 3/ab covers $m_{\tau_4} < 234\ (264)$ GeV

with "a very optimistic BKG estimation"

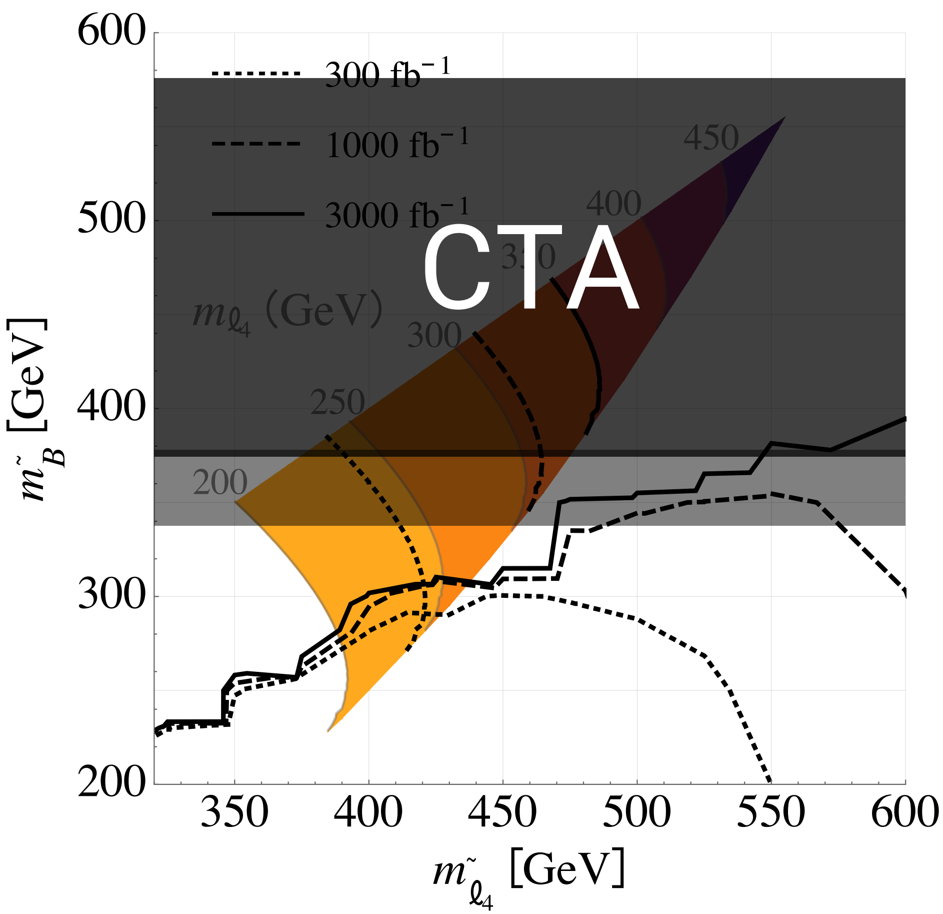
- e/μ-mixing cases

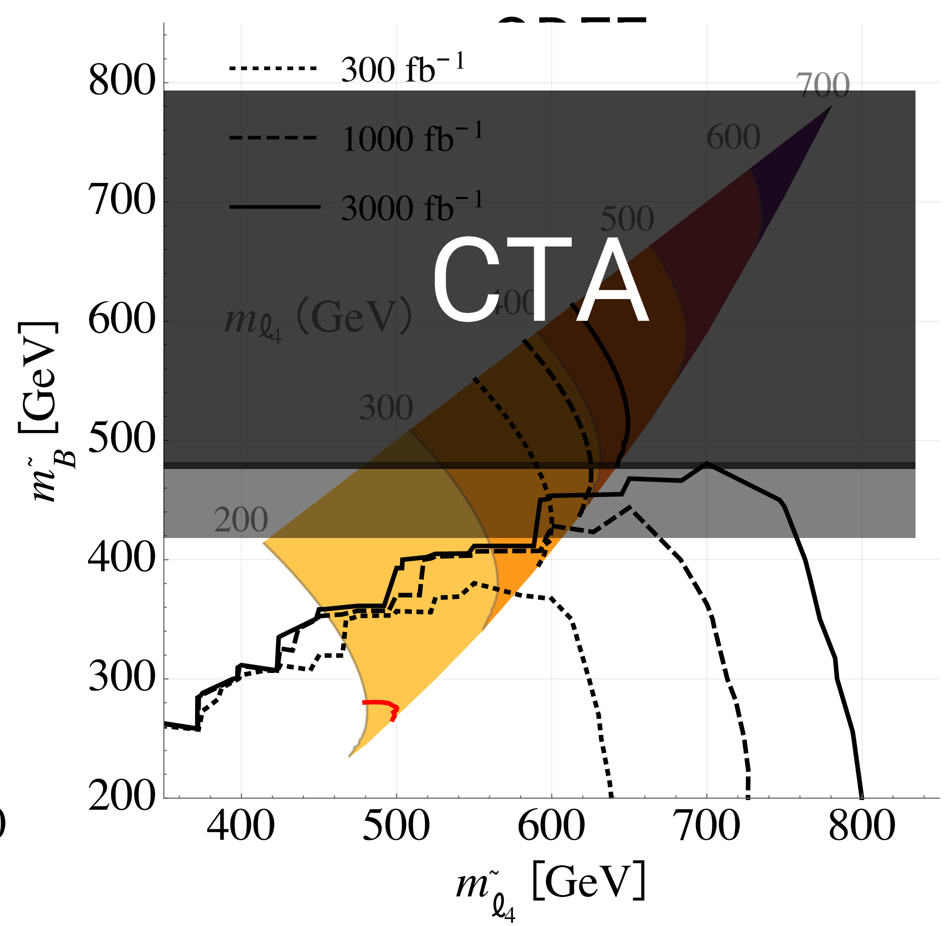




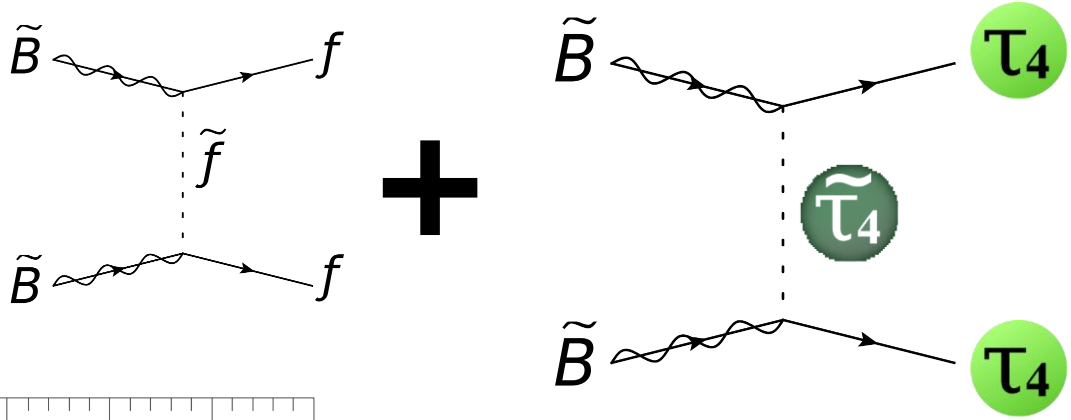
- τ-mixing case
  - LHC insensitive … (´・ω・`)

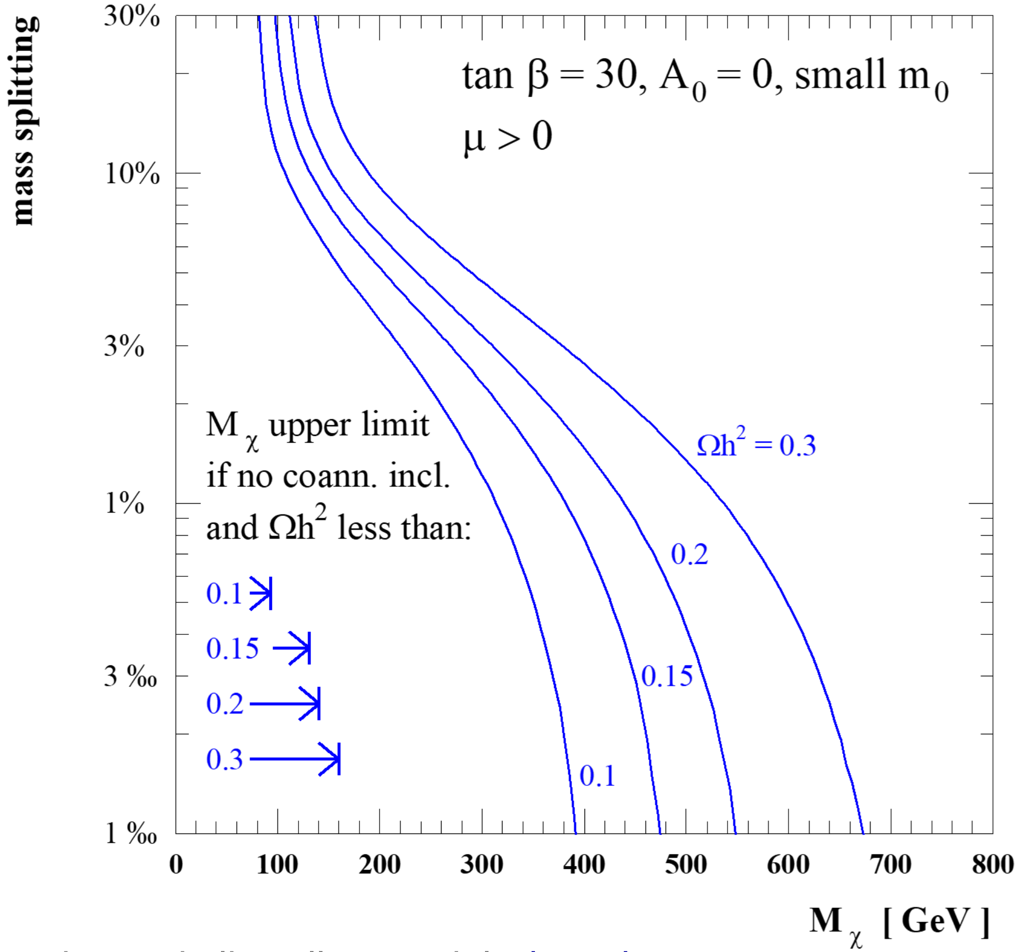
- e/μ-mixing cases





- τ-mixing case
  - ➢ LHC insensitive, but CTA covers full region





extra annihilation channel

→ larger Ωh^2

→ "proper" $\langle \sigma v \rangle$

if $\tilde{\tau}_4 \gtrsim \tilde{B} > \tau_4$

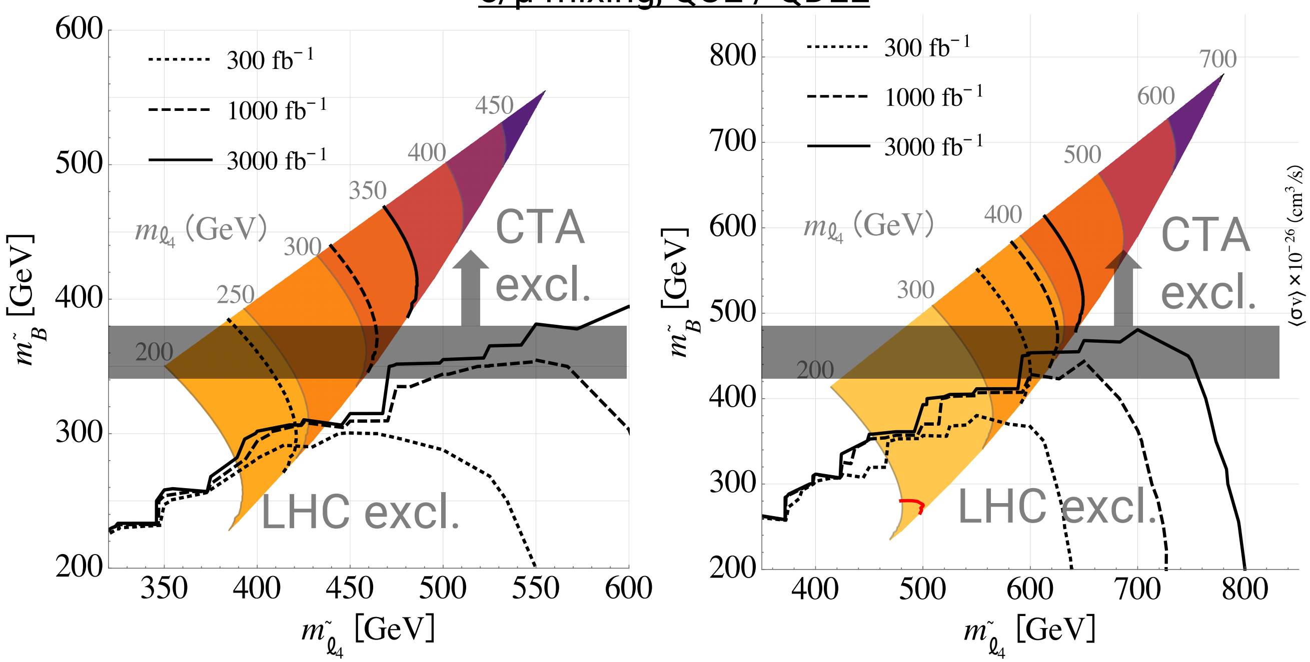
$$\langle \sigma v \rangle \propto Y^4 \implies \text{MSSM} + E\bar{E}$$

$$Y_{\mathrm{u}} H_{\mathrm{u}} Q \bar{U} + Y_{\mathrm{d}} H_{\mathrm{d}} Q \bar{D} + Y_{\mathrm{e}} H_{\mathrm{d}} L \bar{E}$$
$$+ M_{E_4} E_4 \bar{E}_4 + \epsilon_i H_{\mathrm{d}} L_i \bar{E}_4$$

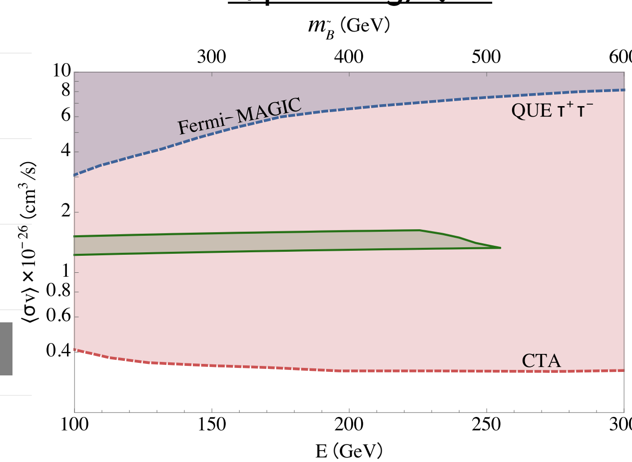
Edsjö, Schelke, Ullio, Gondolo, hep-ph/0301106

	e-mixing	μ-mixing	τ-mixing
CTA 500hr	covers $m_{\tilde{B}}$ > 340–380 GeV		**full coverage**
HL-LHC (slepton)	covers $m_{\tilde{B}}$ < 400 (480) GeV (but not “degenerate” region)		–
HL-LHC (lepton)	covers m_{τ_4} < 350 (430) GeV equivalent to $m_{\tilde{B}}$ < 380 (480) GeV		–

e/μ-mixing, QUE / QDEE



τ/μ-mixing, QUE



Introduction: why overabundant?

Model: **MSSM4G** solves overabundance.

Analysis:

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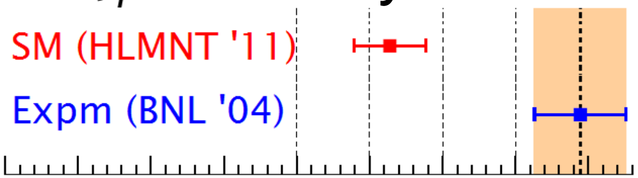
- colliders (LHC)
- direct detection (LUX)

Summary with discussion seeds

: "muon g−2 problem"

$$\left(a_\mu := \frac{g_\mu - 2}{2} \right)$$

■ $(g-2)_\mu$ anomaly



Hagiwara, Liao, Martin, Nomura, Teubner [1105.3149]

$$a_\mu^{SM} = (116\,591\,828 \pm 49) \times 10^{-11}$$

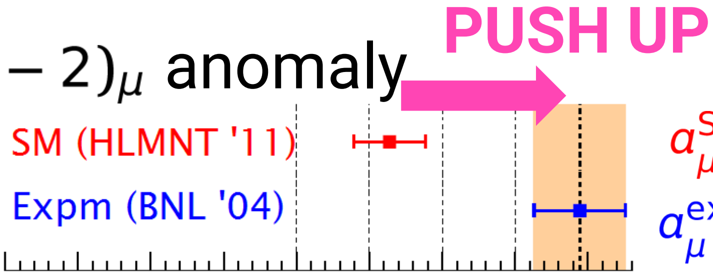
$$a_\mu^{exp} = (116\,592\,089 \pm 63) \times 10^{-11}$$

3.3σ discrepancy

MSSM: extra contribution → MSSM **may** explain this anomaly.

$$\left(a_\mu := \frac{g_\mu - 2}{2} \right)$$

- $(g-2)_\mu$ anomaly



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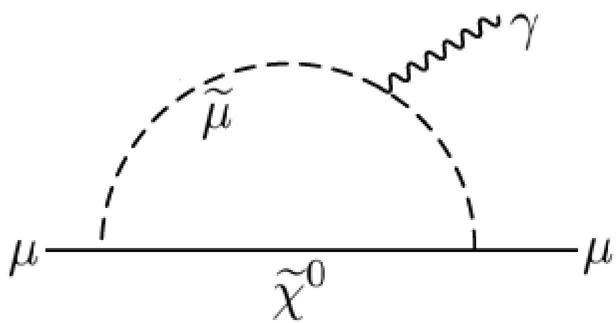
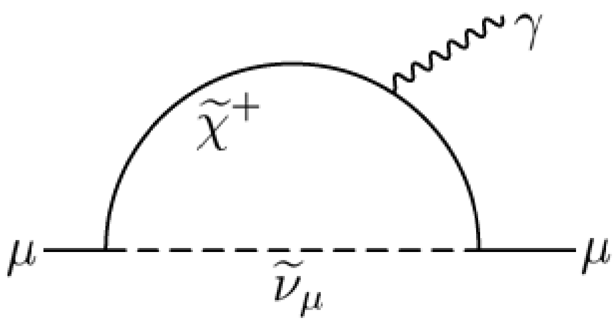
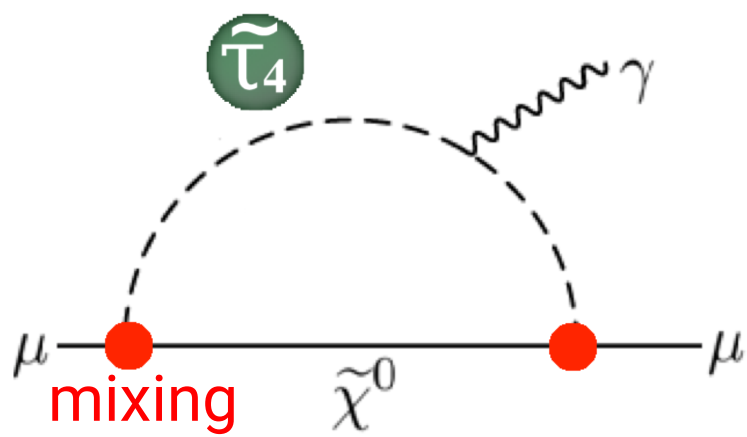




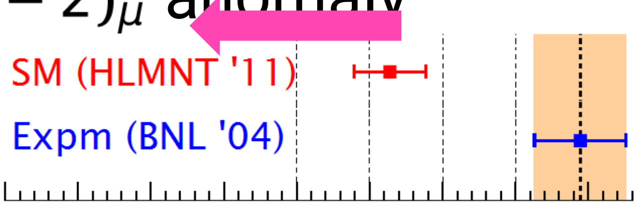
4G extra contribution?



$$\left(a_\mu := \frac{g_\mu - 2}{2}\right)$$

PUSH DOWN

- $(g-2)_\mu$ anomaly



Hagiwara, Liao, Martin, Nomura, Teubner [1105.3149]

$$a_\mu^{SM} = (116\,591\,828 \pm 49) \times 10^{-11}$$

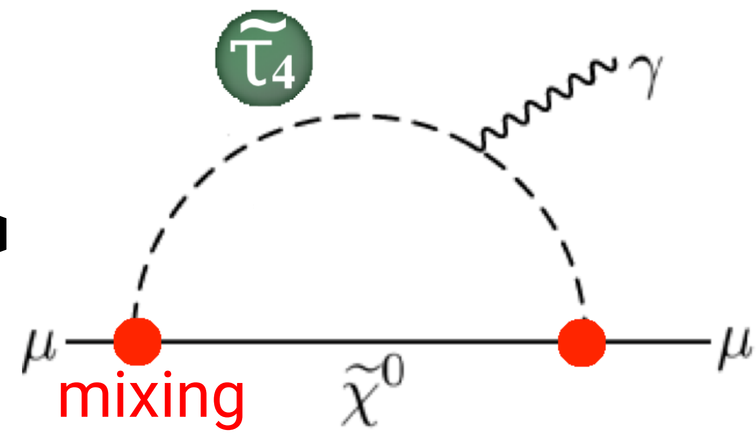
$$a_\mu^{exp} = (116\,592\,089 \pm 63) \times 10^{-11}$$

3.3σ discrepancy

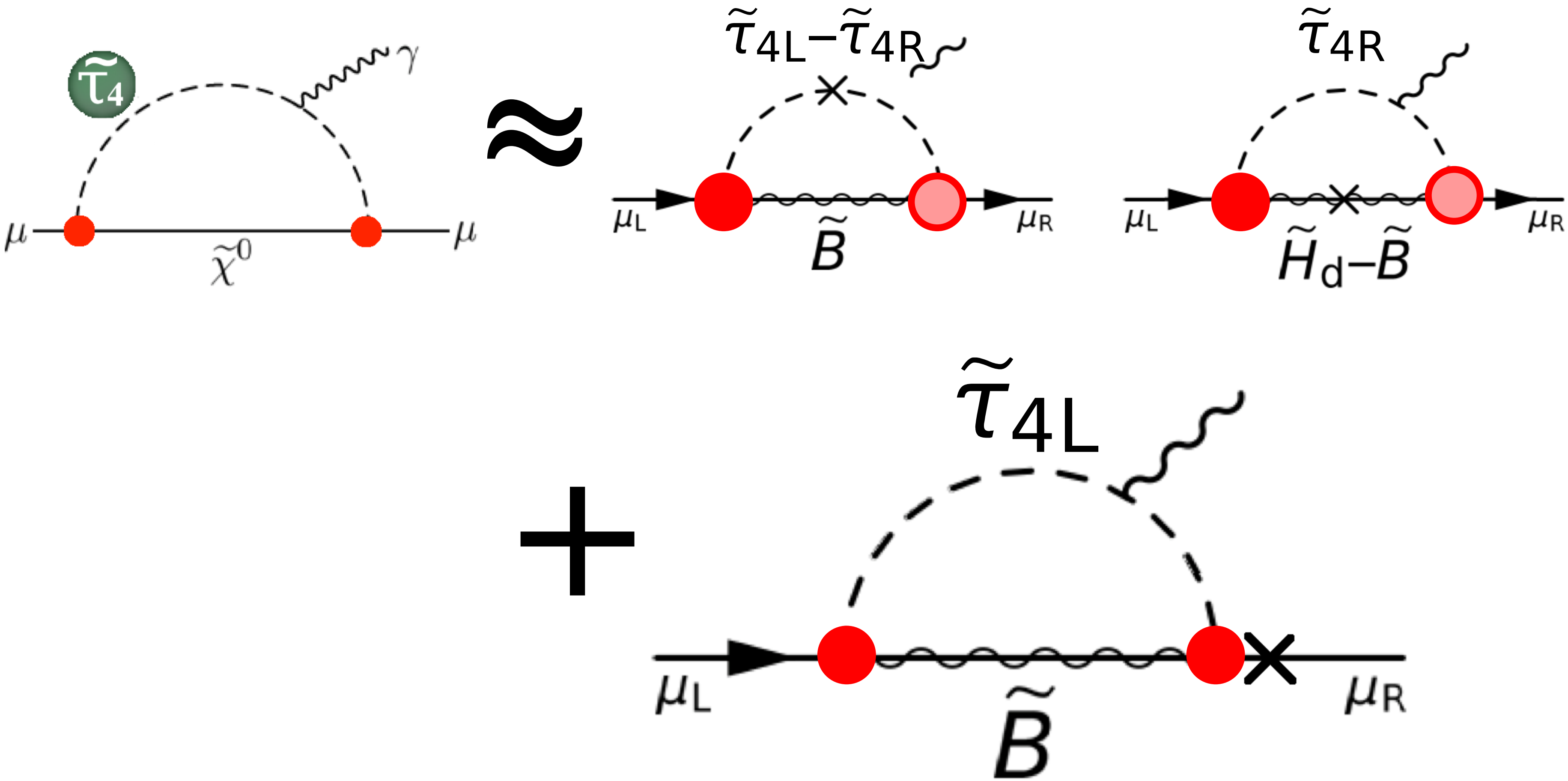
MSSM: extra contribution → MSSM **may** explain this anomaly.

4G extra c ribution?

$0 >$



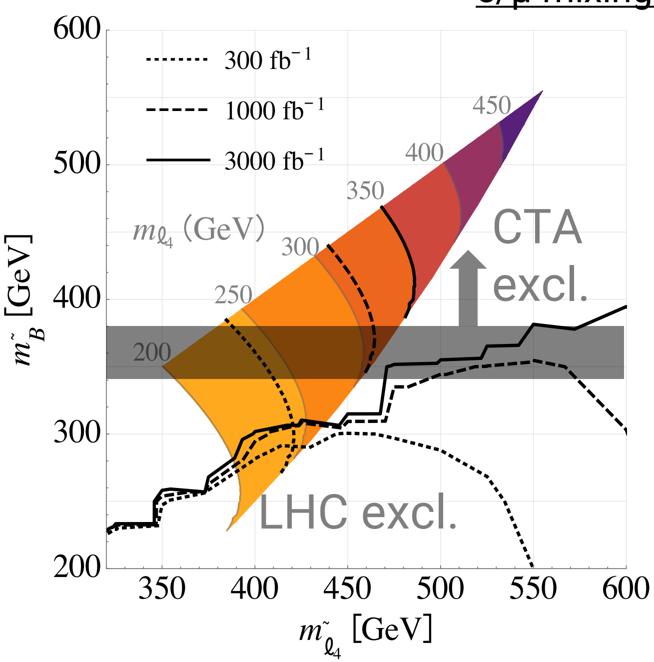
- Why always negative?

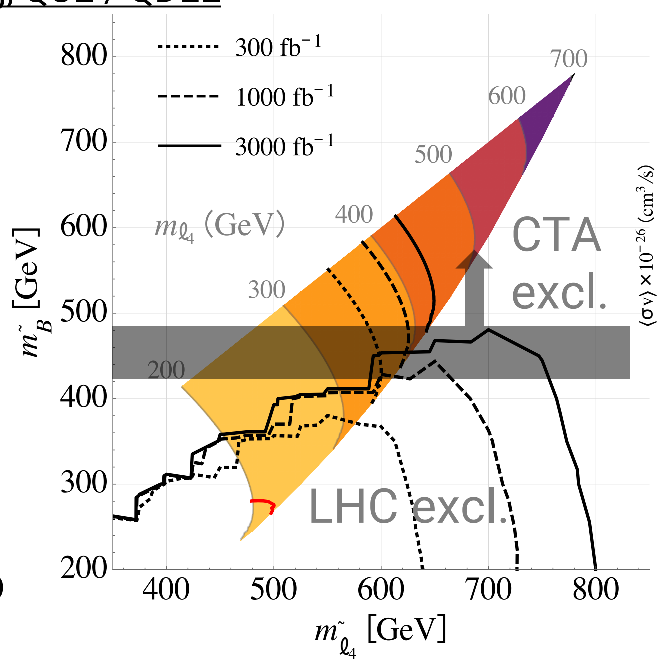


$$= -\frac{|\epsilon|^2}{16\pi^2}\frac{m_\mu^2}{6(|M_E|^2+m_{\widetilde{E}^c}^2)}N_1\left(\frac{\mu^2}{|M_E|^2+m_{\widetilde{E}^c}^2}\right)$$

	e-mixing	μ-mixing	τ-mixing
CTA 500hr	covers $m_{\tilde{B}}$ > 340–380 GeV		**full coverage**
HL-LHC (slepton)	covers $m_{\tilde{B}}$ < 400 (480) GeV (but not “degenerate” region)		–
HL-LHC (lepton)	covers m_{τ_4} < 350 (430) GeV equivalent to $m_{\tilde{B}}$ < 380 (480) GeV		–

e/μ-mixing, QUE / QDEE





τ/μ-mixing, QUE