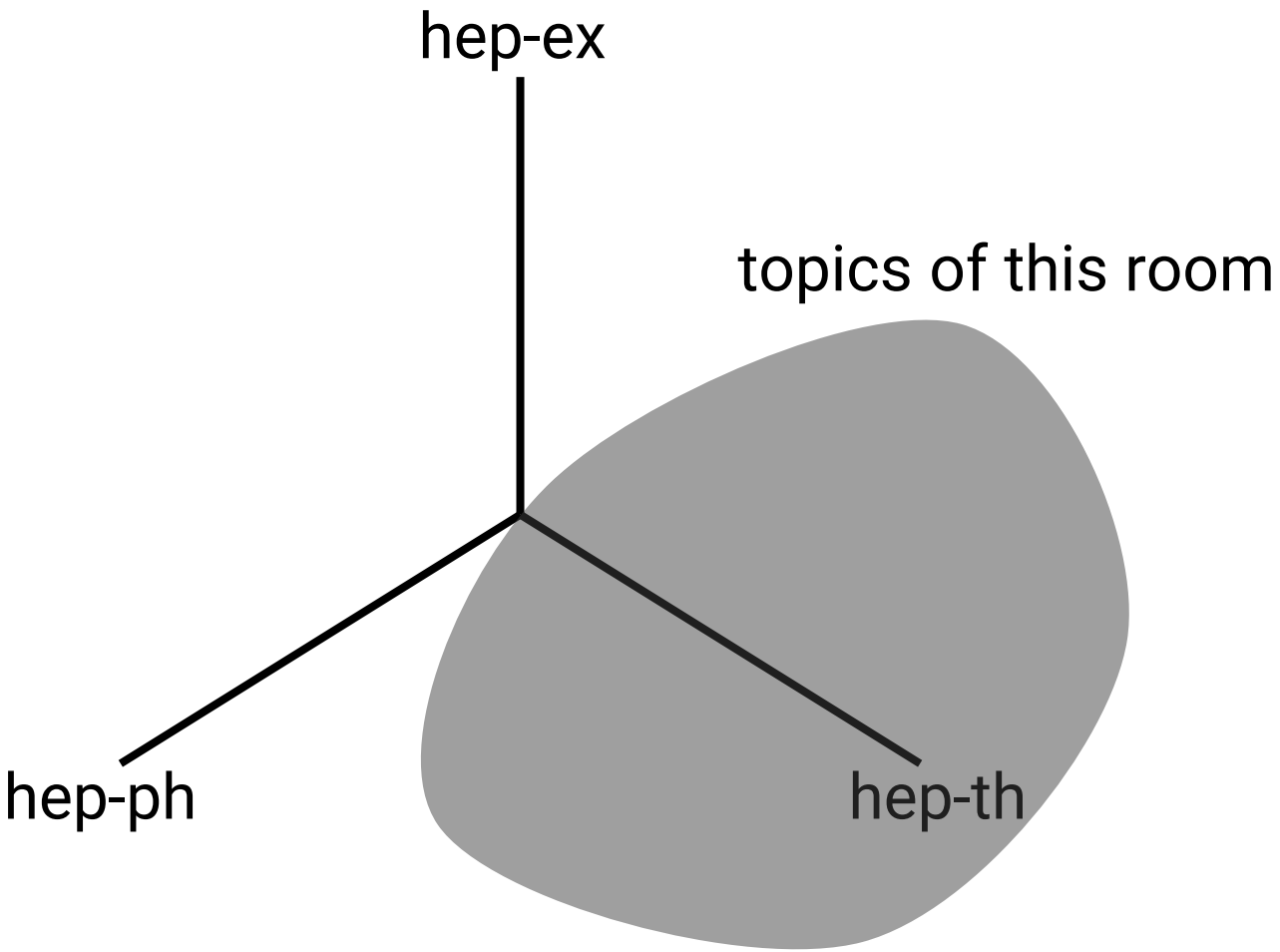
MSSM 4G scenario

Sho IWAMOTO（岩本　祥）

25 Dec. 2016
IPS 62nd annual meeting @ Tel-Aviv University

Based on [1608.00283] in collaboration with
M. Abdullah, **J. L. Feng**, and **B. Lillard** (UC Irvine)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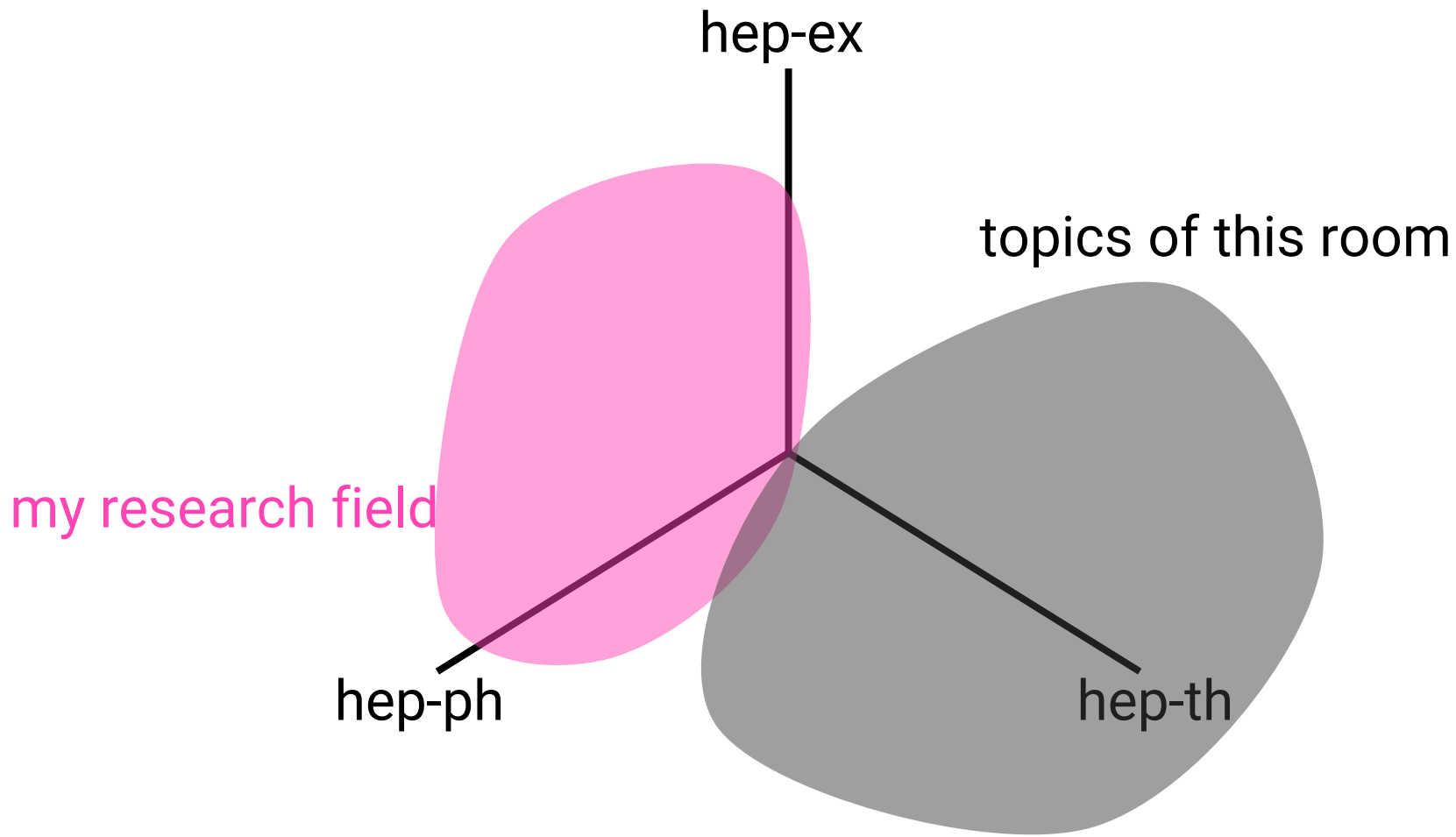
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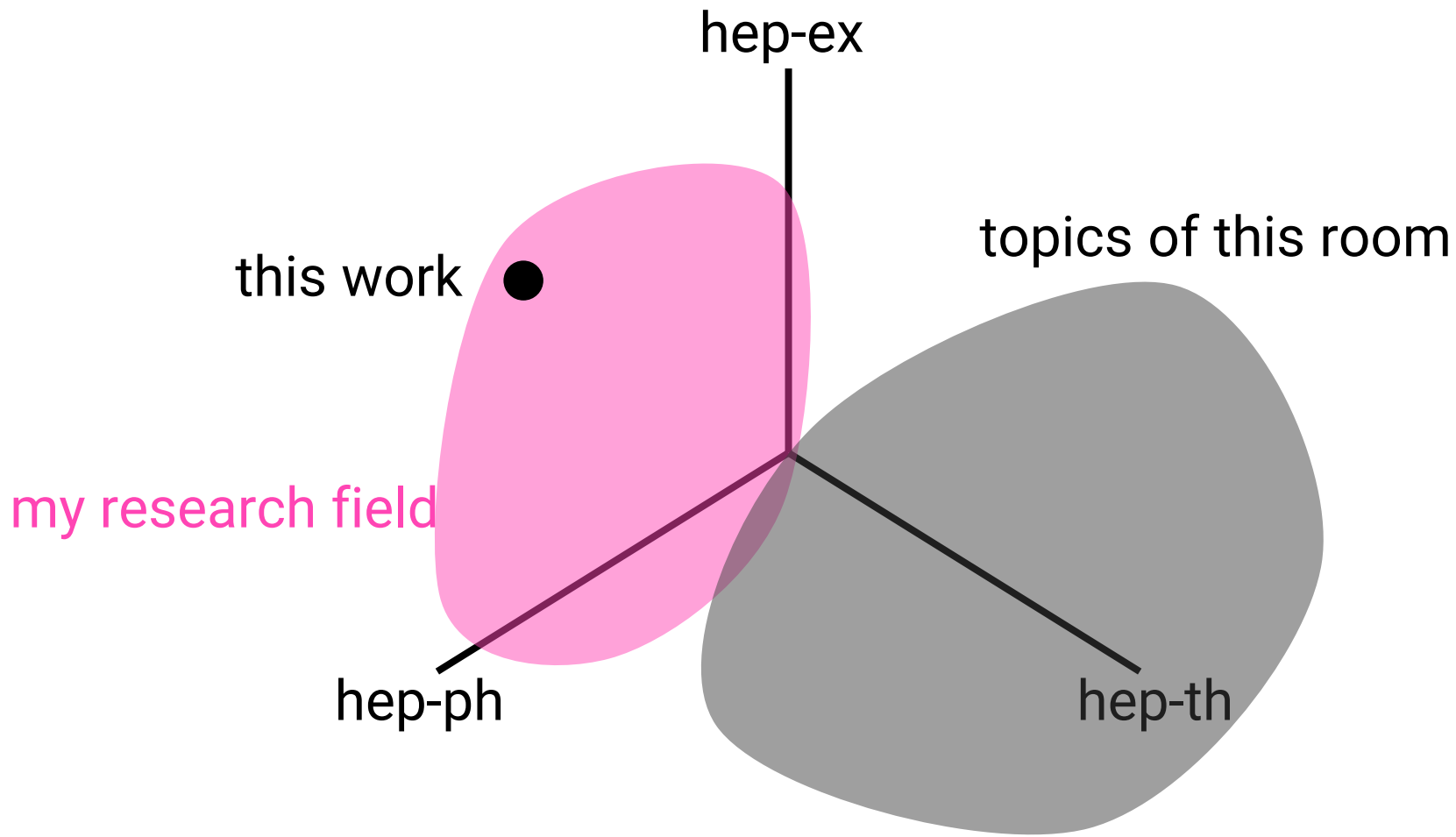
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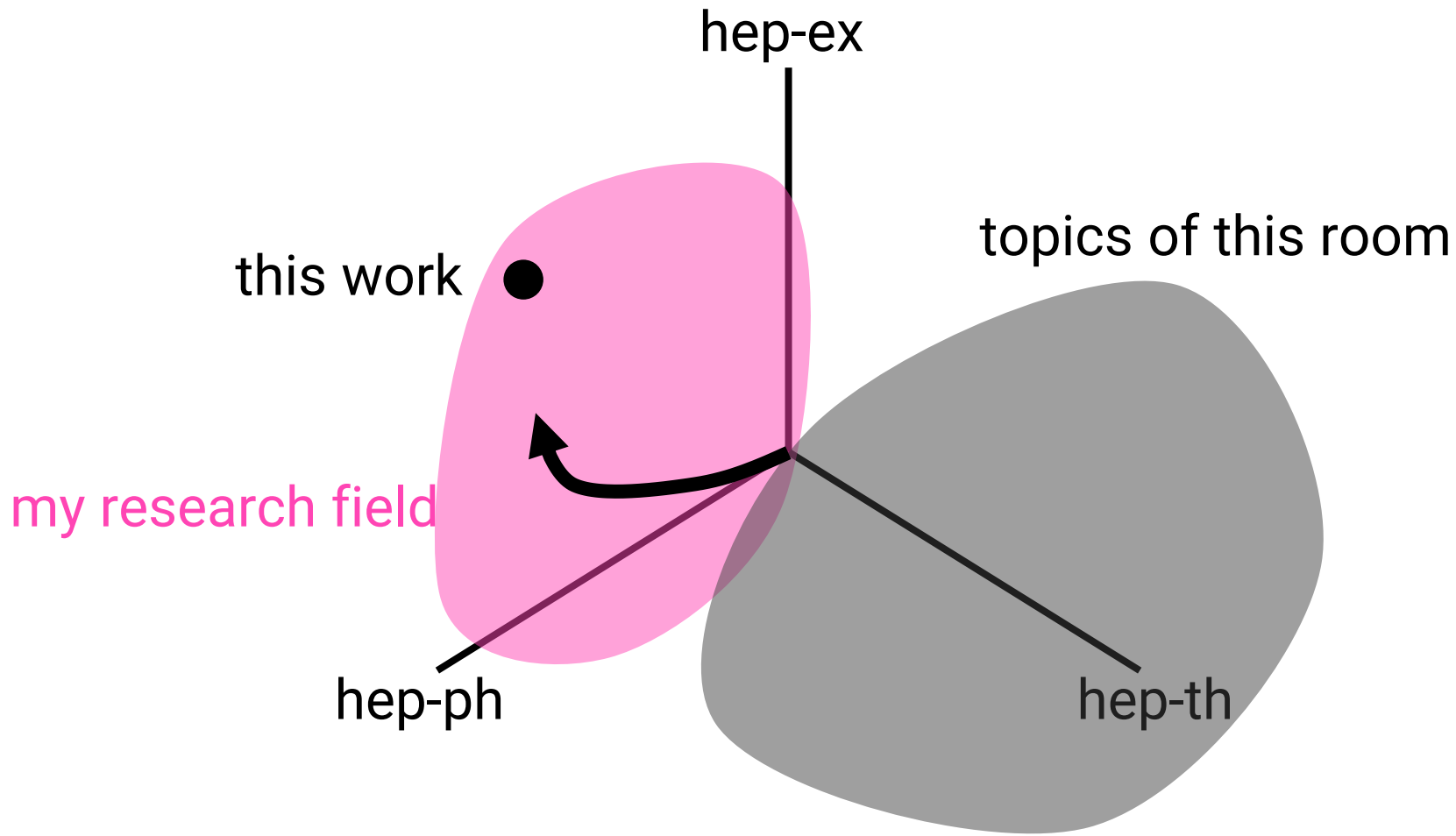
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Problems of the Standard Model = Hints of “New Physics”

- Anomalies in *B*-physics
- Proton charge radius
- Beryllium anomaly
- Muon “$g-2$”
- Higgs mass (“naturalness”)
- Neutrino mass
- Dark matter
- Unification of 3 forces
- Dark energy
- Gravity

New Physics Candidates

- SUSY [supersymmetry]
-
-
-

Please fill this list with your models / models you like

etc…

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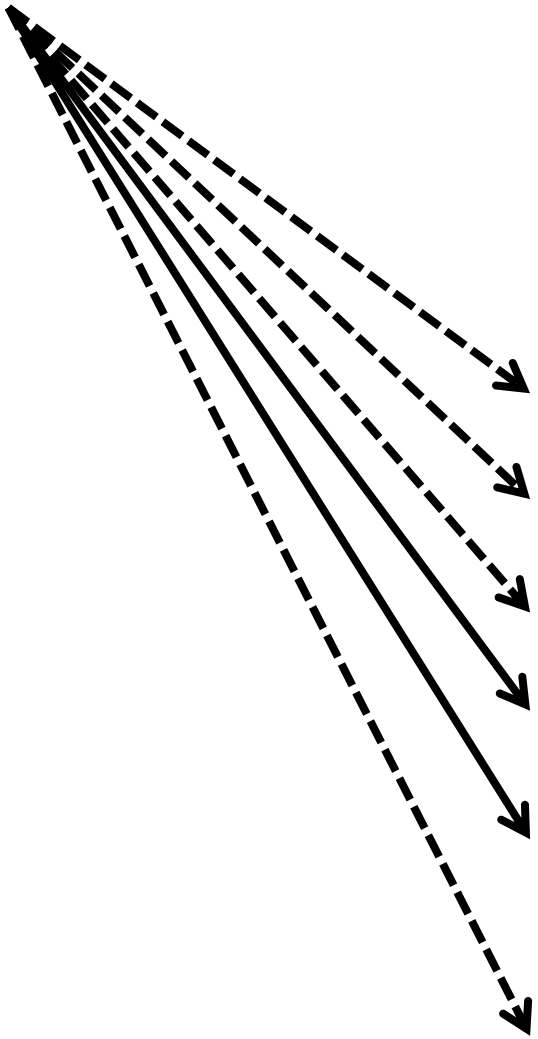

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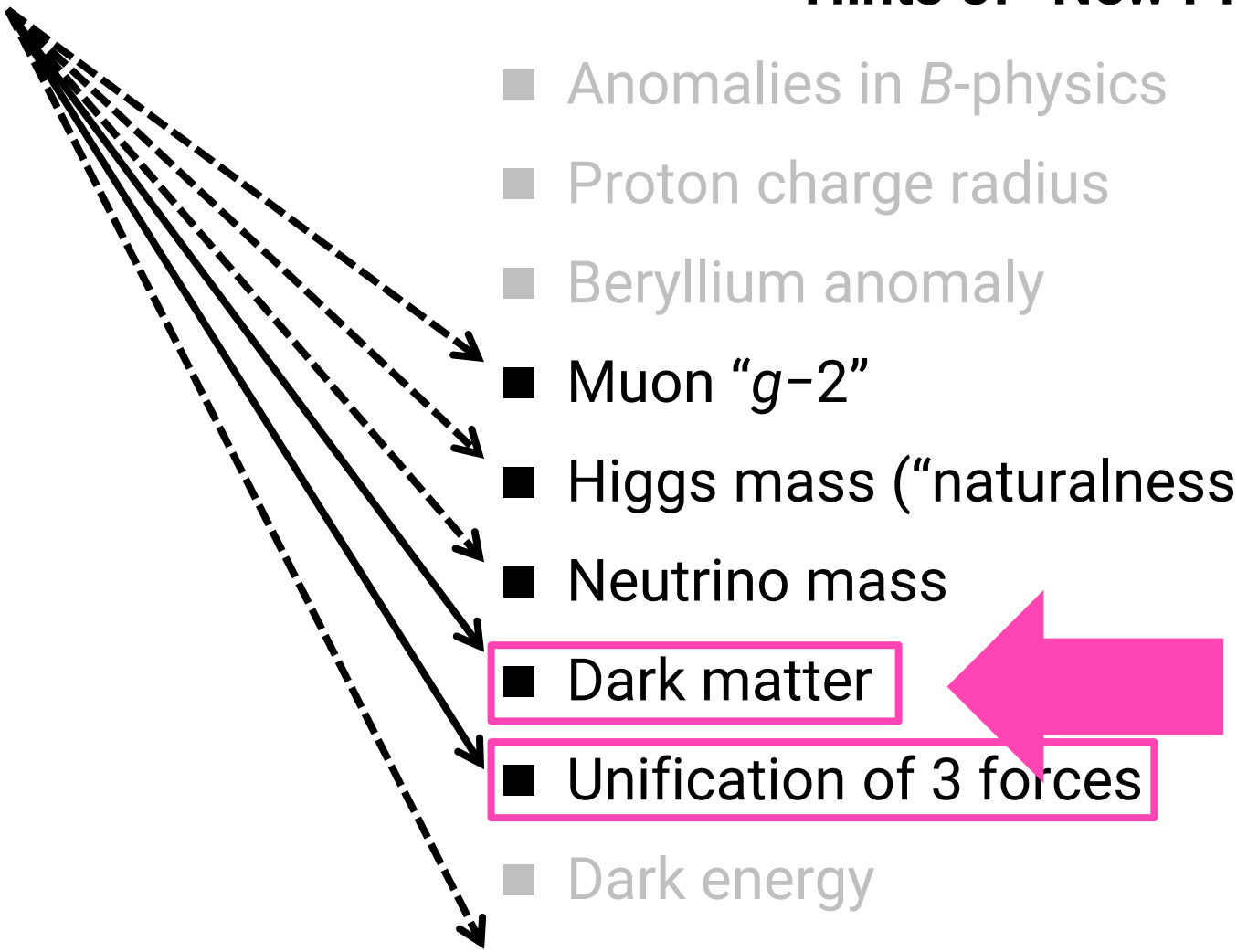
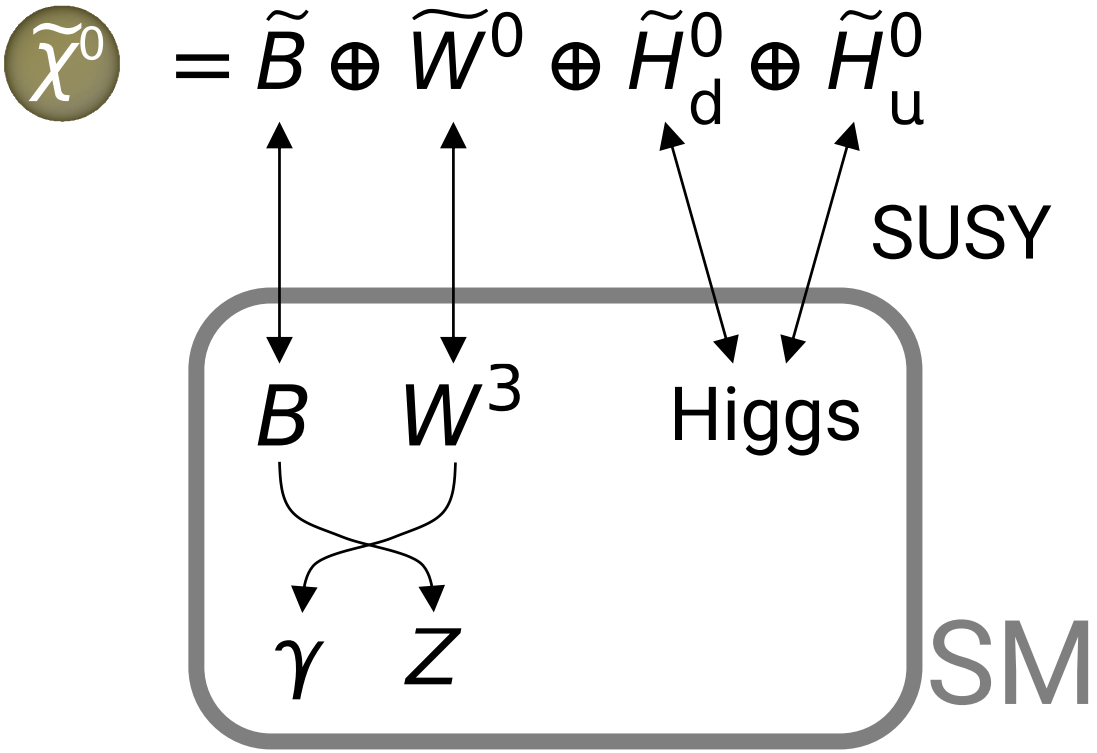


- MSSM $\ni$ Dark matter candidate



- MSSM ⊇ Dark matter candidate

- Pure-$\tilde{B}$ dark matter (i.e., DM is $\tilde{\chi}^0$ and it is purely $\tilde{B}$-like)
  - ✓ theoretically motivated & simple
  - ✗ **“thermal overabundance”** problem
    - → MSSM4G model as one solution

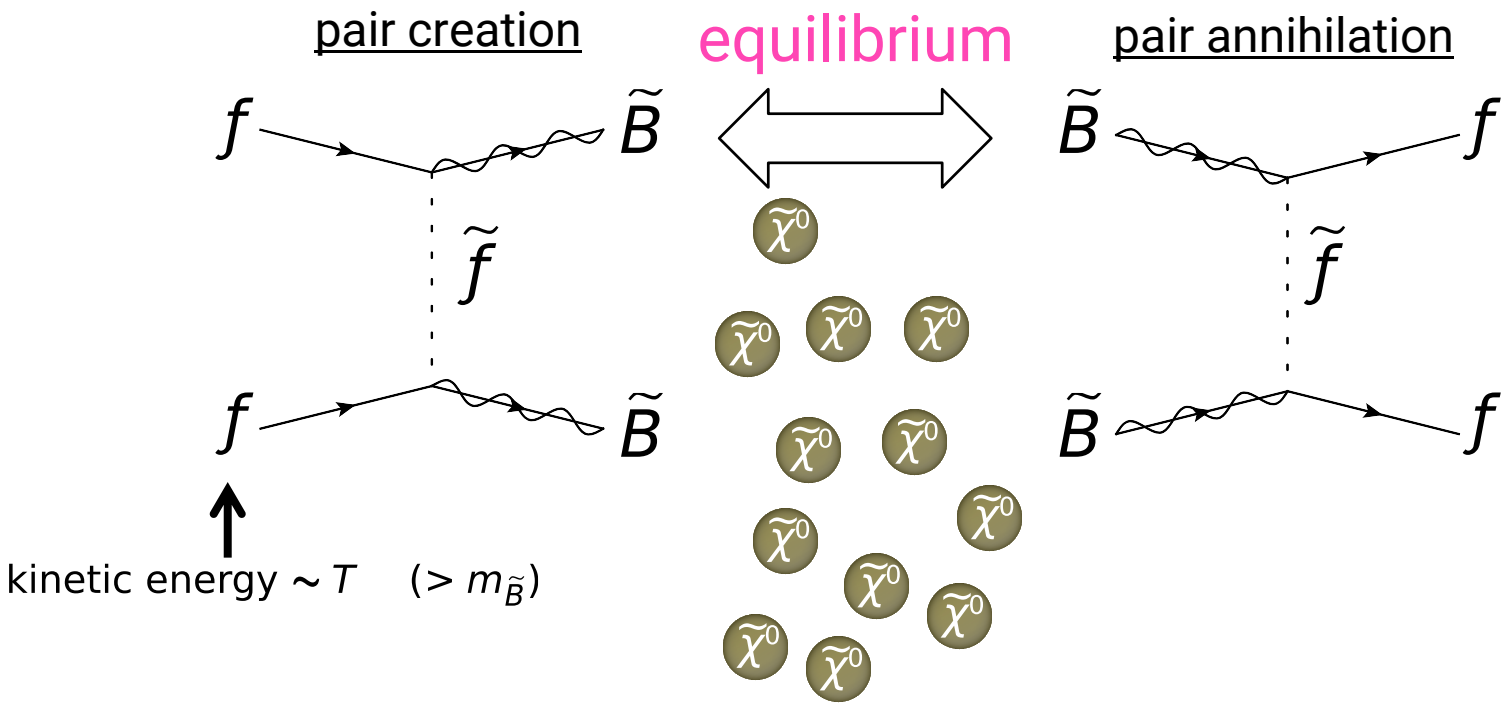
Introduction: Overabundant problem

Model: MSSM4G

Phenomenology: Gamma-ray obs. & LHC

Summary

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



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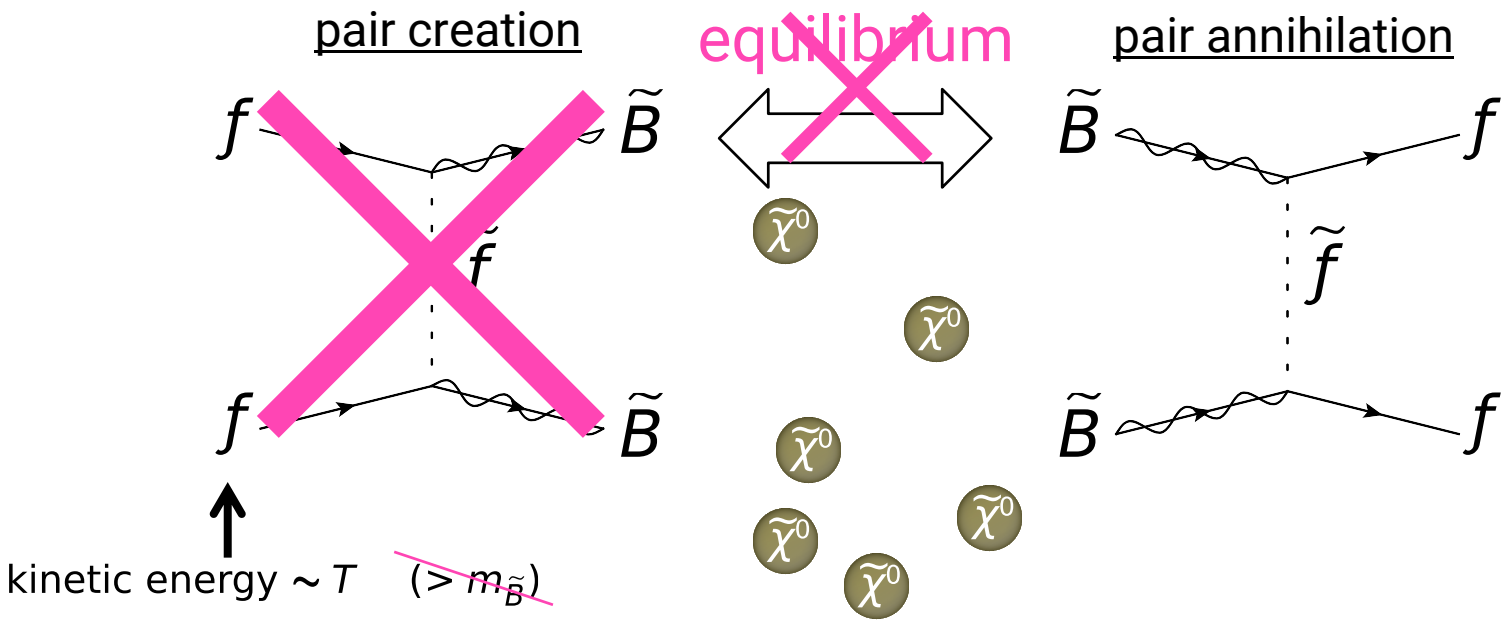
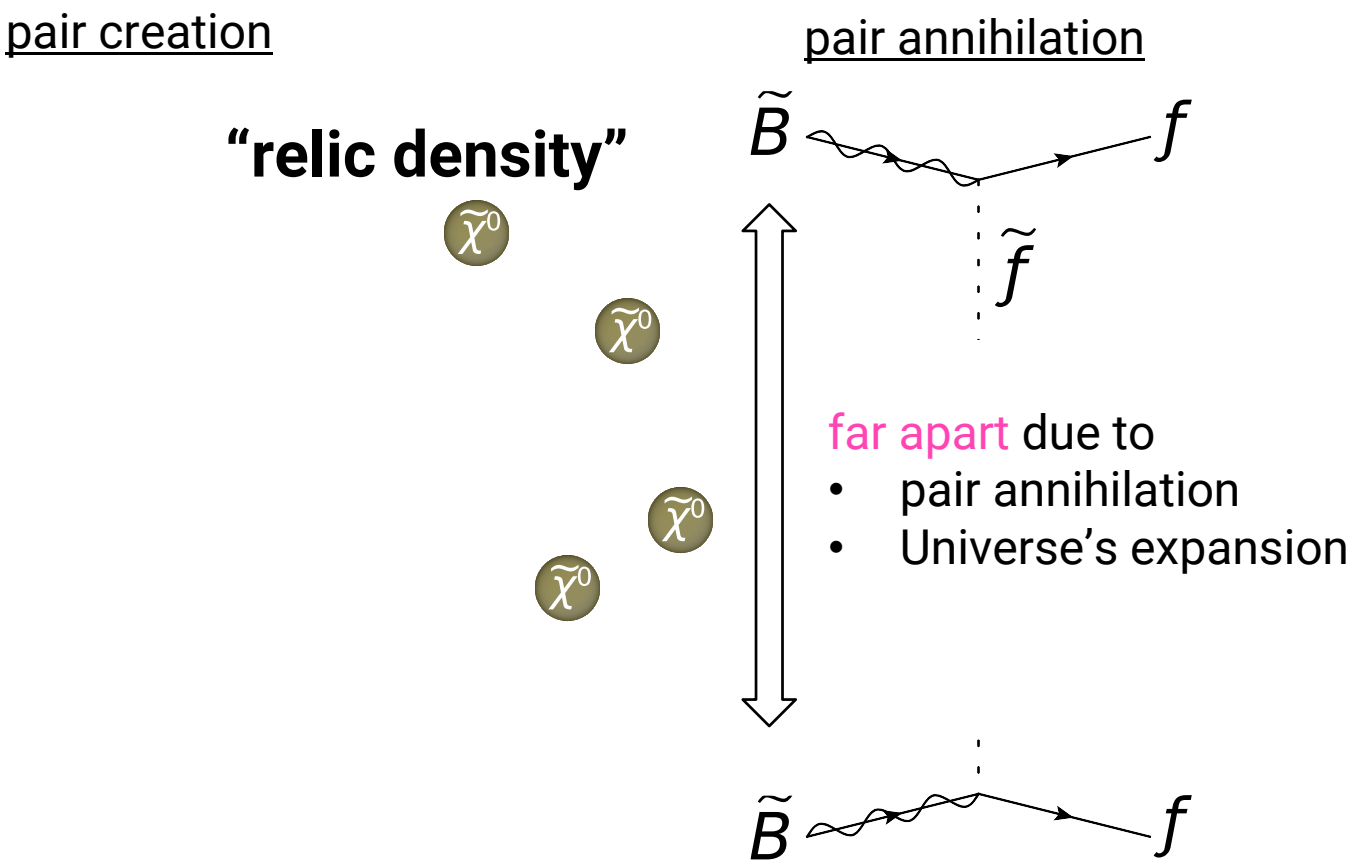


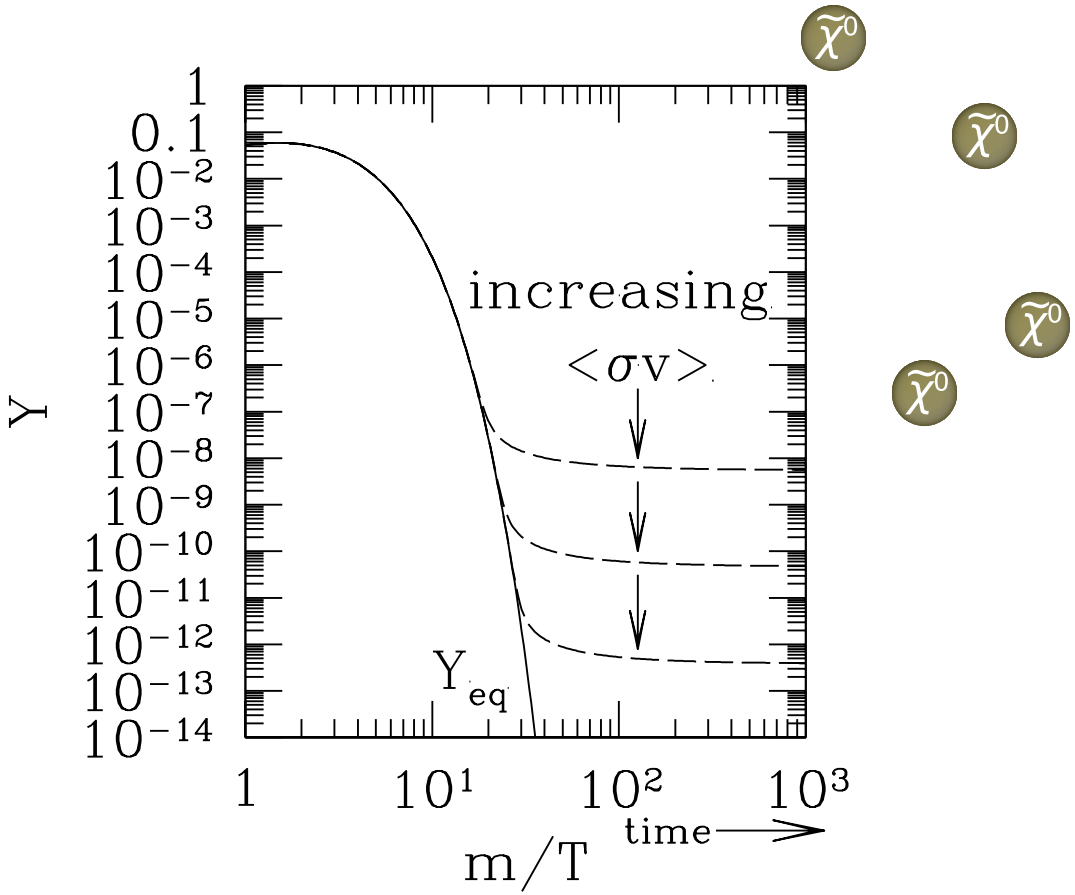
- Early Universe with $T \lesssim m_{\tilde{B}}/20$



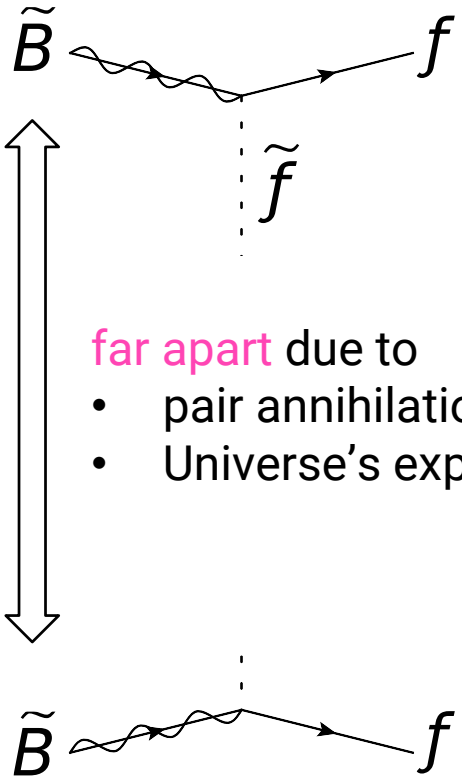
- Early Universe with $T \lesssim m_{\tilde{B}}/20$

pair creation

“relic density”



pair annihilation



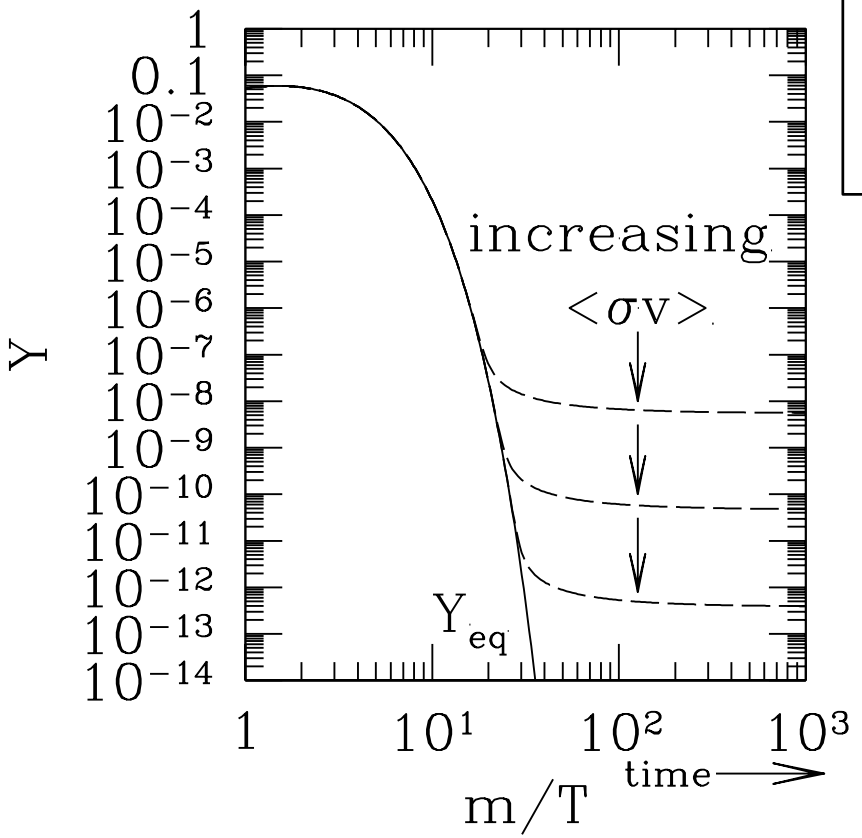
far apart due to
- pair annihilation
- Universe’s expansion

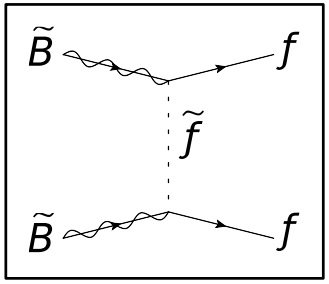
Figure from Gelmini and Gondolo, 1009.3690

- pure-$\tilde{B}$ DM

  $m_{\tilde{B}} \lesssim 100$ GeV: DM density ("relic density") ~ observation

  $m_{\tilde{B}} \gtrsim 100$ GeV: smaller crosssection → larger DM density





"overabundant problem"

of Bino thermal relic DM

Figure from Gelmini and Gondolo, 1009.3690

- pure-$\widetilde{B}$ DM

  $m_{\widetilde{B}} \lesssim 100$ GeV: DM density ("relic density") ~ observation

  $m_{\widetilde{B}} \gtrsim 100$ GeV: smaller crosssection → larger DM density

  - DM is not pure $\widetilde{B}$?
    - pure-$\widetilde{W}^0$ DM
    - $\widetilde{B}$–$\widetilde{H}$ mixing

  - Other annihilation channels?
    - co-annihilation [Griest, Seckel, 1991]
    - **MSSM4G** [Abdullah, Feng, 2015]

"overabundant problem"

of Bino thermal relic DM

Introduction: Overabundant problem

Model: MSSM4G

Phenomenology: Gamma-ray obs. & LHC

Summary

- SM = **3G**enerations
- MSSM = **3G**enerations

SUSY

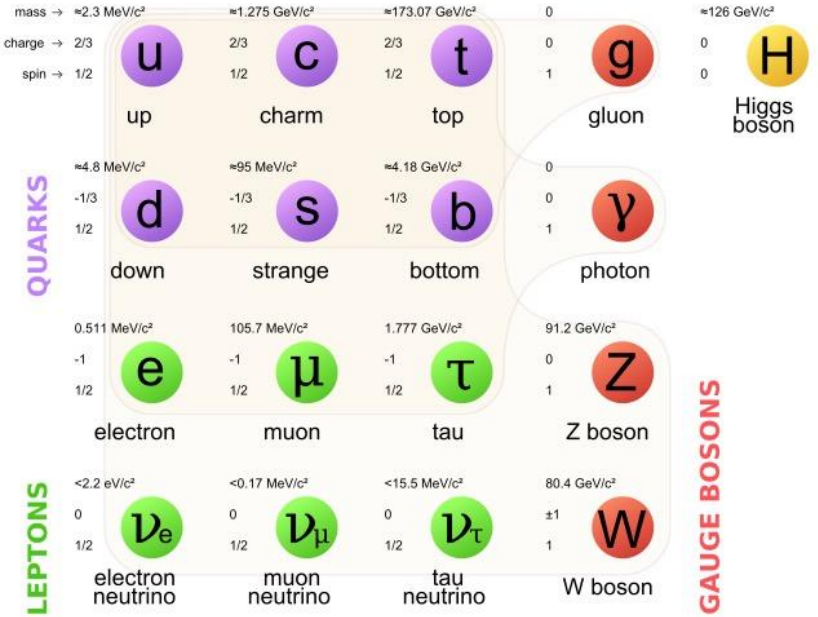
+

extra vector-like
4th-Generation lepton

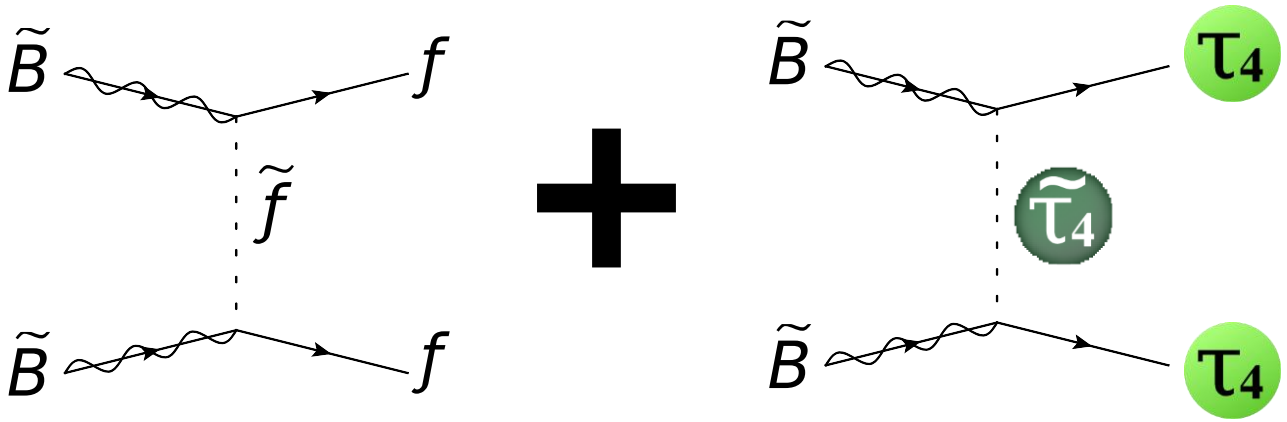
τ_4 $\tilde{\tau}_4$

=

MSSM4G



- A new solution to $\widetilde{B}$-overabundant problem: MSSM4G

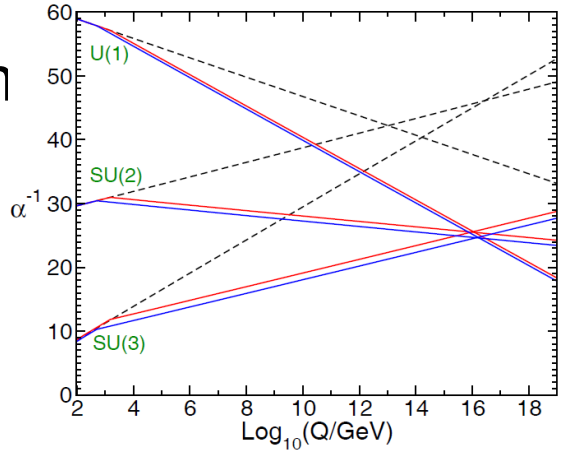


extra annihilation channel

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

$$\langle \sigma v \rangle = \frac{g_Y^4 Y_{\mathrm{L}}^2 Y_{\mathrm{R}}^2}{2\pi} \frac{m_f^2}{m_{\widetilde{B}}} \frac{\sqrt{m_{\widetilde{B}}^2 - m_f^2}}{\left(m_{\widetilde{B}}^2 + m_{\widetilde{f}}^2 - m_f^2\right)^2}$$

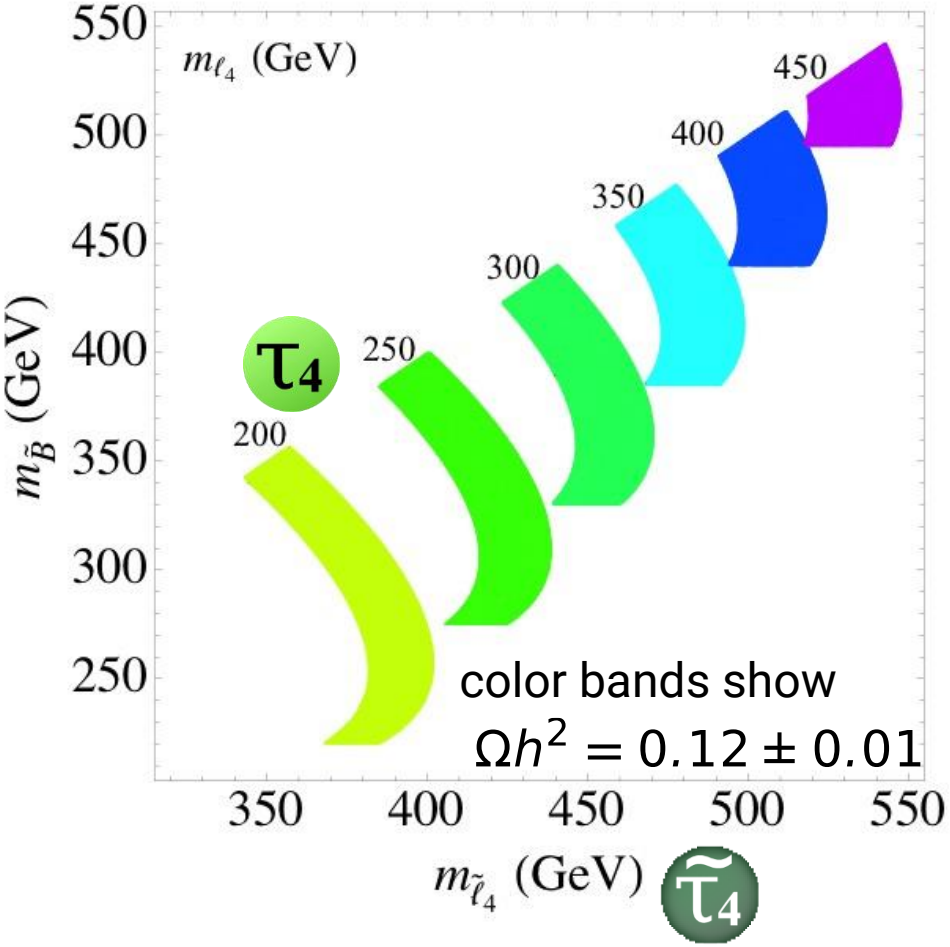
- MSSM + $E\bar{E}$ → breaks coupling unification



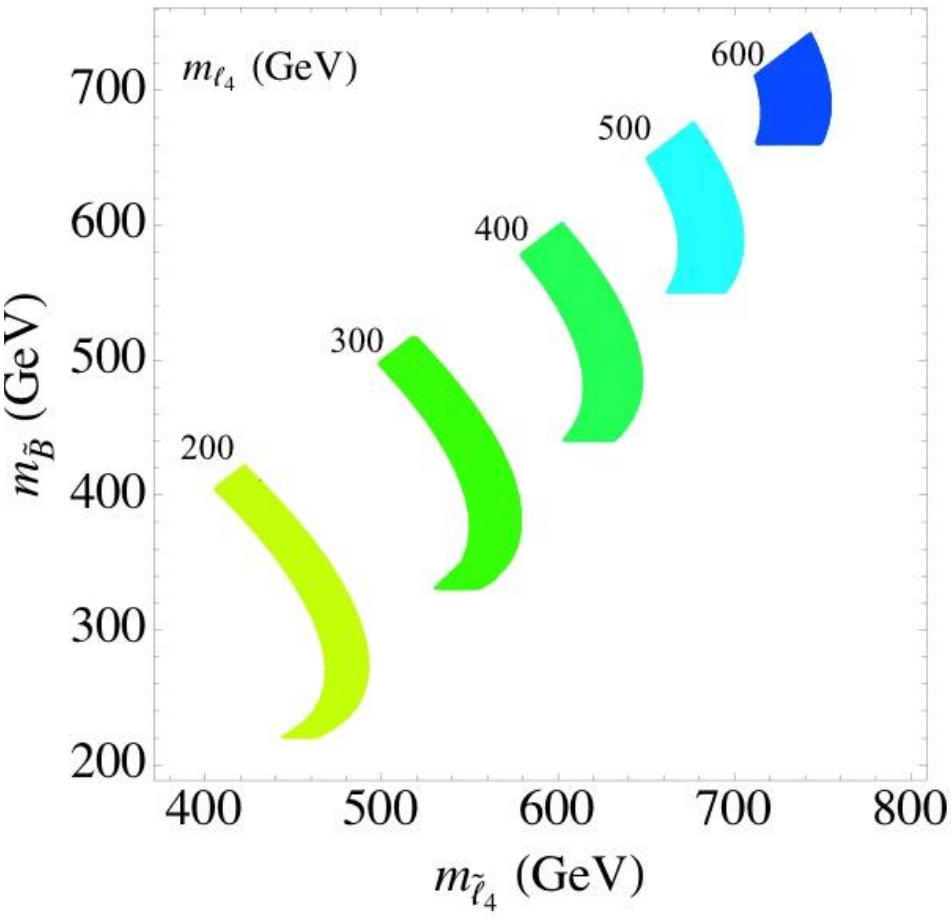
- QUE model : MSSM + $Q\bar{Q}U\bar{U}E\bar{E}$
  - ✓ gauge coupling unification
  - ✓ SU(5) GUT
  - ➢ extra $H_u Q_4 \bar{U}_4$ interaction → m_h UP
- QDEE model : MSSM + $Q\bar{Q}D\bar{D}E\bar{E}E\bar{E}$
  - ✓ gauge coupling unification
  - ✗ SU(5) GUT
  - ➢ extra $H_d Q_4 \bar{D}_4$ coupling → m_h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

Abdullah, Feng [1510.06089]

QUE model



QDEE model



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

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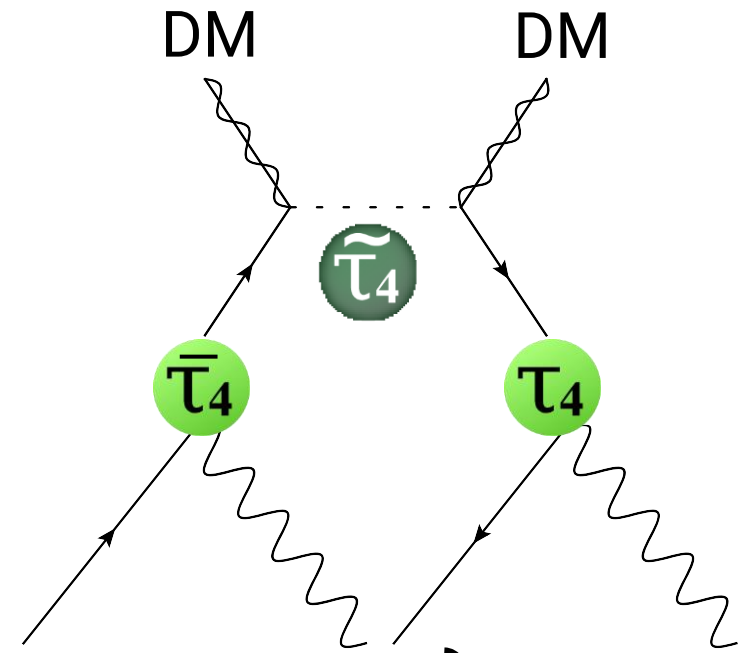
- DM indirect detection by Gamma-ray observation



$$\nu + W$$
$$l + h$$
$$l + Z$$
$$\sim 2:1:1$$

$$\begin{pmatrix} \nu = \nu_e, \nu_\mu, \nu_\tau \\ l = e, \mu, \tau \end{pmatrix}$$

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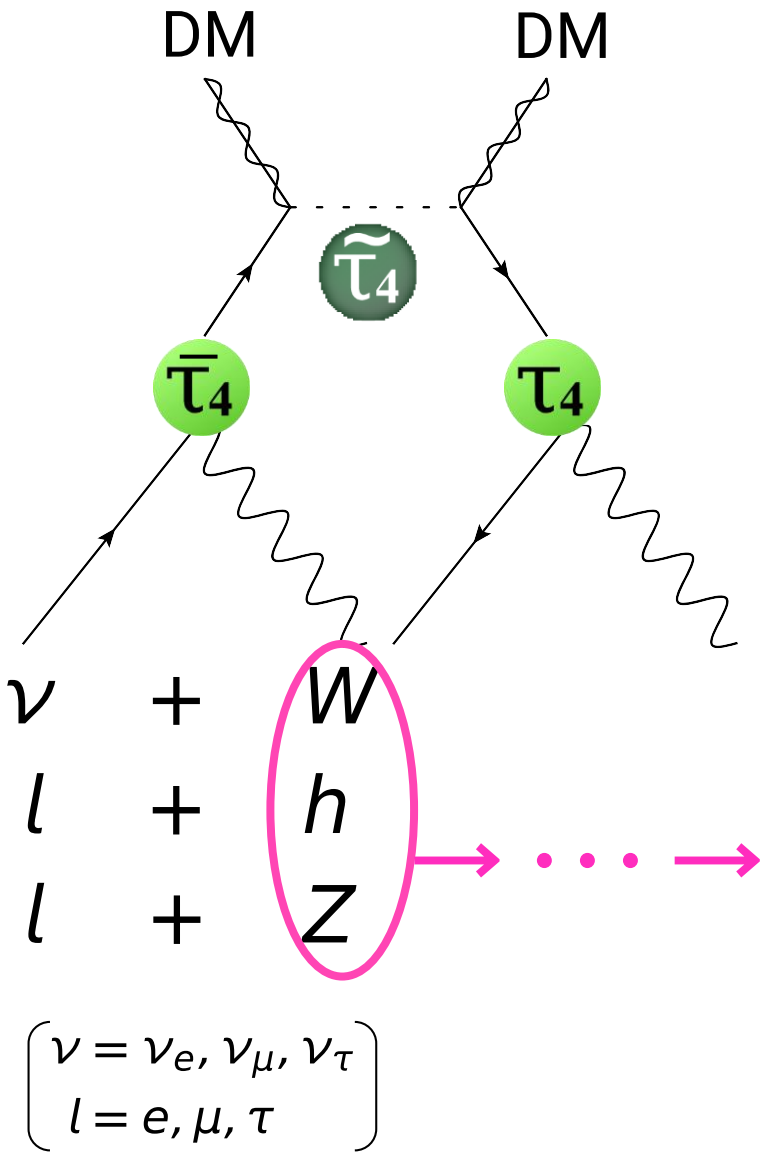
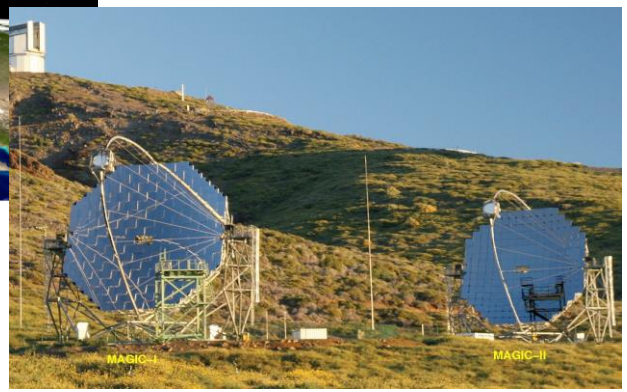
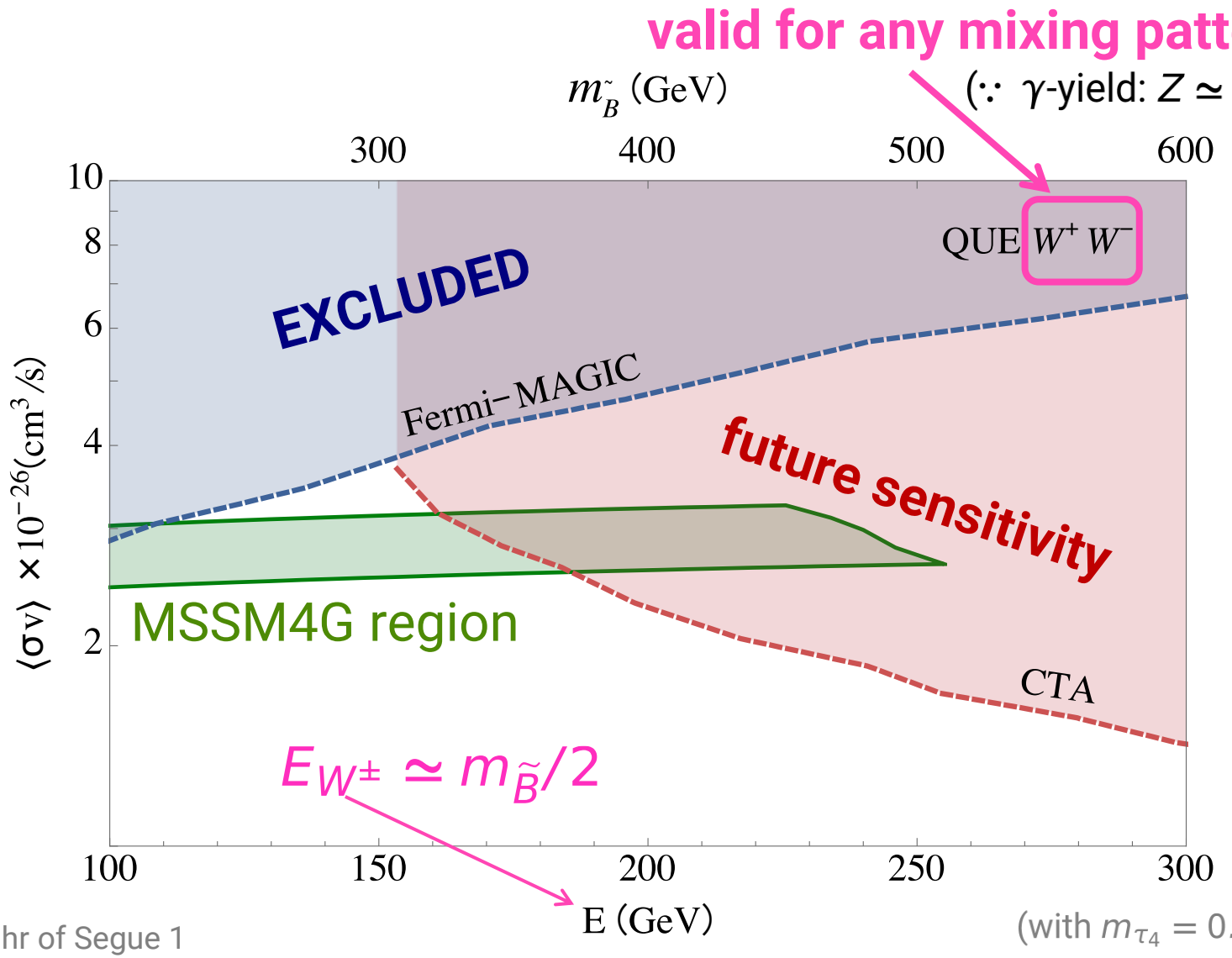




Fermi-LAT (satellite)
MAGIC (Air Cherenkov telescope)

CTA (**future** A. C. Telescope)

Abdullah, Feng, SI, Lillard [1608.00283]



MAGIC: 158 hr of Segue 1

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

DM profile: NFW

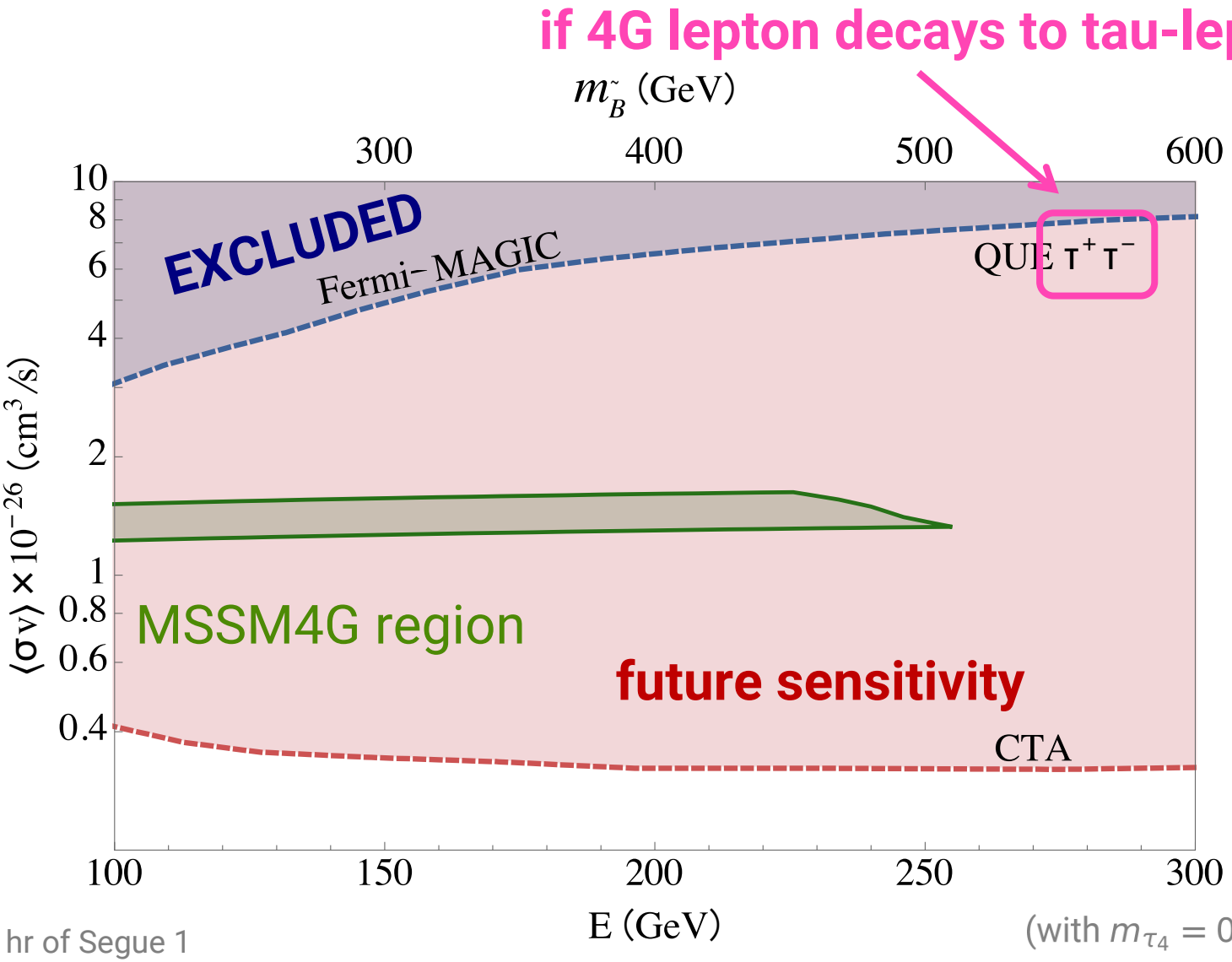
Fermi-LAT dominates MAGIC in almost all *E*-range.

CTA prospect : 500hr of Milky Way

DM profile: Einasto

No syst. unc. (stat only)

Abdullah, Feng, SI, Lillard [1608.00283]



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

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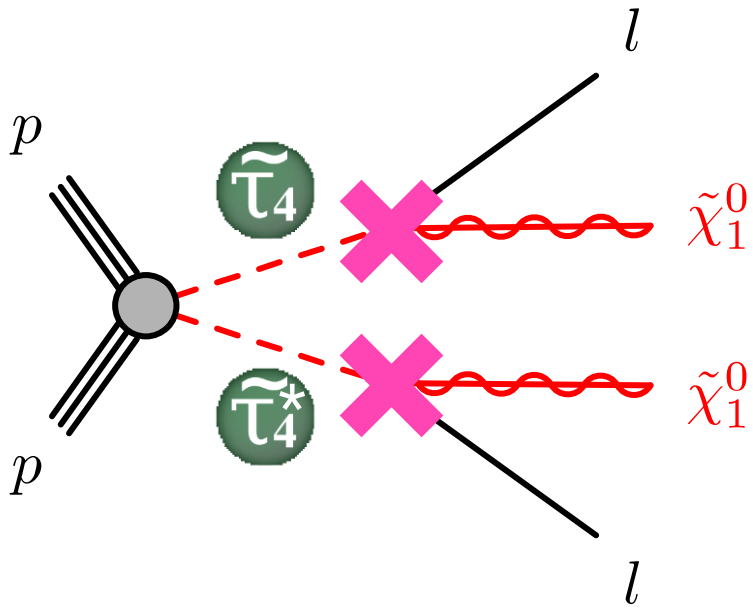
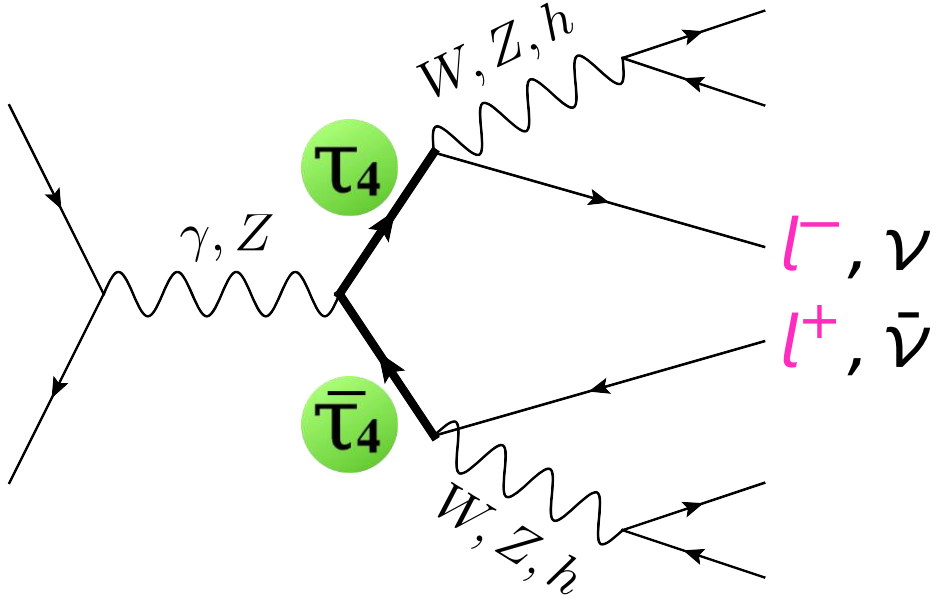
$\tilde{\tau}_4$ (4G slepton) search



→ searches for
2-lepton + Missing E_T

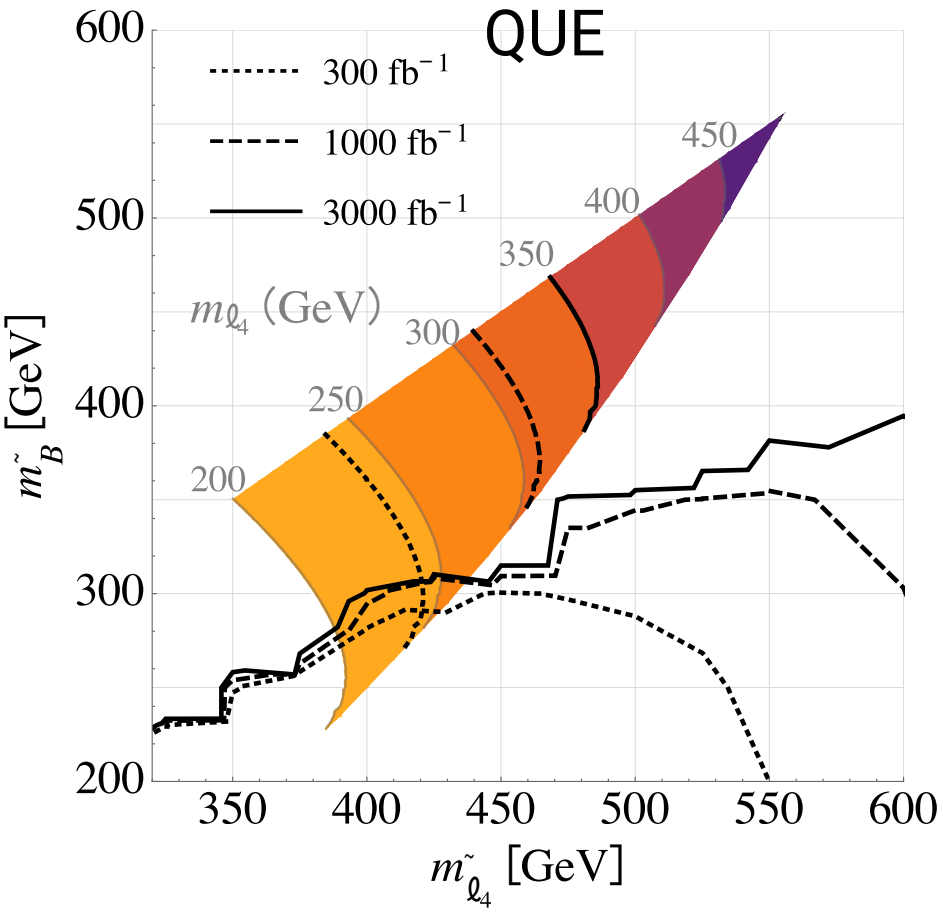
(same as MSSM slepton searches)

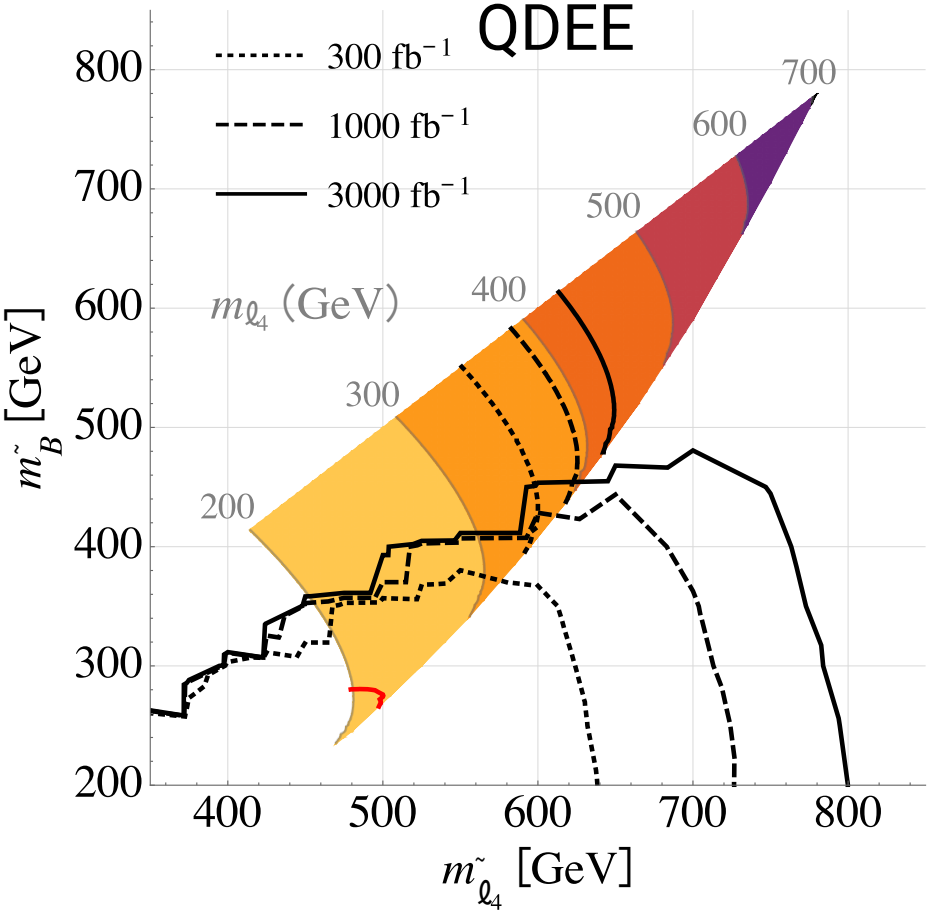
τ_4 (4G lepton) search



→ searches for
multi-lepton final state

- **if 4G lepton decays to electron or muon**





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LHC insensitive … (´ ・ω・ `)

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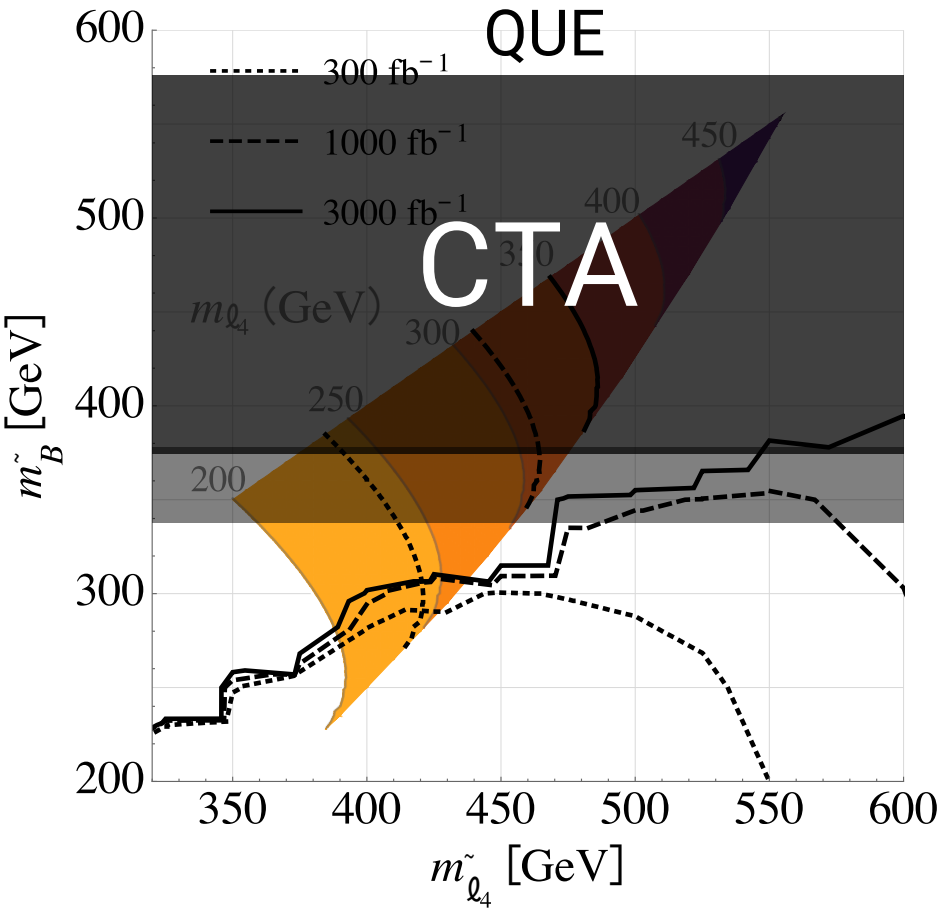

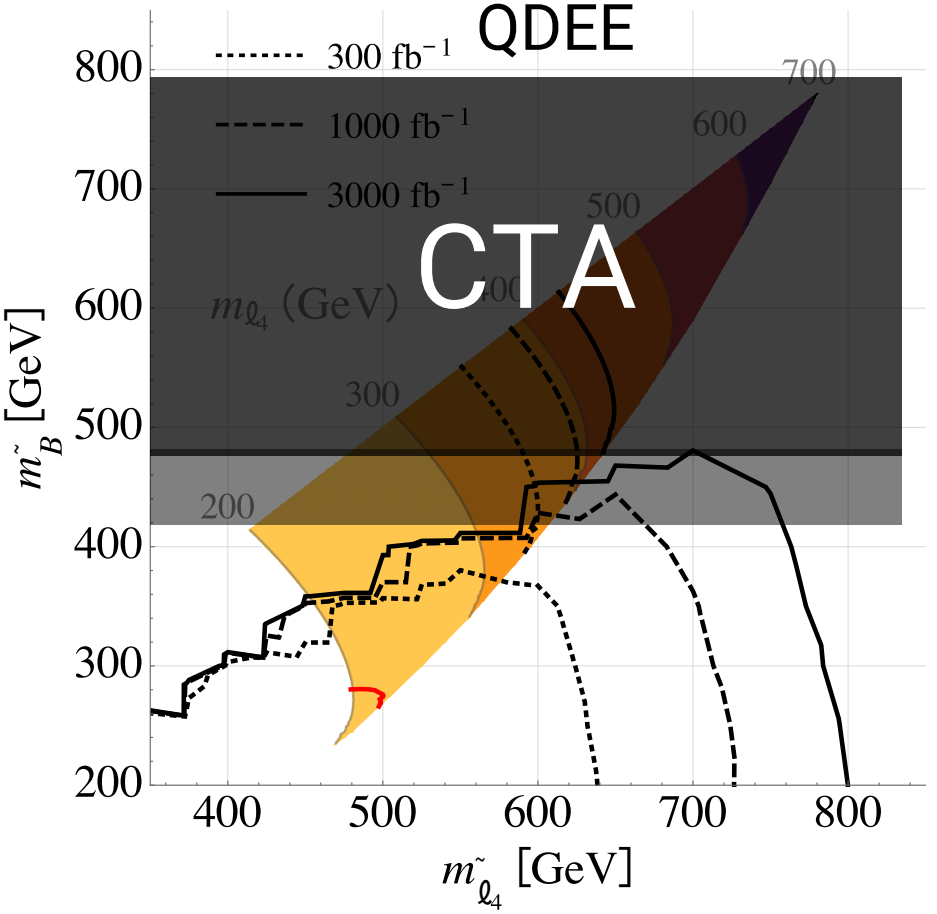

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- Pure-$\widetilde{B}$ DM may cause DM overabundance
- MSSM4G is a solution to this problem.
- MSSM4G will be **ALL** explored soon.

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- MSSM4G: provides additional **DM-annihilation** channel.
  → correct relic density even w. $m_{\widetilde{B}} \gtrsim$ 100 GeV.
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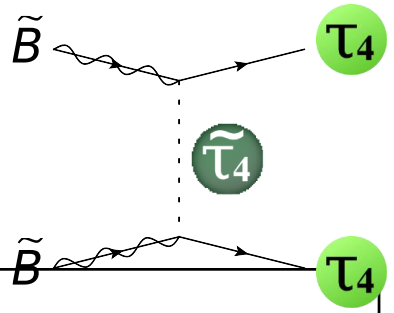

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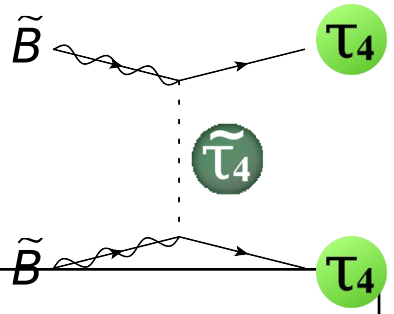

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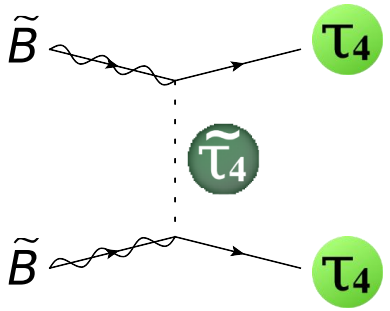

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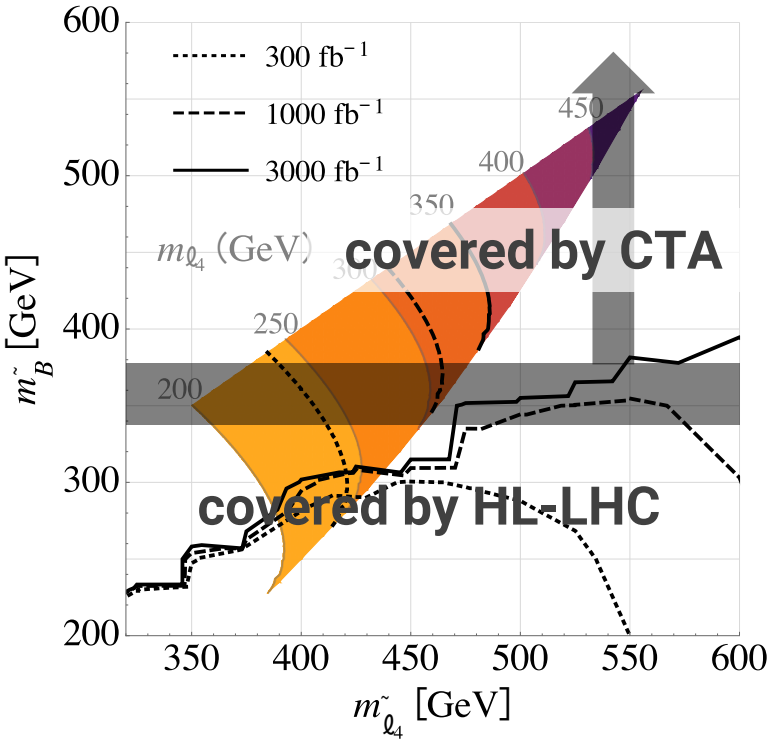

tau-lepton