Gravitational Positivity For Dark Gauge Bosons

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How dark is “dark”?

Gravity to Rescue?

"(other forces) $\gtrsim$ (gravity)"

cf. · (gauge) weak gravity conjecture

Arkani-Hamed, Motl, Nicolis, Vafa '06

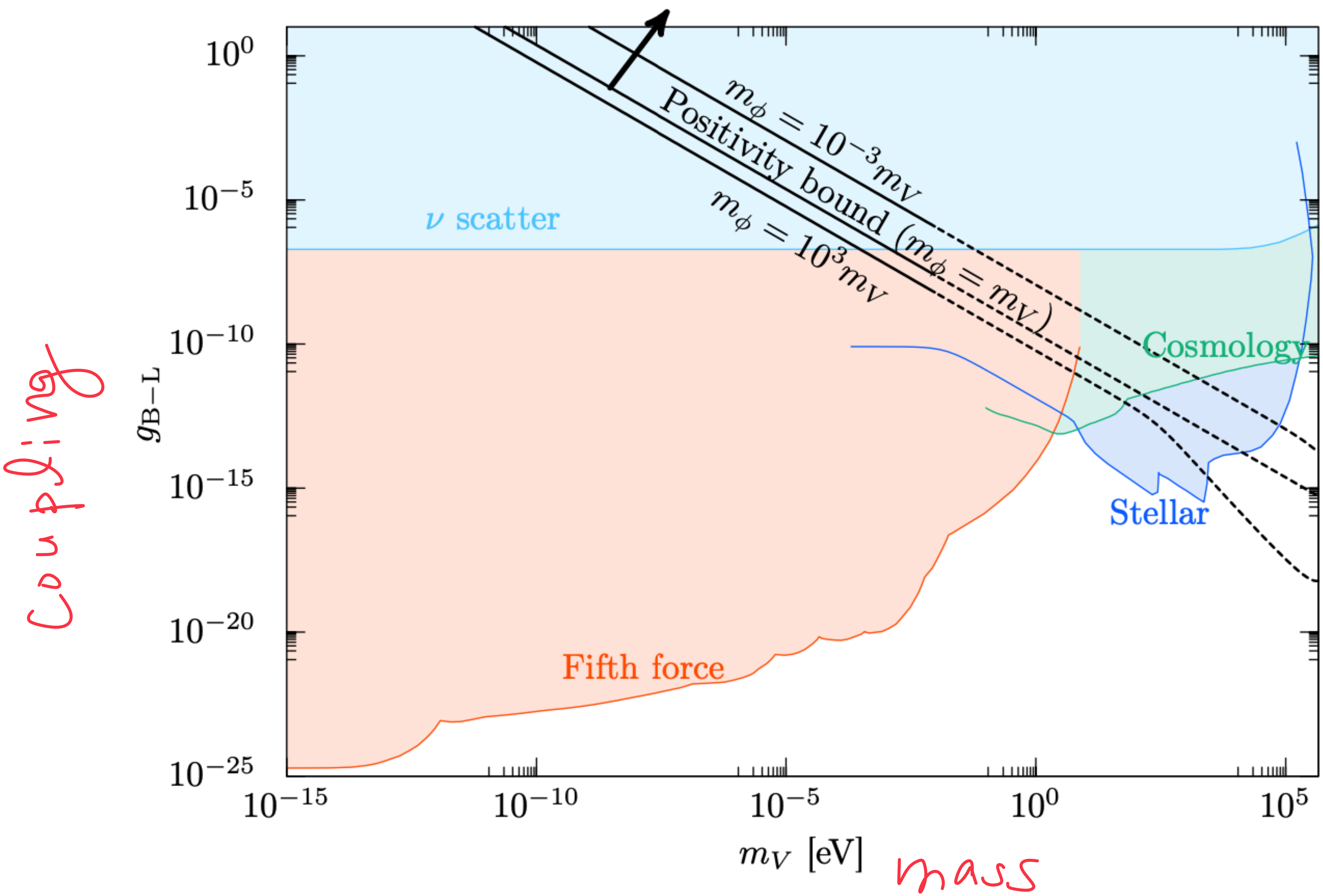
· scalar weak gravity conjecture

Palti '17, Shiraishi-MY '19, Kusenko-Takhistov-Yamada-MY '19

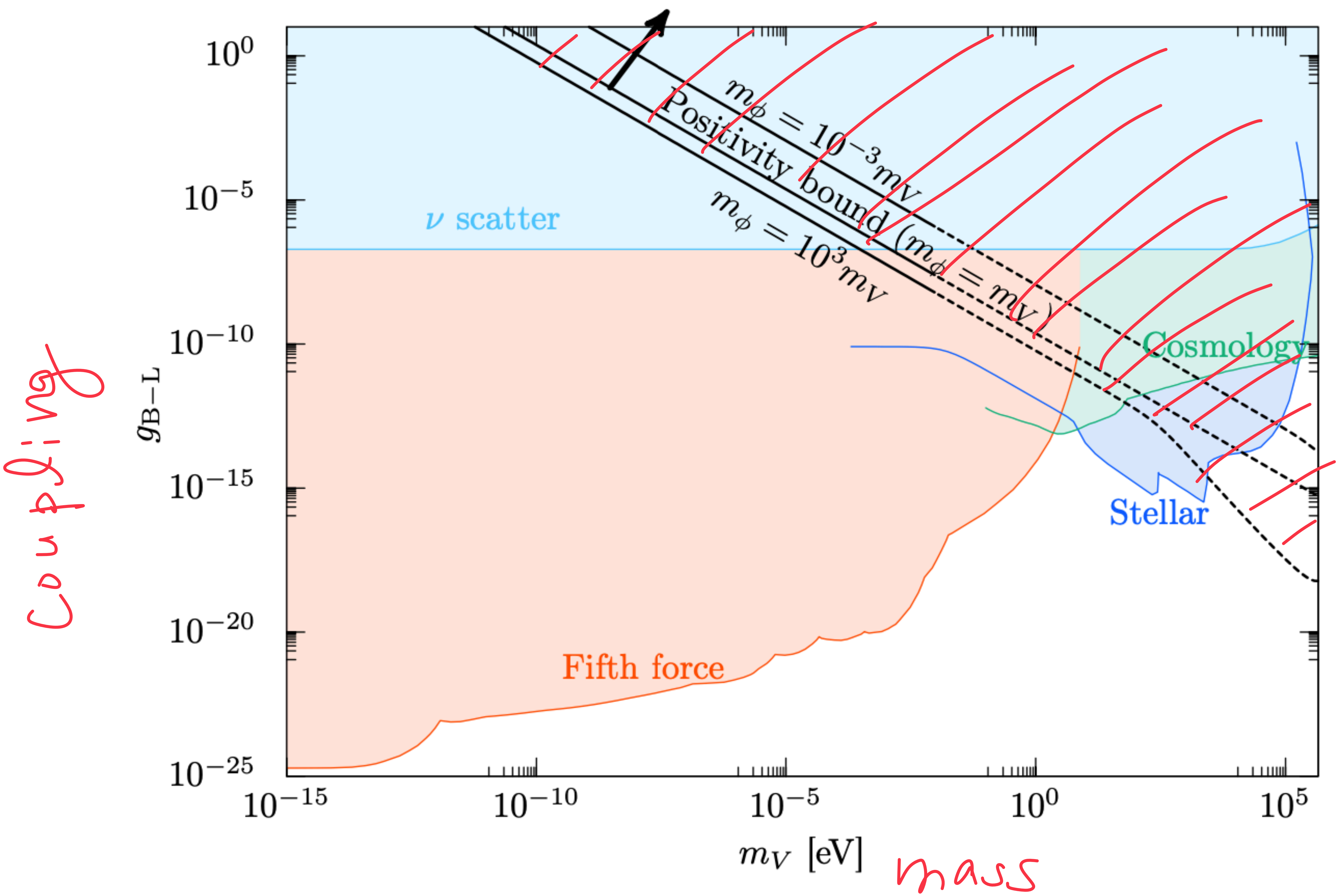
· gravitational positivity

Tokuda, Aoki, Hirano '20, ...

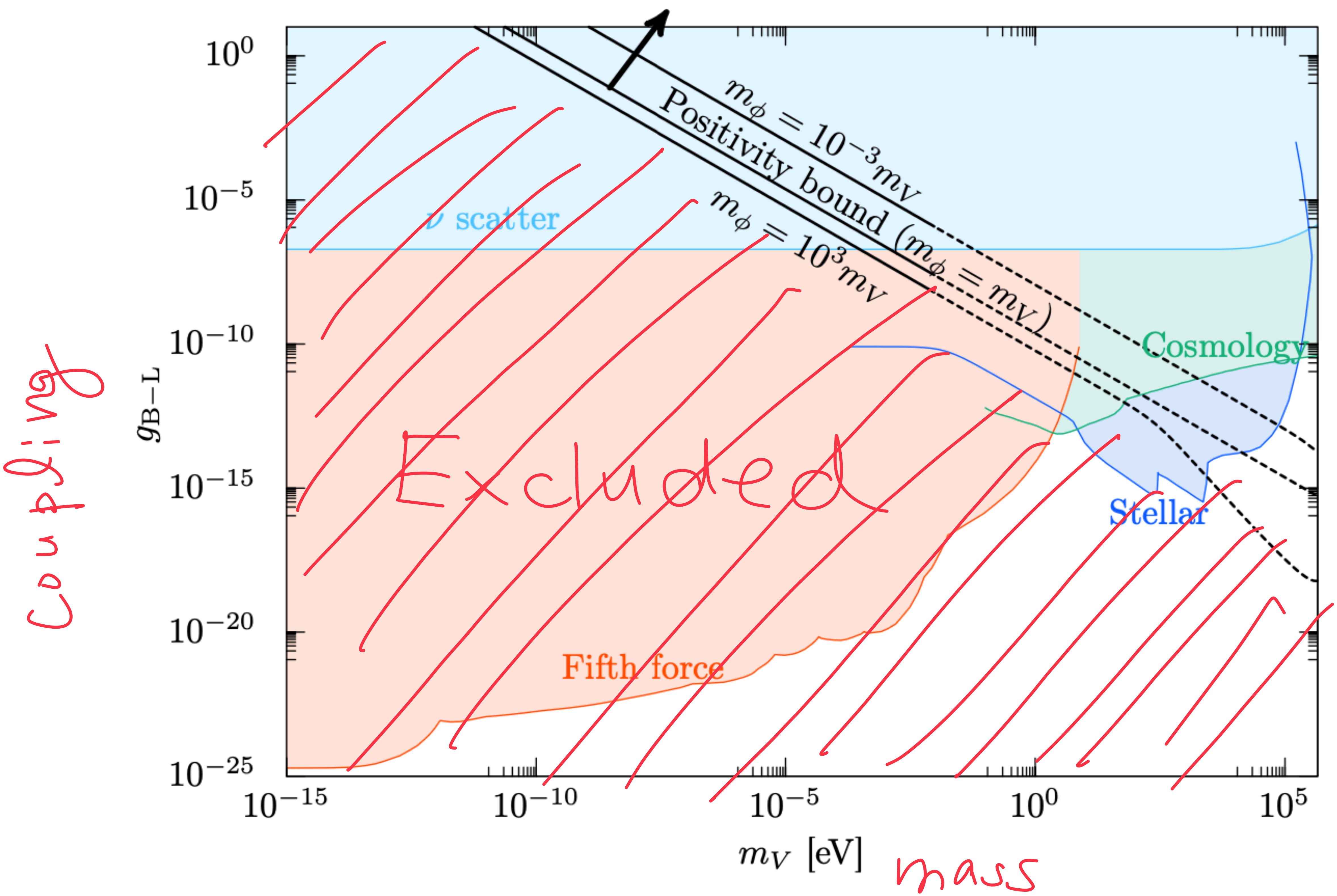
"Result" of gouged $U(1)_{B-L}$



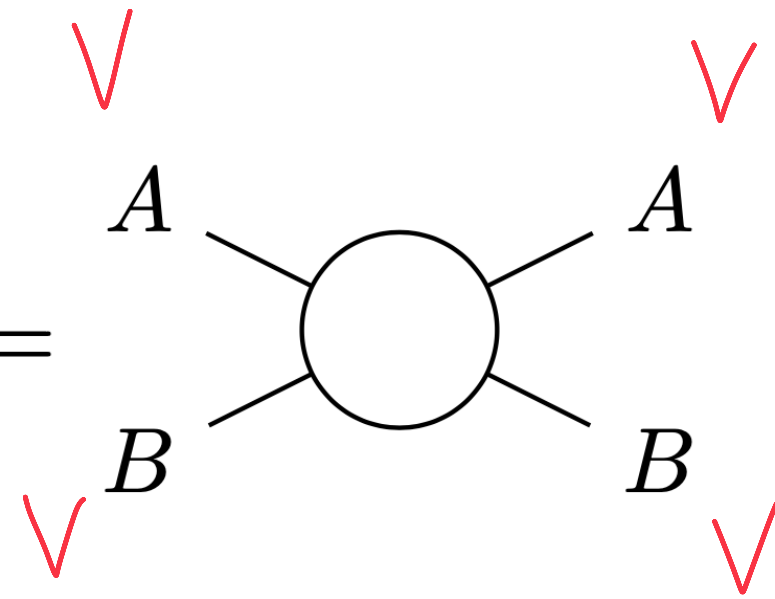
"Result" of gouged $U(1)_{B-L}$



"Result" of gauged $U(1)_{B-L}$



$$i\mathcal{M}_{\text{non-grav}}(s,t) =$$



$$+ \cdots$$

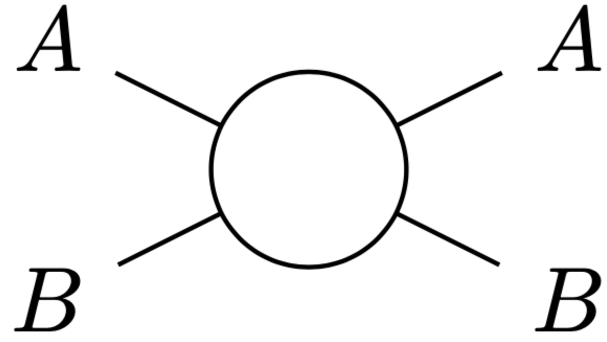
Assumptions

(i) analyticity

(ii) unitarity $(\mathrm{Im}\, \mathcal{M} \geq 0)$

(iii) s^2- boundedness $\lim_{|s|\to\infty} \frac{|\mathcal{M}(s,0)|}{s^2} = 0$

["old" S-matrix theory since '60s]

$$i\mathcal{M}_{\text{non-grav}}(s,t) =$$  $$+ \cdots$$

IR data

$$a_2 := \left.\frac{\partial^2 \mathcal{M}(s,t=0)}{\partial s^2}\right|_{s=2m_V^2}$$

$$B_2 := a_2 - \frac{2\cdot 2!}{\pi}\int_{m_{th}^2}^{\Lambda^2} ds\, \frac{\text{Im}\,\mathcal{M}(s,t=0)}{(s-2m_V^2)^3}$$

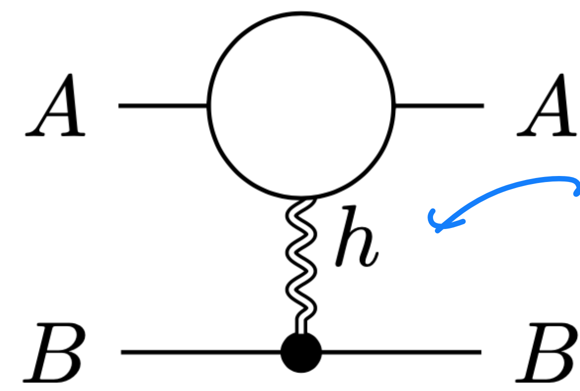
$$= \frac{2\cdot 2!}{\pi}\int_{\Lambda^2}^{\infty} ds\, \frac{\text{Im}\,\mathcal{M}(s,t=0)}{(s-2m_V^2)^3} \geq 0$$

dispersion rel, analyticity + s^2-boundedness

UV data

[Adams, Arkani-Hamed, Dubovsky, Nicolis, Rattazzi '06
Bellazzini '16 de Rham, Melville, Tolley, Zhou '17, ...]

$$i\mathcal{M}_{\text{grav},t\text{-channel}}(s,t) = $$

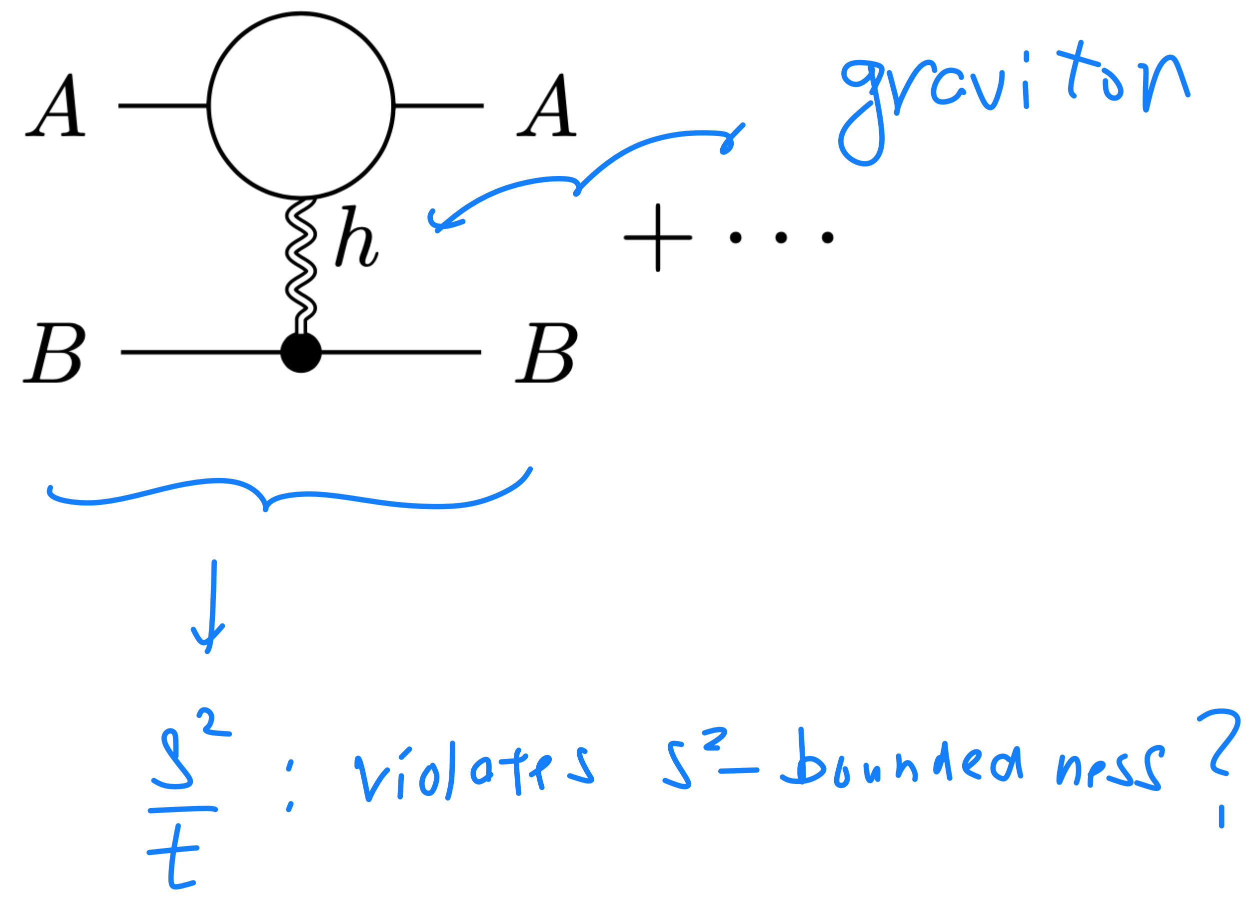


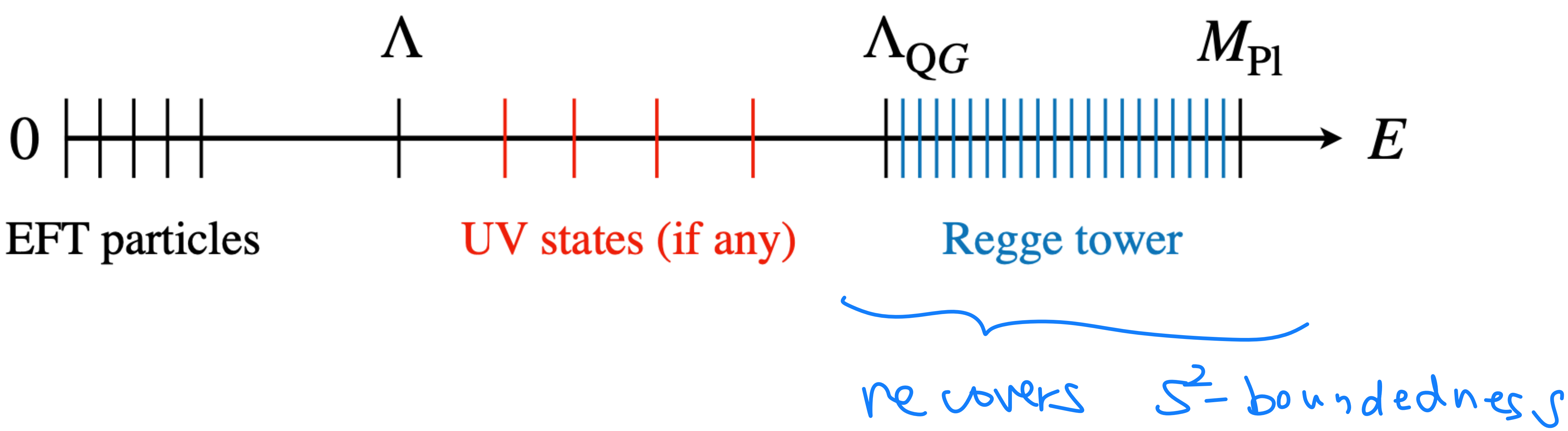
$$+\cdots$$

graviton

$\frac{s^2}{t}$: violates s^2-boundedness ?

$$i\mathcal{M}_{\text{grav},t\text{-channel}}(s,t) =$$





$$B_{\text{non-grav}}(\Lambda) \simeq \frac{4}{\pi}\int_{\Lambda^2}^{\infty} ds \, \frac{\mathrm{Im}\,\mathcal{M}_{\text{non-grav}}(s,t=0)}{(s-2m_V^2)^3}$$

$$B_{\text{grav}}(\Lambda) \simeq \lim_{t\to -0}\left[\frac{\partial^2 \mathcal{M}_{\text{grav},t\text{-channel}}(s,t)}{\partial s^2} + \frac{2}{M_{\text{Pl}}^2 t} - (\text{kinematic singularity})\right]_{s=2m_V^2}$$

sum

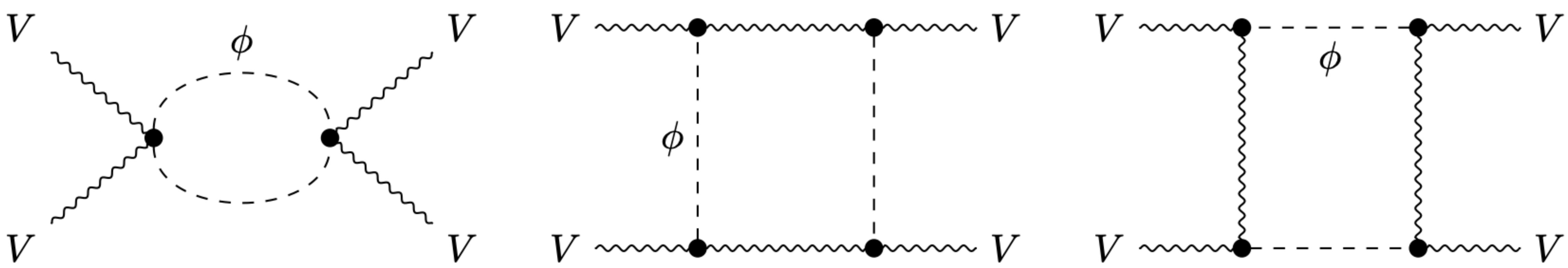
$$B(\Lambda) \geq \mathcal{O}\left(\frac{1}{M_{pl}^2 M^2}\right)$$

↑ related to Λ_{QG}

[Tokuda, Aoki, Hirano '20

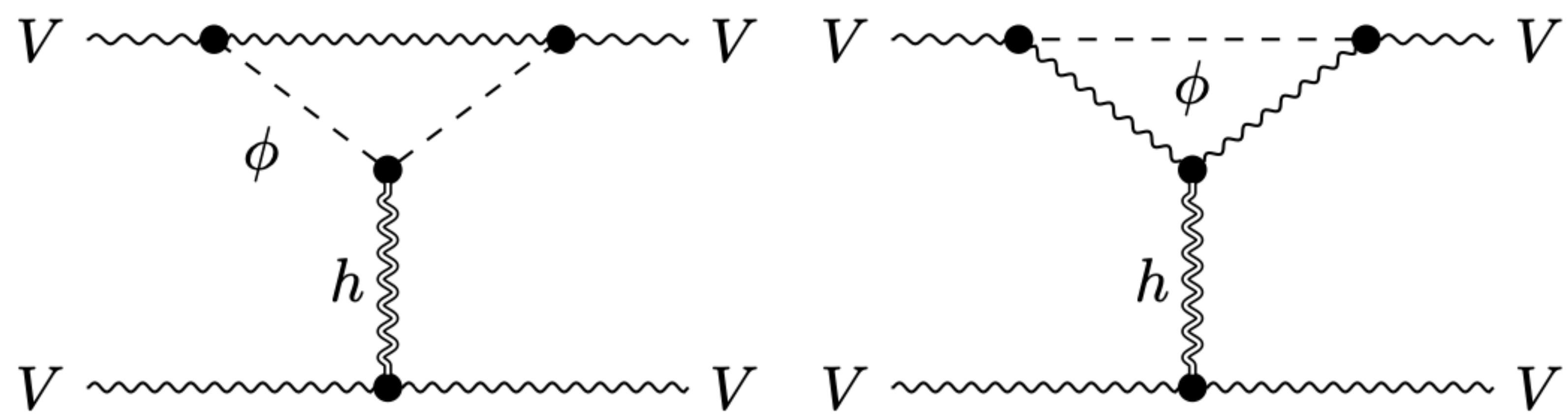
cf. Alberte, de Rham, Jaitly, Tolley '20]

Example: U(1) gauge boson with Higgs mass



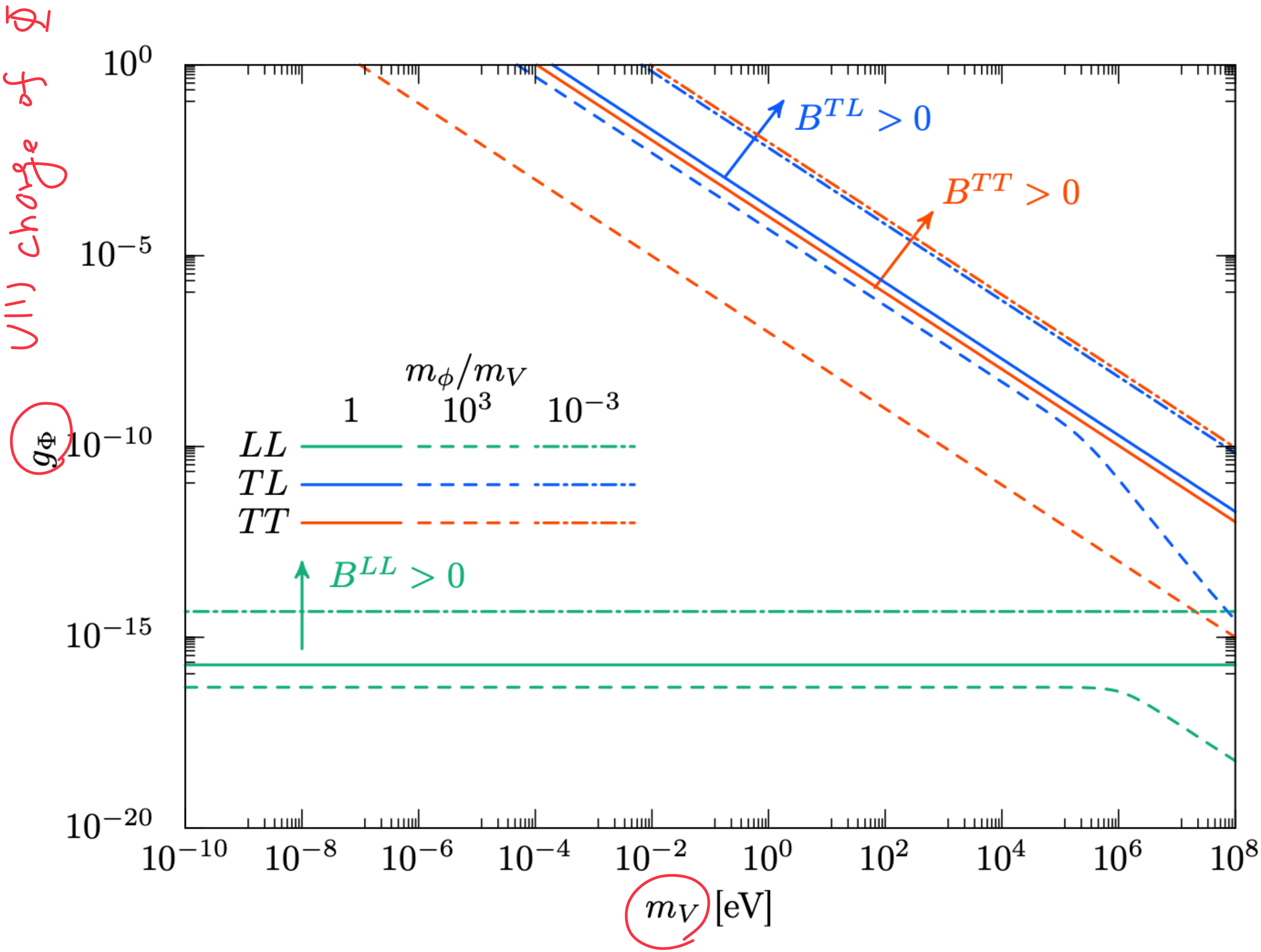
non-gravitational

$$B_{\text{non-grav}} \sim + \frac{g_\Phi^4}{\Lambda^4} + \cdots$$



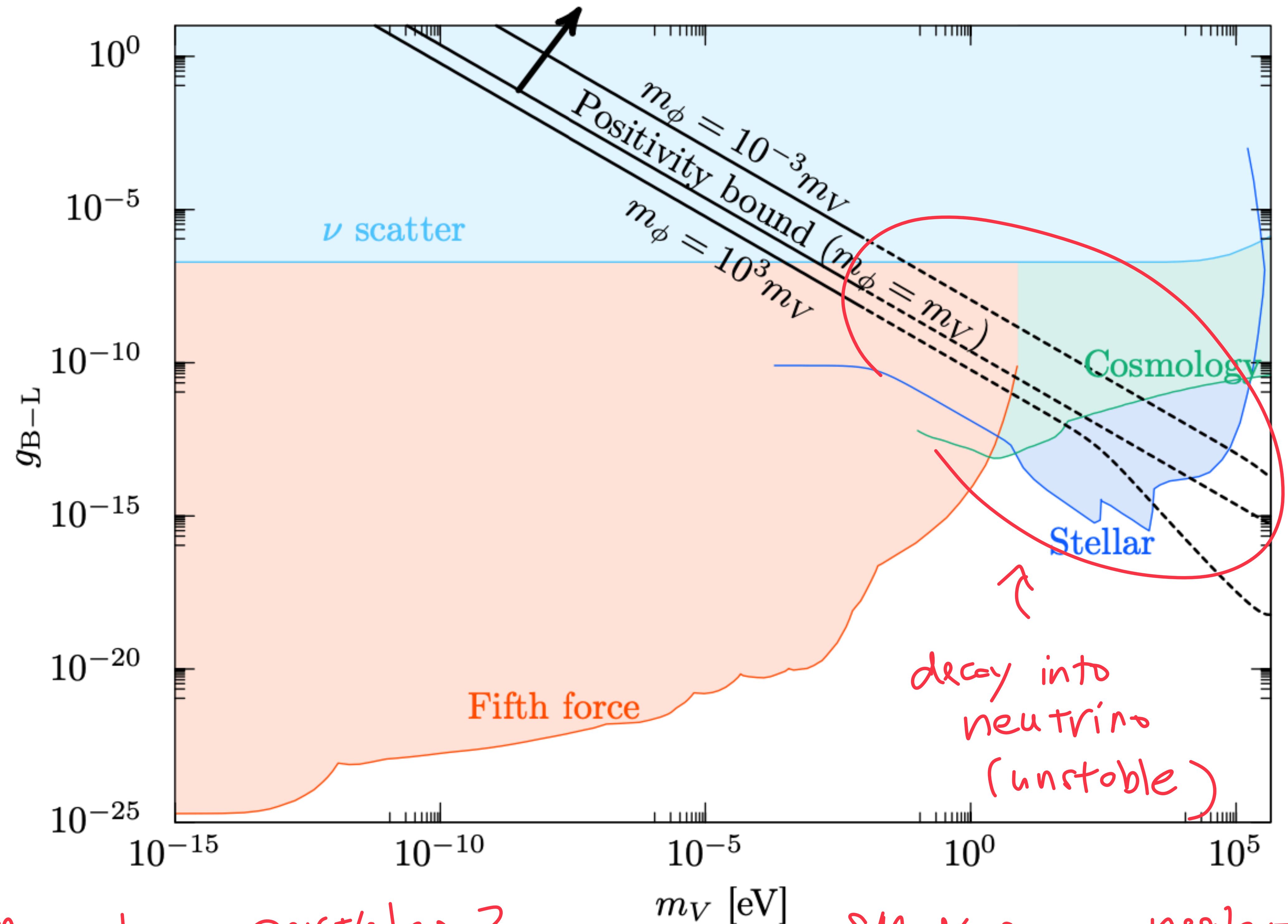
gravitational

$$B_{\text{grav}} \sim - \frac{g_\Phi^2}{m_\Phi^2 M_{pl}^2}$$



U(1) charge of Φ
g_Φ
10^{0}
10^{-5}
10^{-10}
10^{-15}
10^{-20}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{4}
10^{6}
10^{8}
m_V [eV]
$B^{TL} > 0$
$B^{TT} > 0$
$B^{LL} > 0$
m_ϕ / m_V
1
10^{3}
10^{-3}
LL
TL
TT

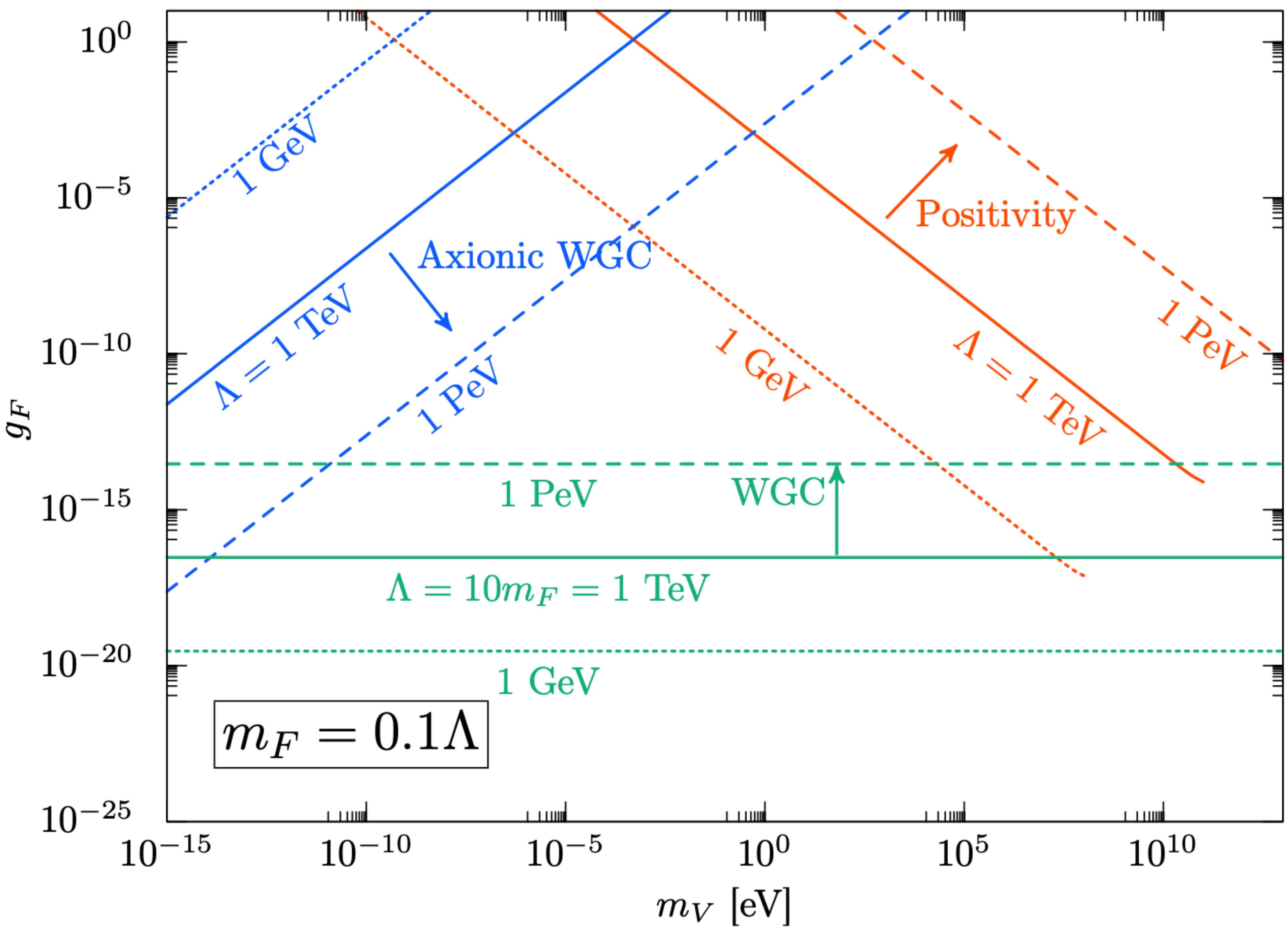
Realistic Cases: Theoretically Subtle



massless particles?

SM diagrams neglected

Example: Stückelberg U(1)



Summary

(Gravity UV completion) $\xrightarrow{\text{practical recipes}}$ (lower bound on dark sector couplings)

Dark side of Universe

= Quantum-Gravity side of Universe