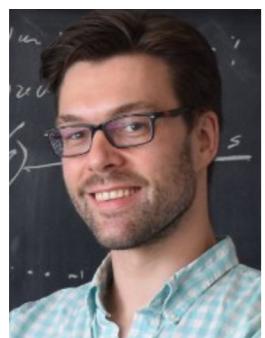


Discovering the New Physics of $(g-2)\mu$ at Colliders

Sixth Colombian Meeting on High
Energy Physics (6th ComHEP)

03/Dec/2021

Rodolfo Capdevilla
Perimeter Institute for Theoretical Physics
and University of Toronto



RC, David Curtin, Yonatan Kahn, Gordan Krnjaic,
arXiv:2006.16277
arXiv:2101.10334
arXiv:2112.?????

Outline

1. Muon Anomalous Magnetic Moment

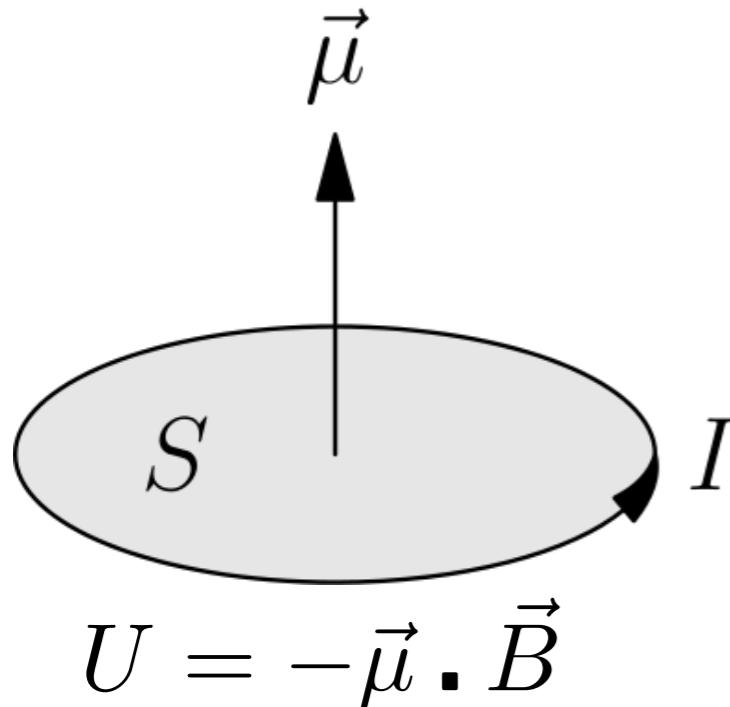
2. Singlet scenarios for $(g-2)\mu$

- Low-energy probes
- High-energy probes

3. Summary

1. Muon Anomalous Magnetic Moment

- Magnetic moment (macroscopic)



- Anomalous Magnetic Moment

$$a = \frac{g - 2}{2}$$

- Possible to define for a fundamental particle

$$\vec{\mu} = -g \frac{\mu_B}{\hbar} \vec{S}$$

↑
g-factor

- Relativistic quantum mechanics prediction

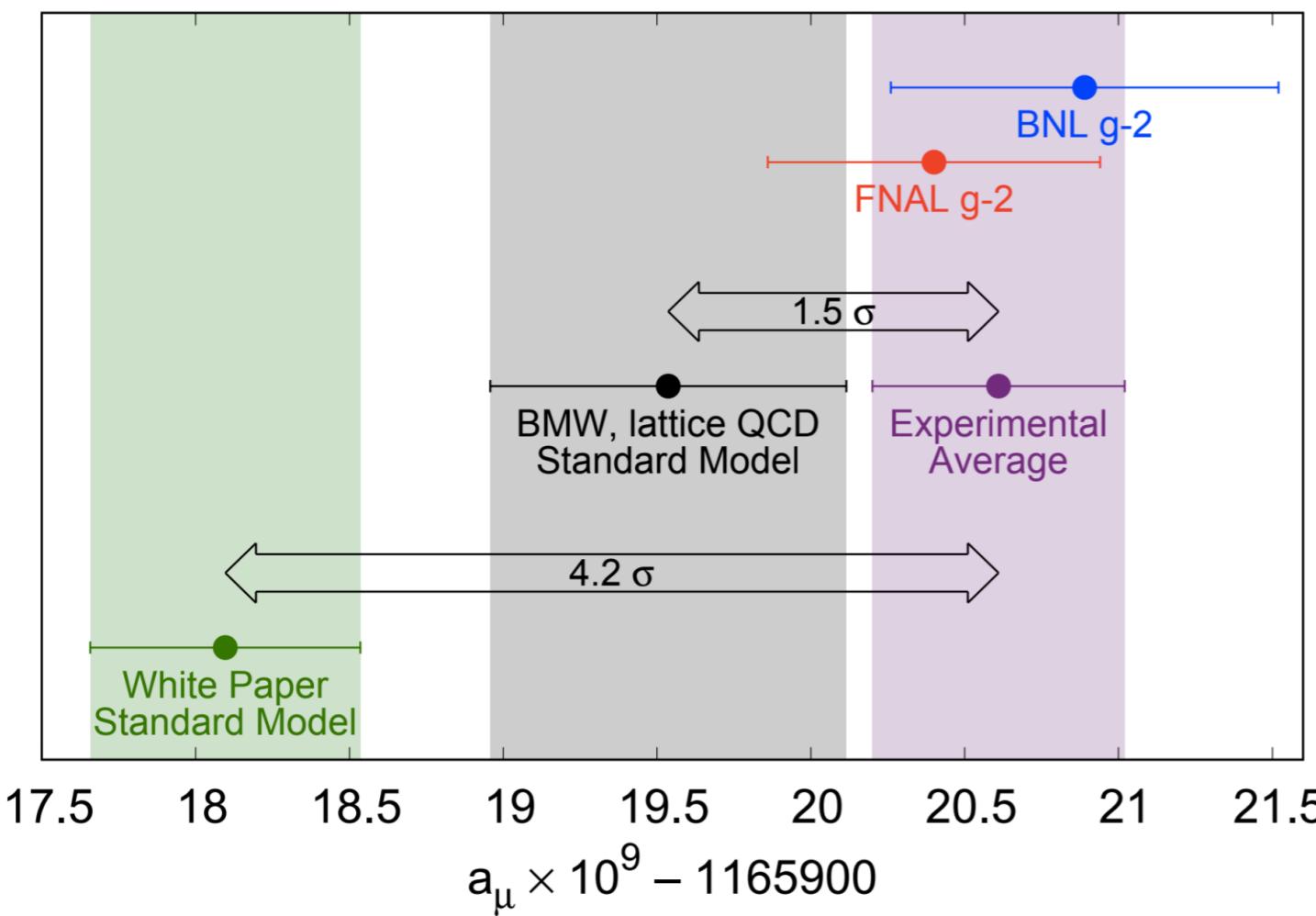
$$i\hbar \frac{\partial \phi}{\partial t} = \left[\frac{p^2}{2m} - \frac{\mu_B}{\hbar} (\vec{L} + 2\vec{S}) \cdot \vec{B} \right] \phi$$

↑
g = 2

1. Muon Anomalous Magnetic Moment

- State of affairs

BMW collaboration, Nature 593 (2021) 7857, 51-55



$$a_\mu(\text{exp}) = 116\,592\,061(41) \times 10^{-11}$$

Muon g-2 Collaboration (BNL),
Phys. Rev. D 73 (2006) 072003

Muon g-2 Collaboration (FNAL), Phys. Rev. Lett. 126 (2021) 14, 141801

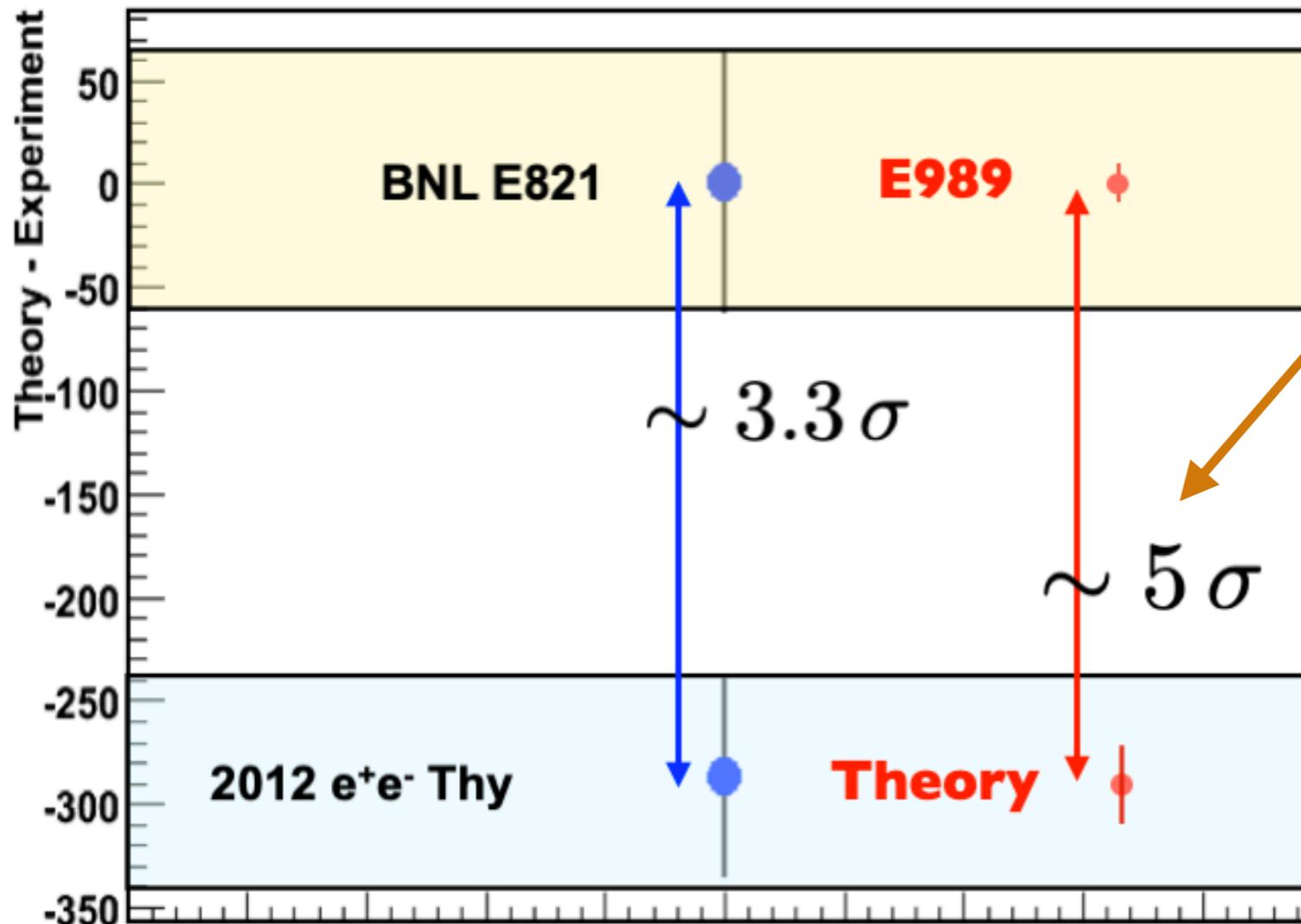
$$a_\mu(\text{the}) = 116\,591\,810(43) \times 10^{-11}$$

Muon g-2 Theory Initiative, Phys. Rept. 887 (2020) 1-166

1. Muon Anomalous Magnetic Moment

- What if?

If new physics is confirmed,
what comes next?



	E821	E989
Number of positrons	9×10^9	2×10^{11} (x 20 BNL)
Statistical Uncertainty	480 ppb	100 ppb
Systematic Uncertainty	248 ppb	100 ppb
Total Uncertainty	540 ppb	140 ppb

Outline

1. Muon Anomalous Magnetic Moment

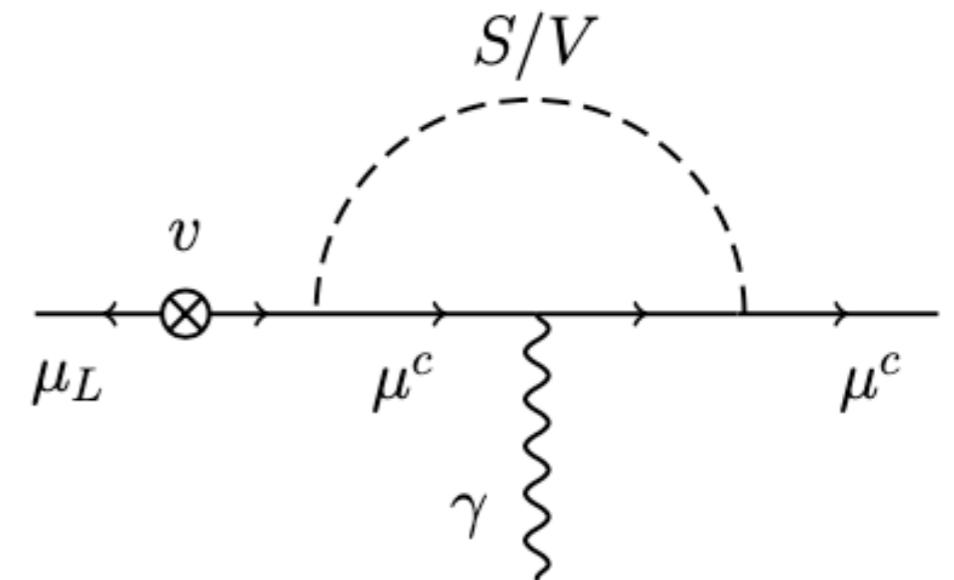
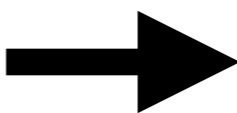
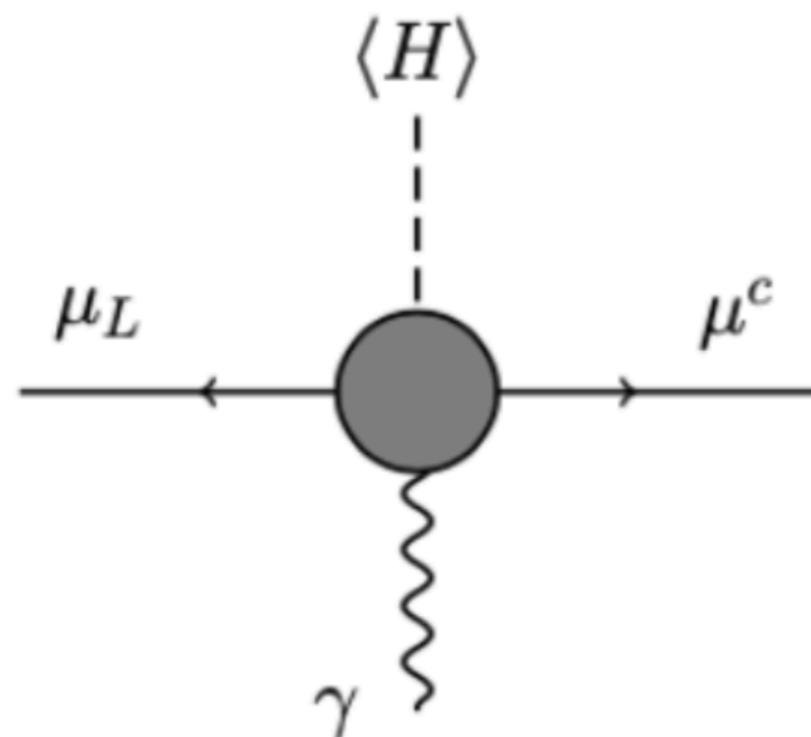
2. Singlet scenarios for $(g-2)\mu$

- Low-energy probes
- High-energy probes

3. Summary

2. Singlet scenarios for $(g-2)\mu$

Dipole operator



Only couple to muons

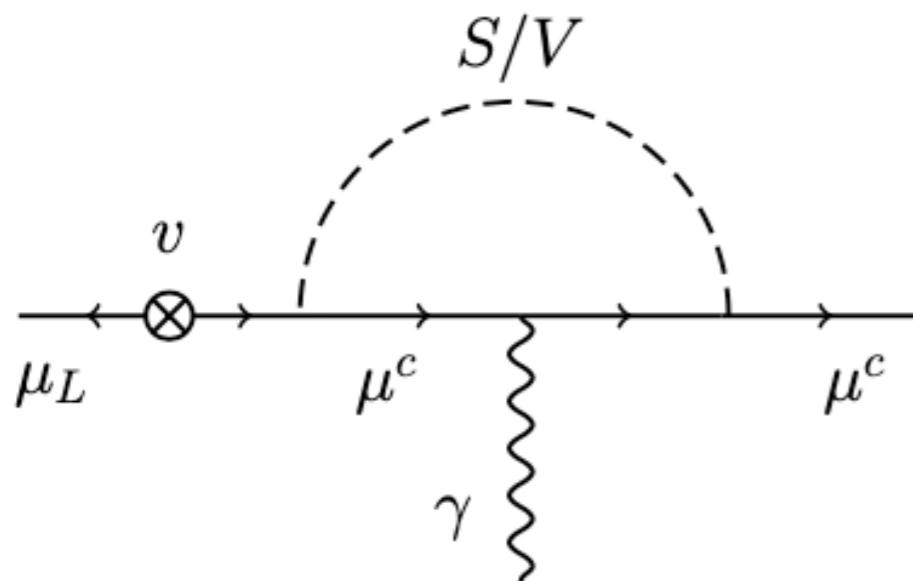
EW breaking insertion
given by the Higgs

Chiral flip insertion
given by muon mass

$$\frac{1}{M^2} H^\dagger (L \sigma^{\nu\rho} \mu^c) F_{\nu\rho}$$

2. Singlet explanations of $(g-2)\mu$

- Singlet scenarios

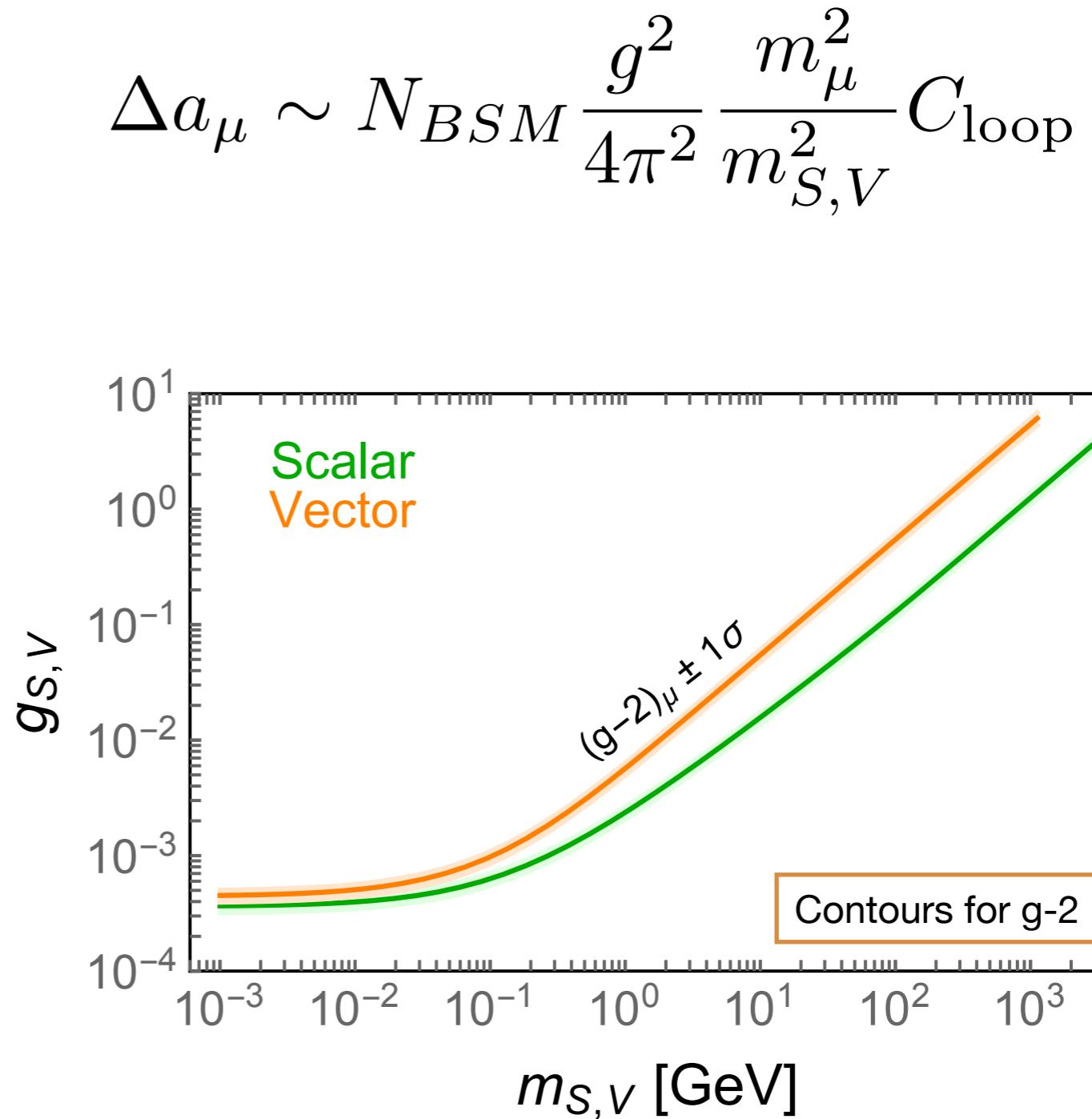


Perturbative Unitarity

$$g_S^2 \leq \frac{4\pi}{N_{BSM}} \quad g_V^2 \leq \frac{12\pi}{N_{BSM}}$$

Scalar

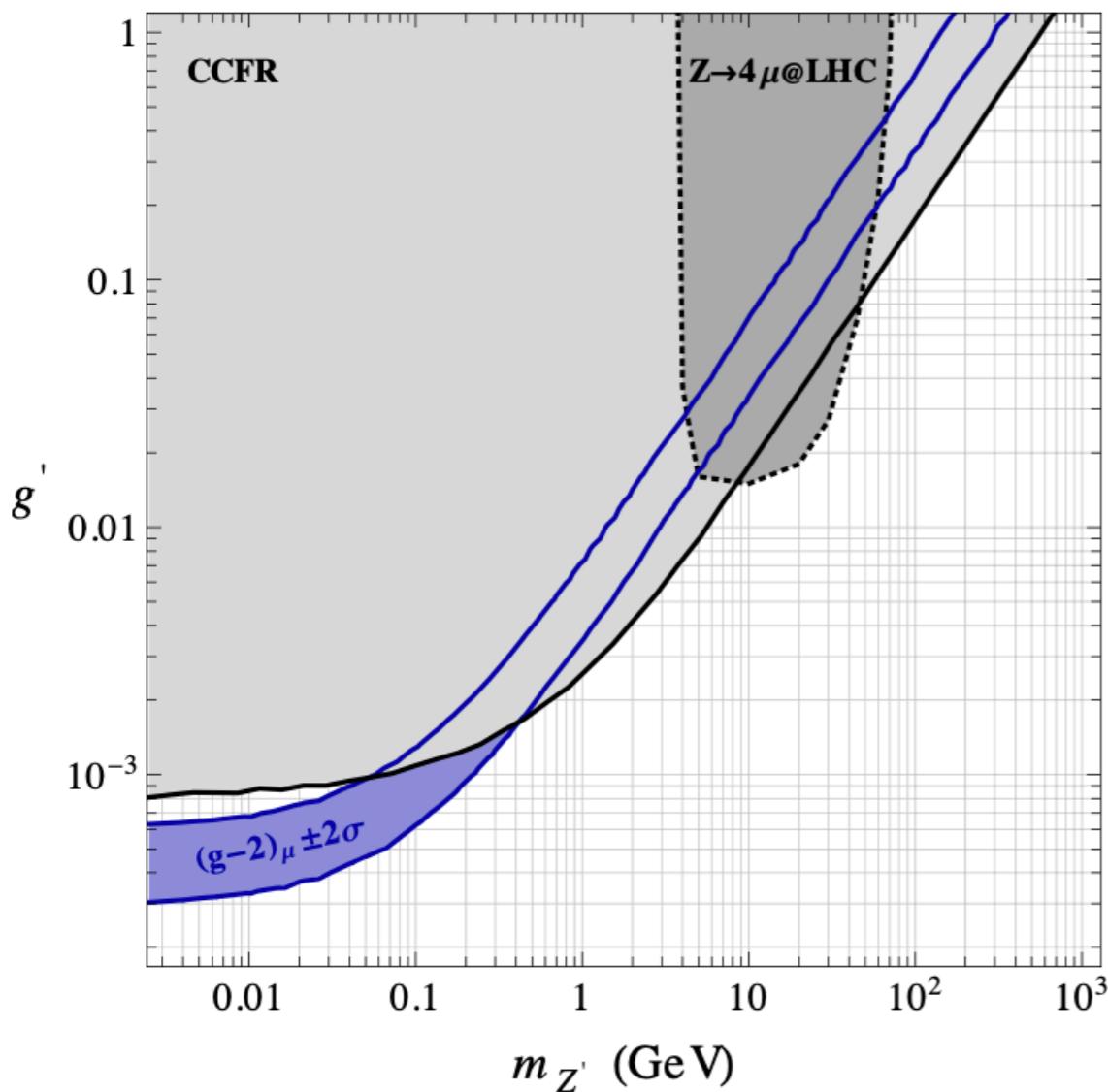
Vector



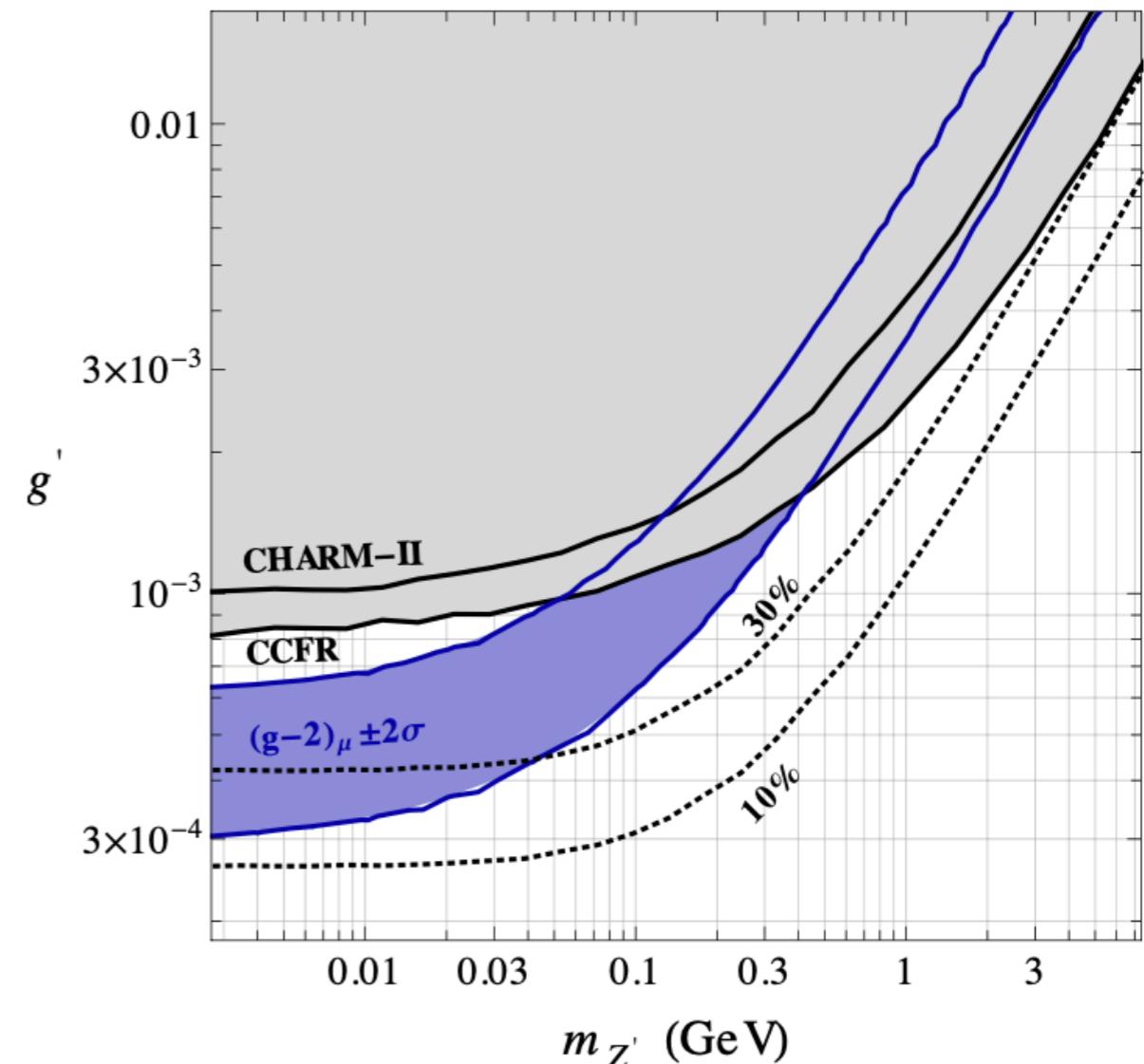
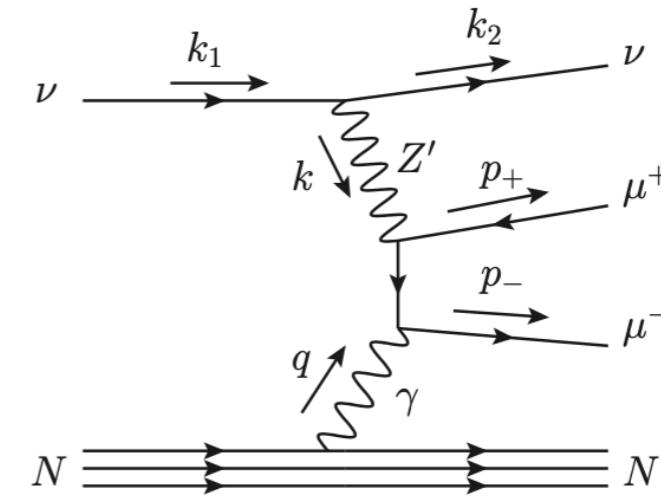
2. Singlet explanations of $(g-2)\mu$: Low- E

- Singlet scenarios

Altmannshofer, Gori, Pospelov, Yavin Phys. Rev Lett 113, 091801 (14)



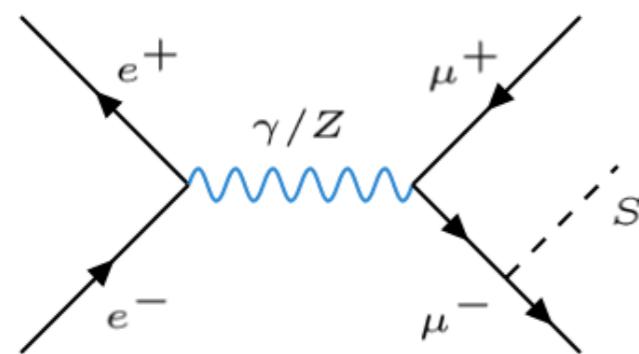
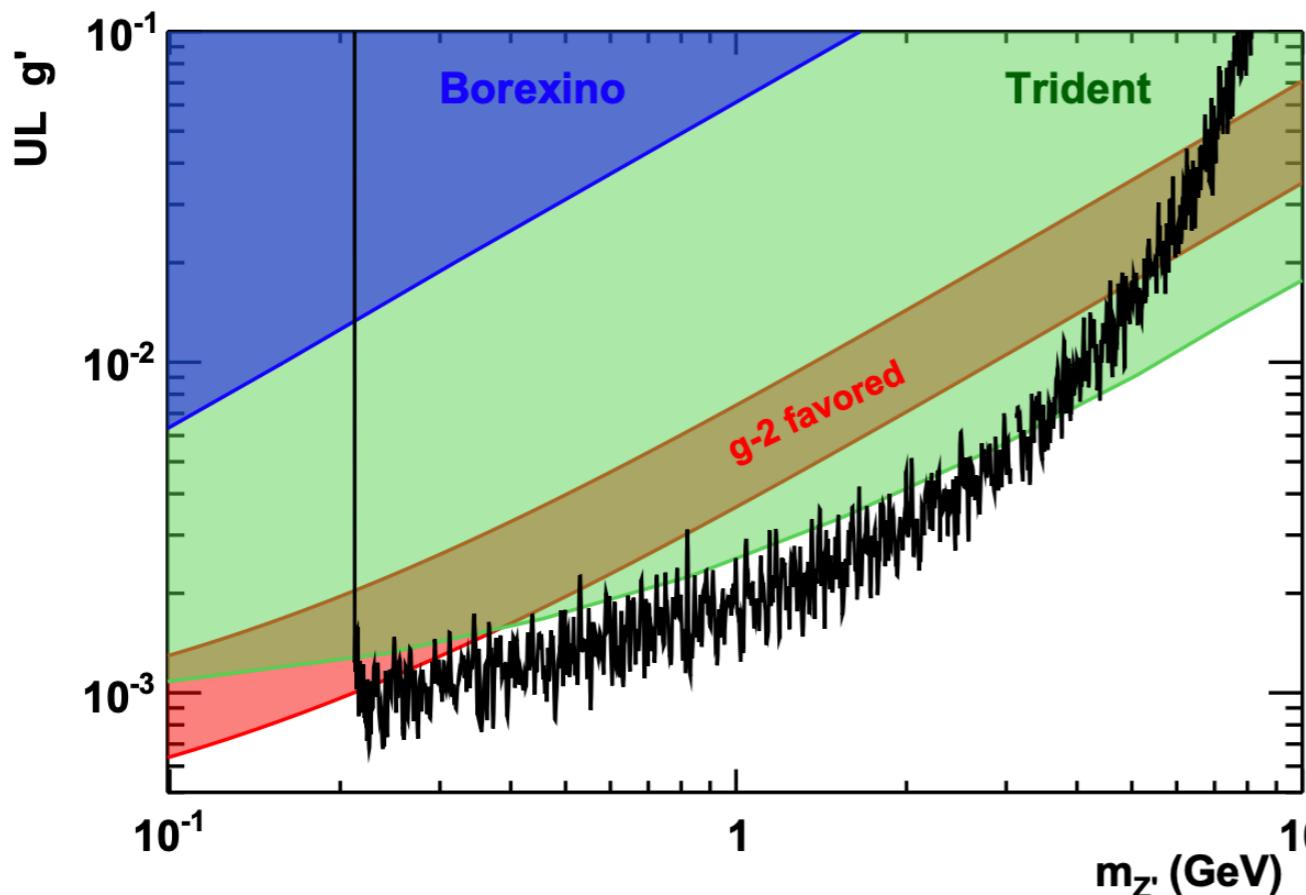
Neutrino trident
Lmu - Ltau model



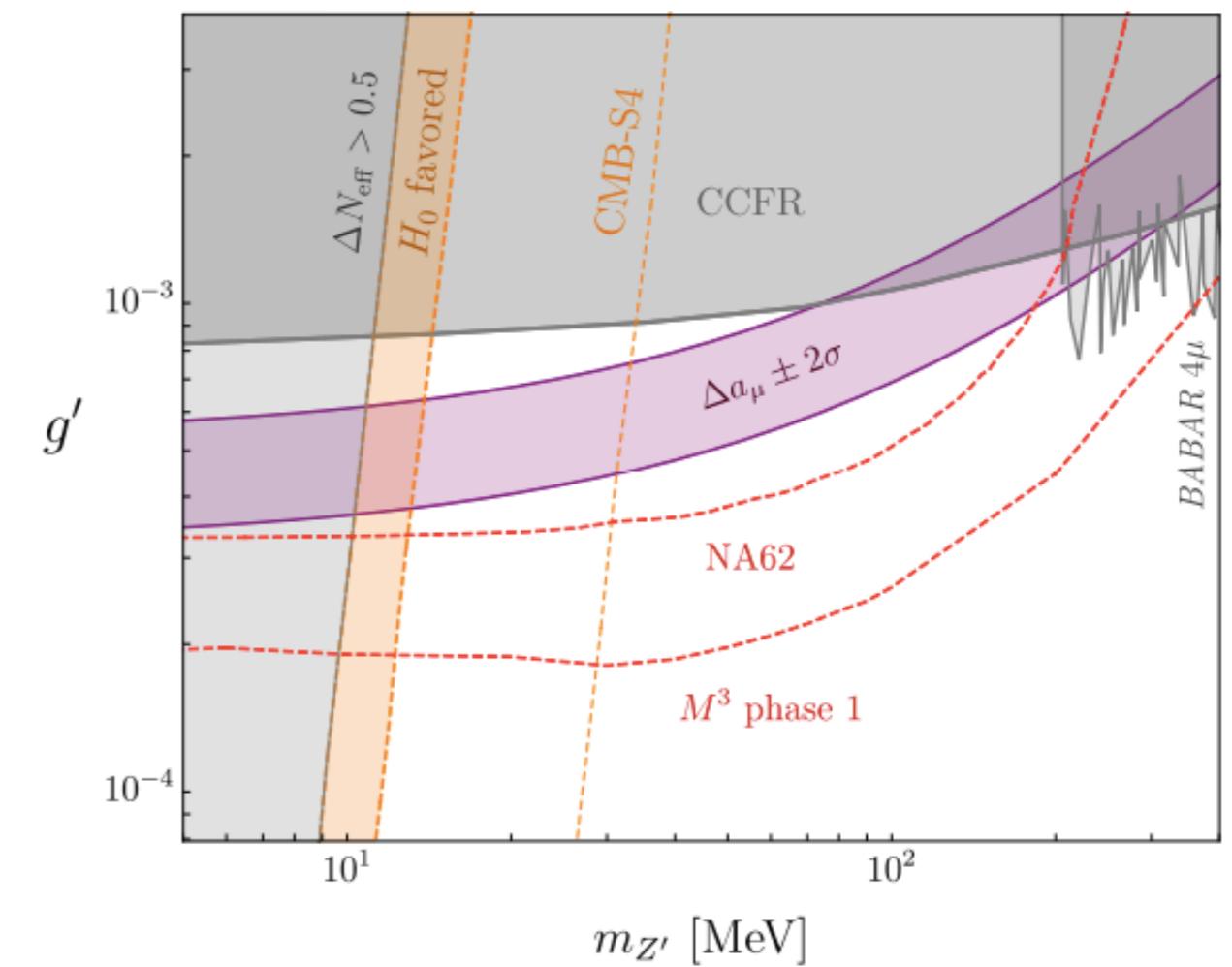
2. Singlet explanations of $(g-2)\mu$: Low- E

- Singlet scenarios

BaBar Collaboration, Phys. Rev. D 94 (2016) 1, 011102



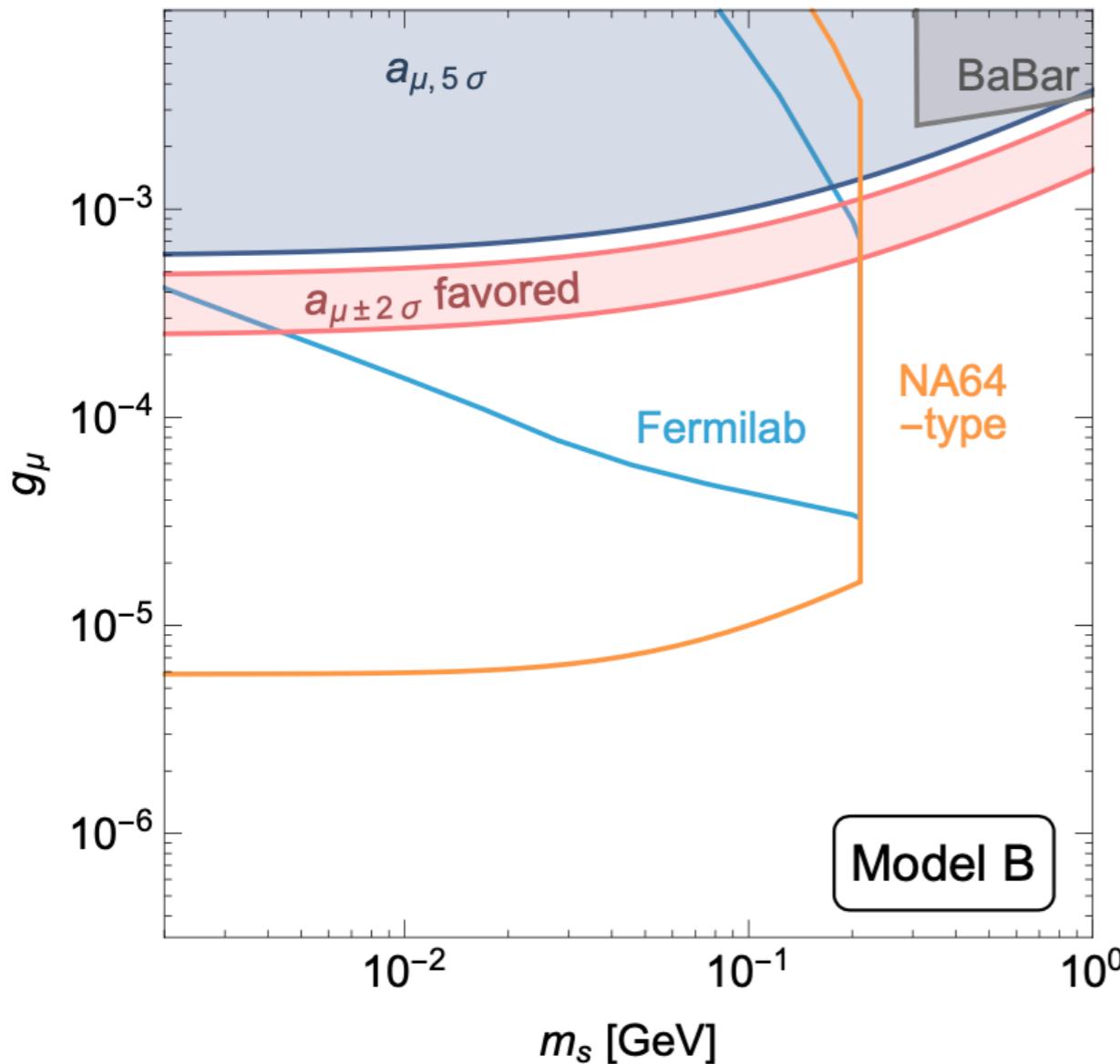
Holst, Hooper, Krnjaic, ArXiv: 2107.09067



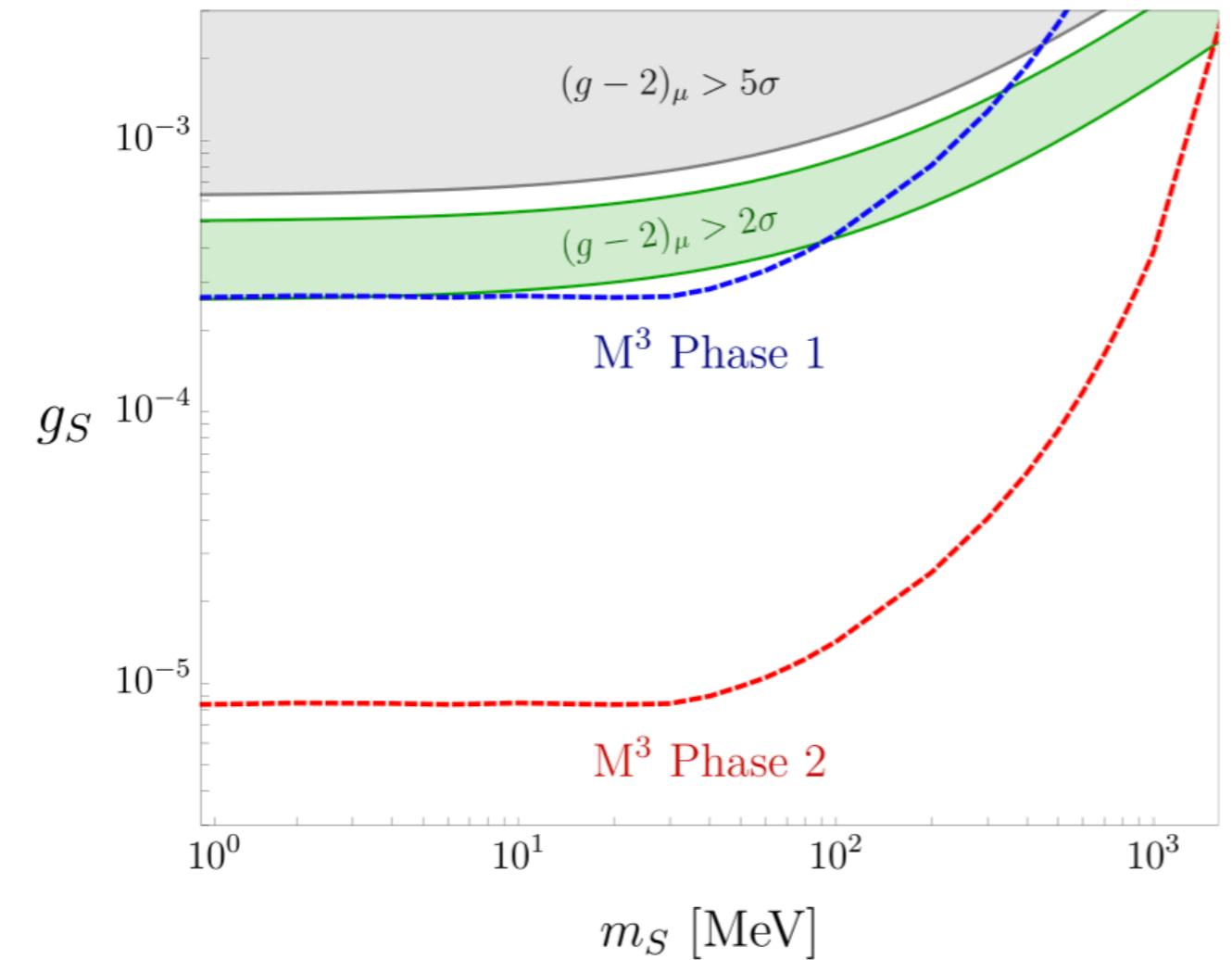
2. Singlet explanations of $(g-2)\mu$: Low- E

- Singlet scenarios

Chen, Pospelov, Zhong, Phys Rev D 95, 115005 (2017)



Kahn, Krnjaic, Tran, Whitbeck, JHEP 09 (2018) 153



Outline

1. Muon Anomalous Magnetic Moment

2. Singlet scenarios for $(g-2)\mu$

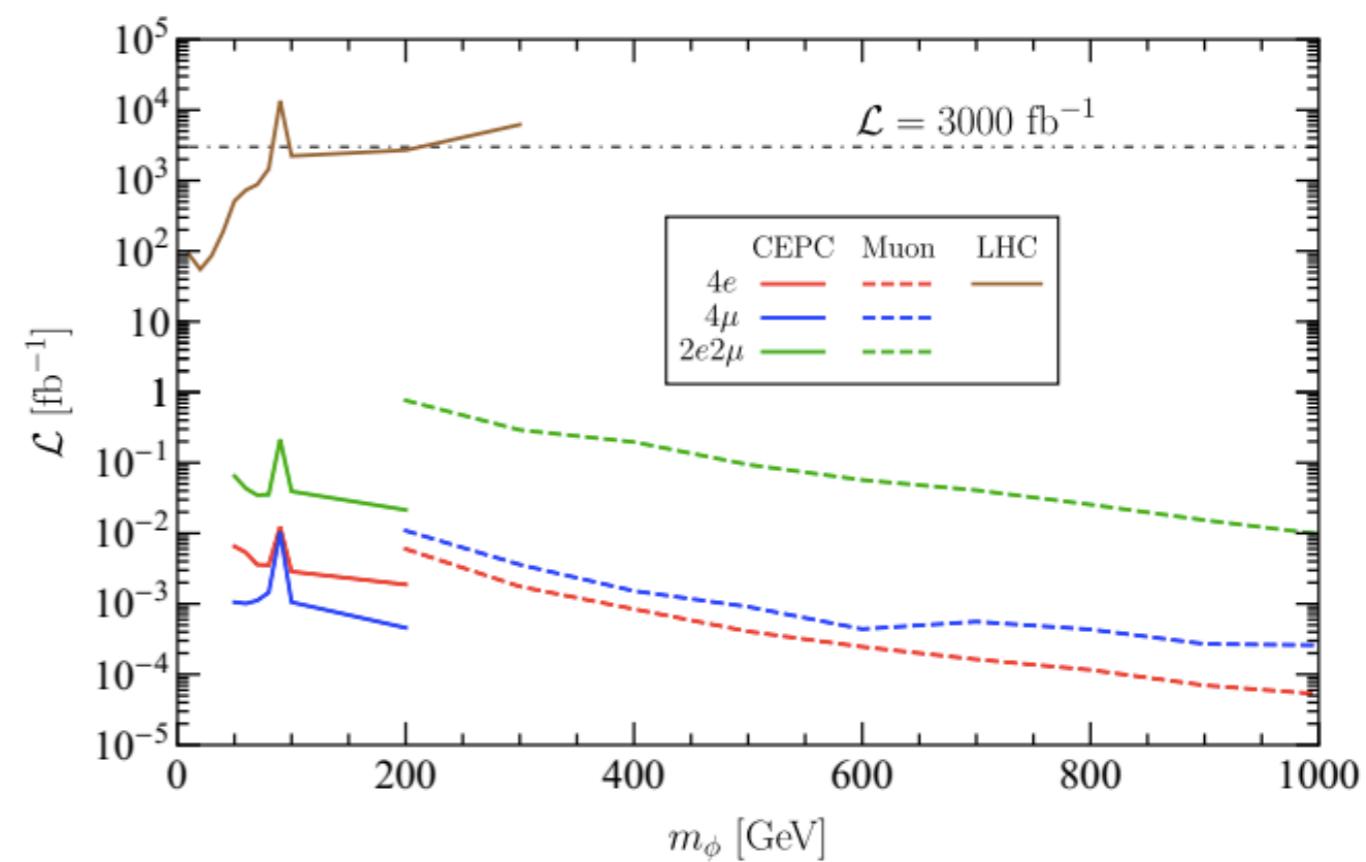
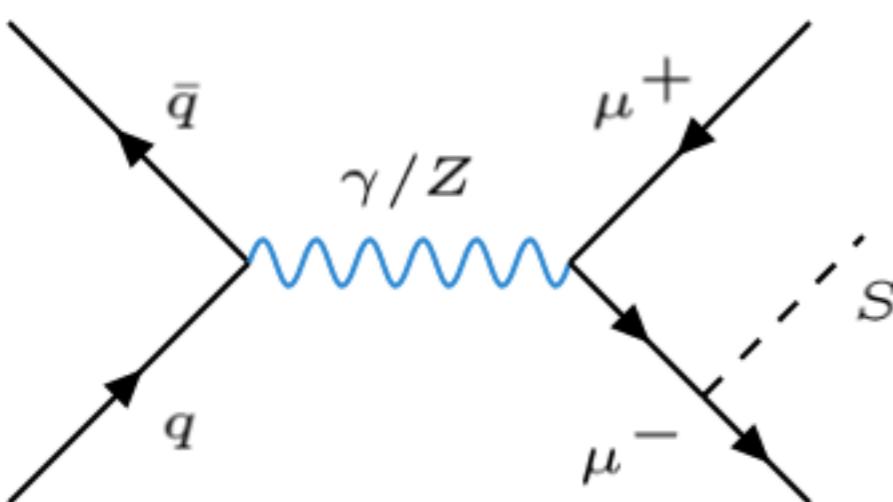
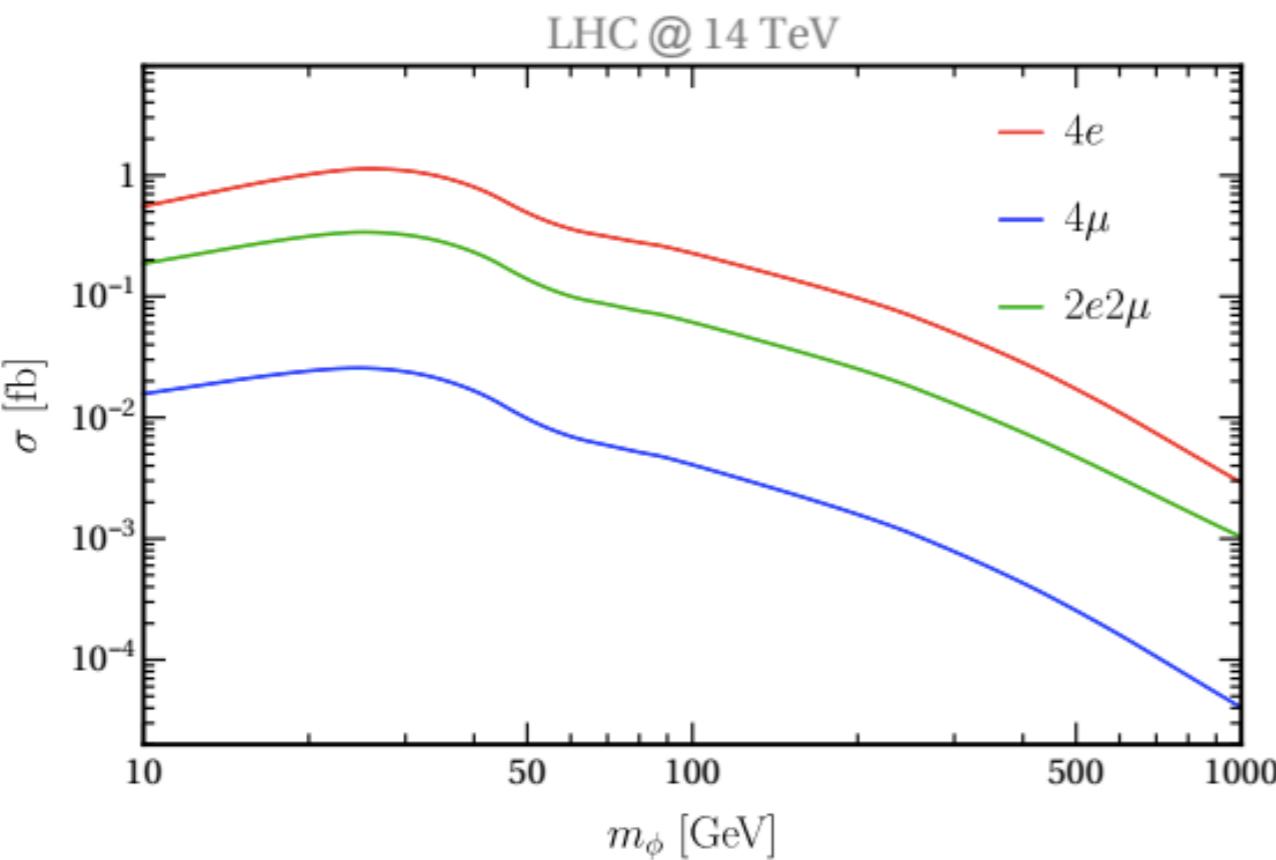
- Low-energy probes
- **High-energy probes**

3. Summary

2. Singlet explanations of $(g-2)\mu$: High- E

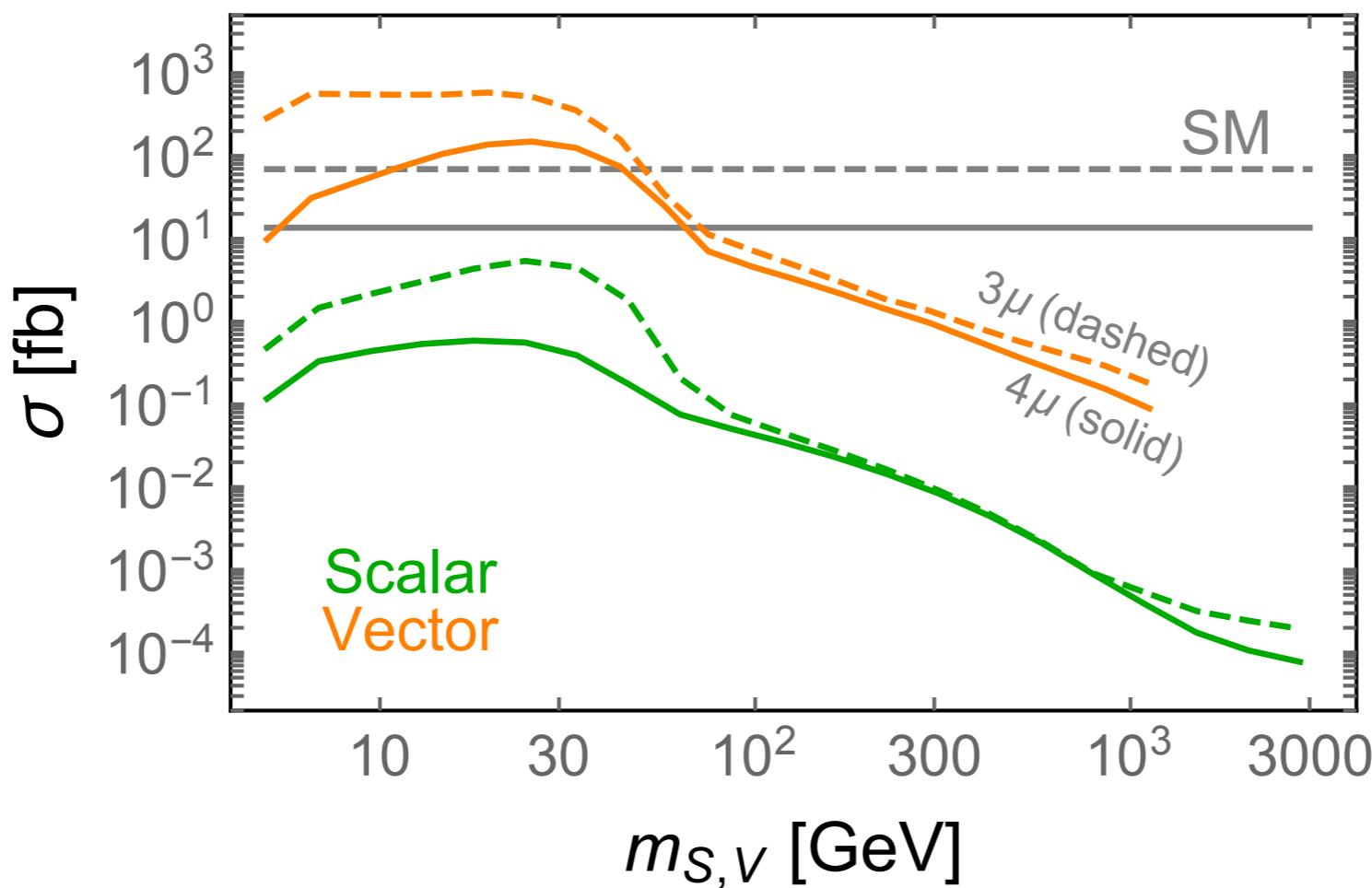
Chen, Wang, Yao, ArXiv:2102.05619

How about LHC?

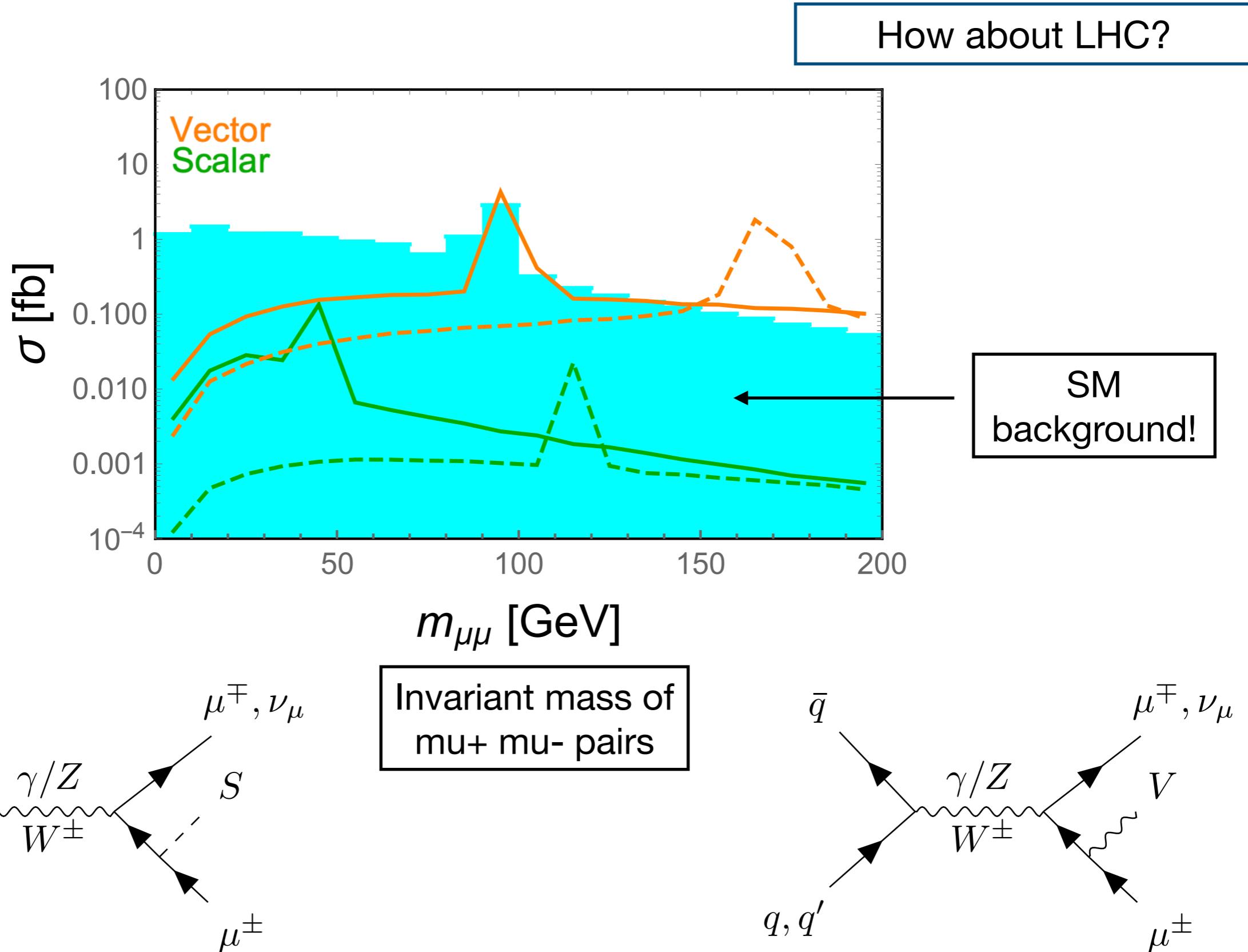


2. Singlet explanations of $(g-2)\mu$: High- E

How about LHC?



2. Singlet explanations of $(g-2)\mu$: High- E

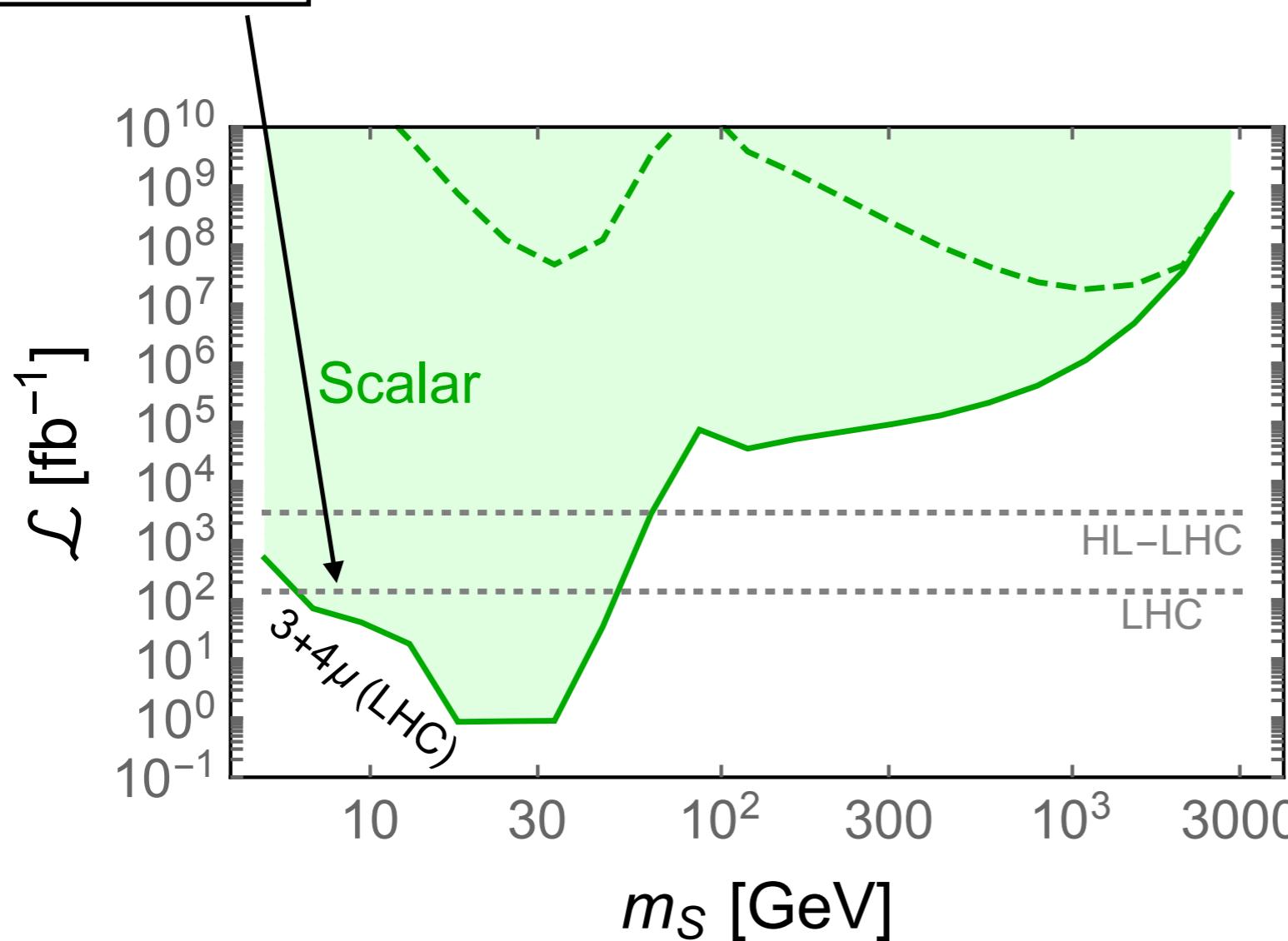


2. Singlet explanations of $(g-2)\mu$: High- E

Preliminary!

Probed!

How about LHC?



$$g_S S \mu_L \mu^c$$

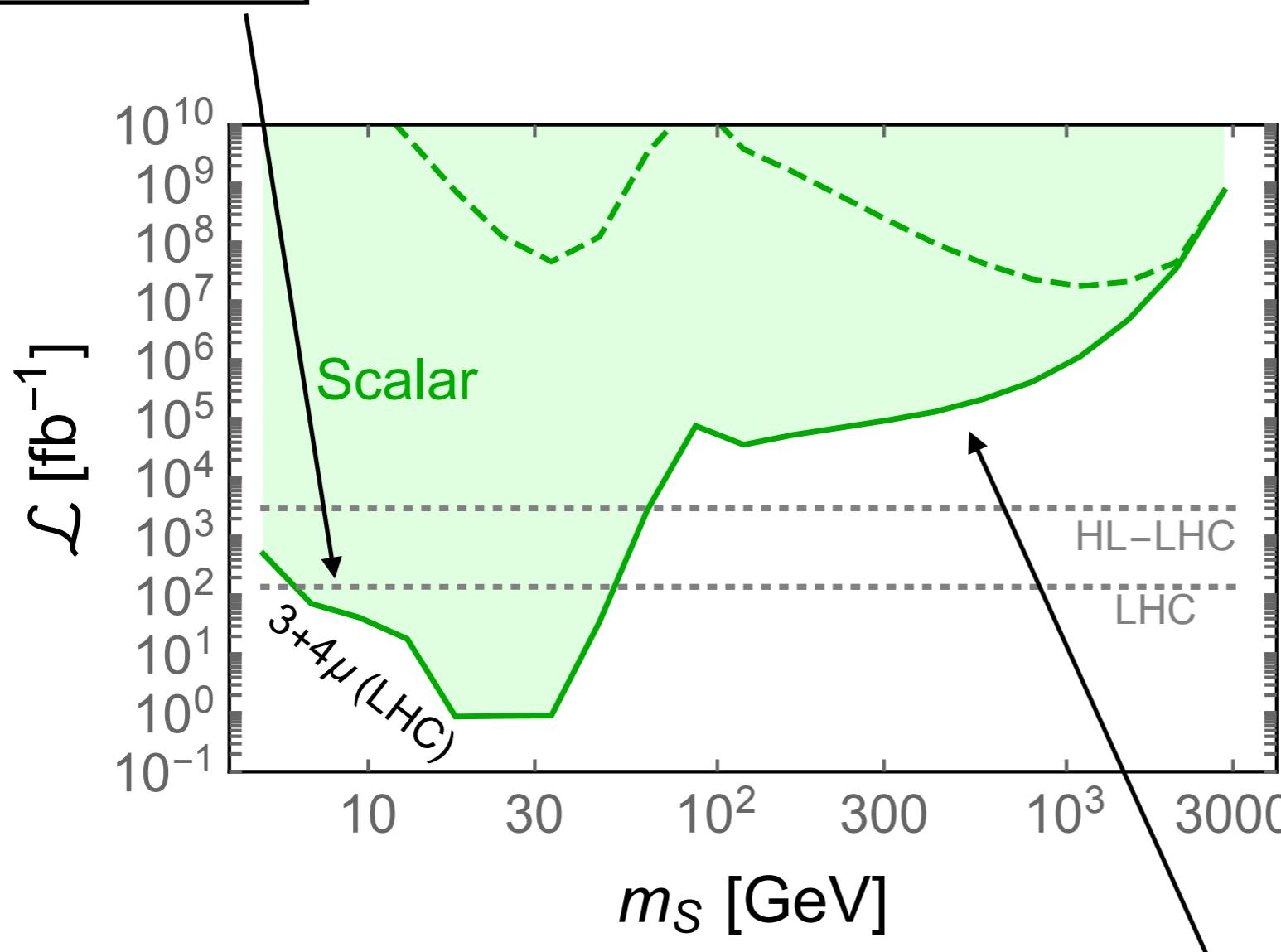
Scalar Singlets

2. Singlet explanations of $(g-2)\mu$: High- E

Preliminary!

Probed!

How about LHC?



$$g_S S \mu_L \mu^c$$

Scalar Singlets

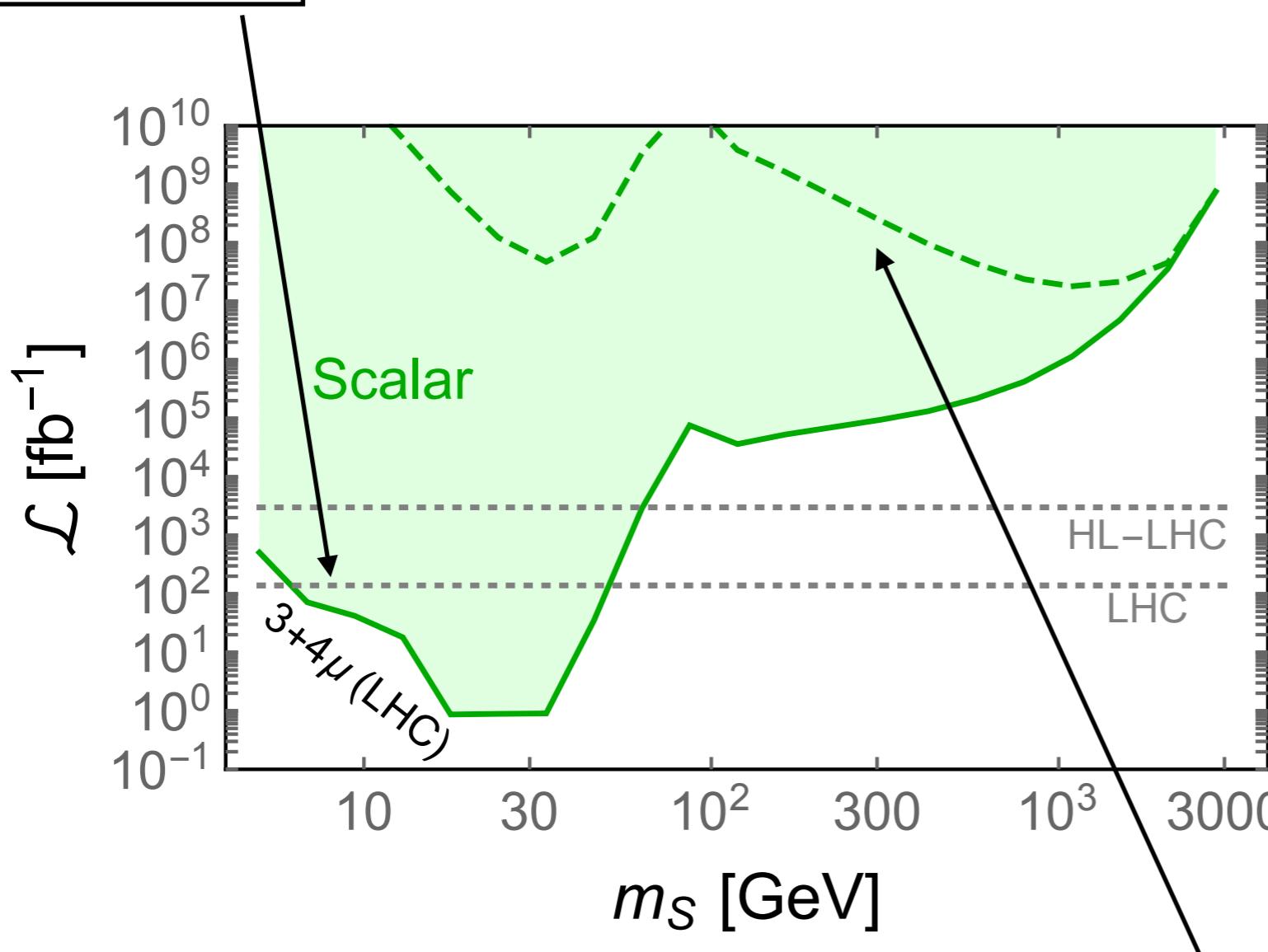
Optimistic scenario
 $\mathcal{BR}(\mu\mu) = 100\%$

2. Singlet explanations of $(g-2)\mu$: High- E

Preliminary!

Probed!

How about LHC?



$$g_S S \mu_L \mu^c$$

Scalar Singlets

Pessimistic scenario

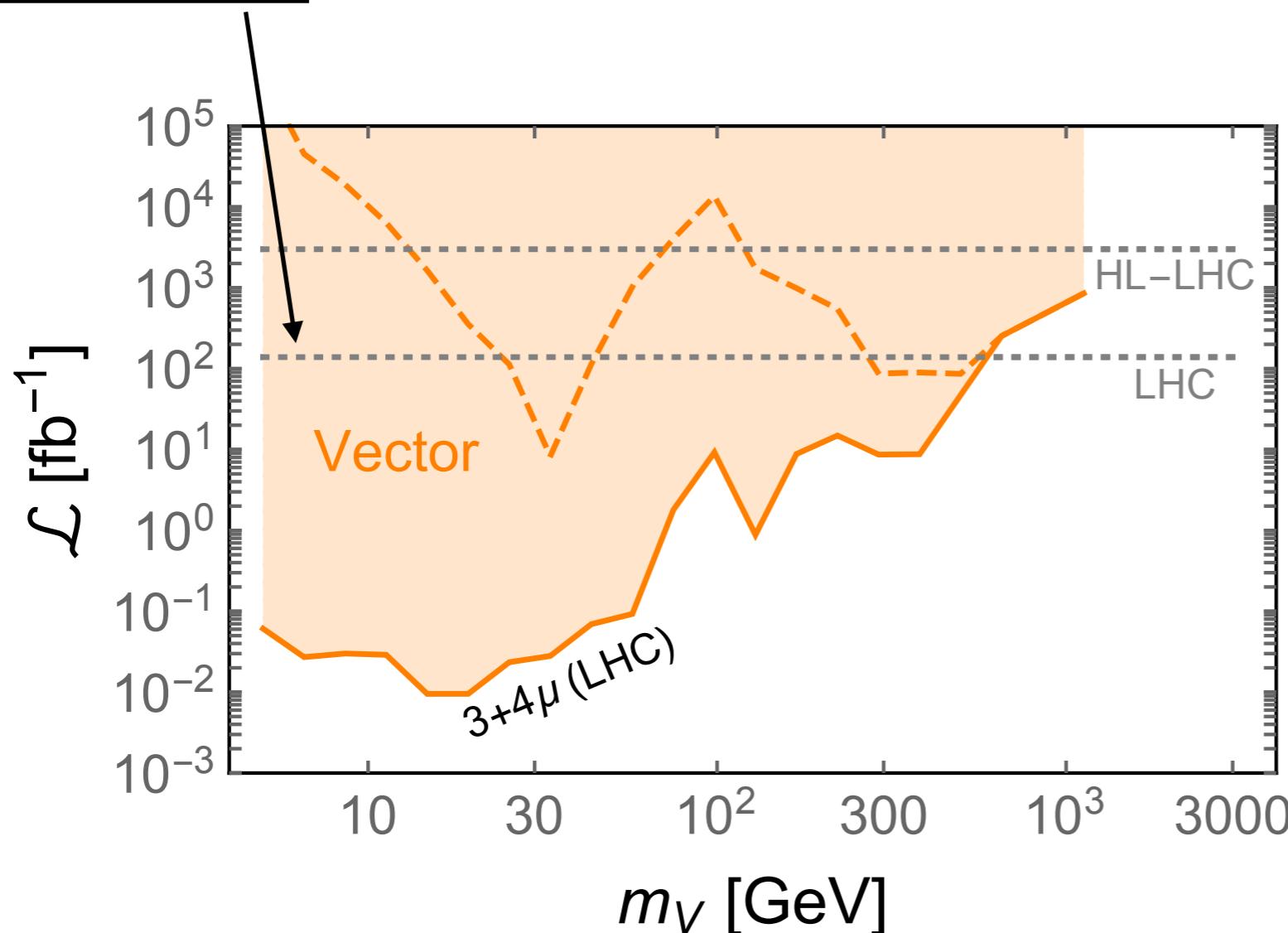
$$\mathcal{BR}(\mu\mu) = \text{Min}[1, \Gamma(\mu\mu)/\Gamma_{\max}]$$

2. Singlet explanations of $(g-2)\mu$: High- E

Preliminary!

Probed!

How about LHC?

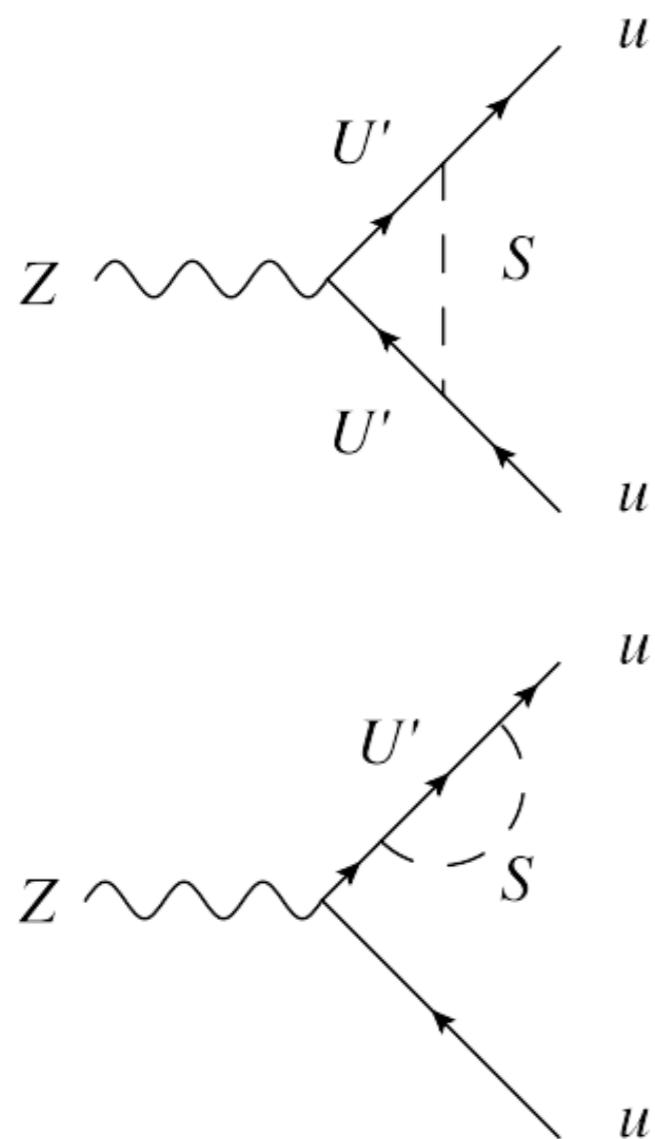


$$g_V (\mu_L^\dagger \bar{\sigma}^\nu \mu_L + \mu^c \sigma^\nu \mu^{c\dagger}) V_\nu$$

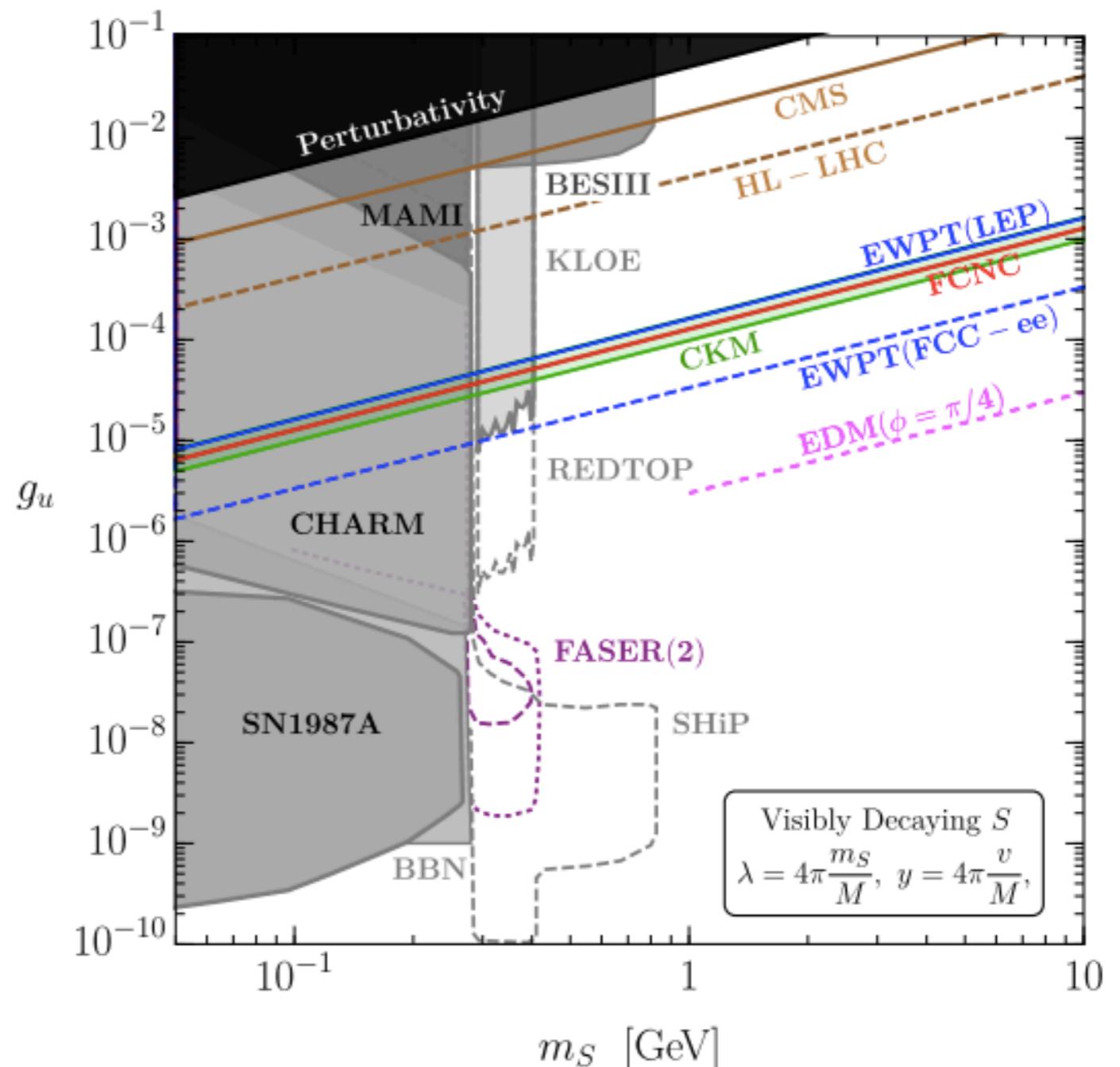
Vector Singlets

2. Singlet explanations of $(g-2)\mu$: High- E

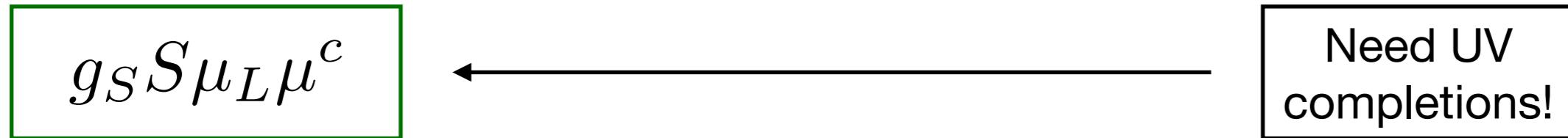
Batell, Freitas, Ismail, ArXiv:2107.08059



How about EW Precision?



2. Singlet explanations of $(g-2)\mu$: High- E



Scalar Singlets

$$\mathcal{L}_\chi \supset -y_1 L H^\dagger \chi^c - y_2 \mu^c \chi S$$

$$\mathcal{L} \supset -y_1 L \Psi^c S - y_2 \mu^c H^\dagger \Psi$$

$$\mathcal{L} \supset -y L \Phi^\dagger \mu^c - \kappa S H^\dagger \Phi$$

$$\mathcal{O} \sim \frac{y_1 y_2}{M} H^\dagger L \mu^c S$$

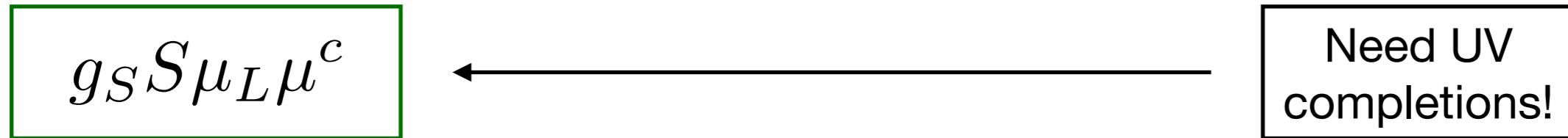


$$\mathcal{O} \sim \frac{y \kappa}{M^2} H^\dagger L \mu^c S$$

$$g_S = \frac{y_1 y_2 v_h}{M}$$

$$g_S = \frac{y \kappa v_h}{M^2}$$

2. Singlet explanations of $(g-2)\mu$: High- E



Scalar Singlets

$$\mathcal{L}_\chi \supset -y_1 L H^\dagger \chi^c - y_2 \mu^c \chi S$$

$$\mathcal{L} \supset -y_1 L \Psi^c S - y_2 \mu^c H^\dagger \Psi$$

$$\mathcal{L} \supset -y L \Phi^\dagger \mu^c - \kappa S H^\dagger \Phi$$

$$\mathcal{O} \sim \frac{y_1 y_2}{M} H^\dagger L \mu^c S$$



$$\mathcal{O} \sim \frac{y \kappa}{M^2} H^\dagger L \mu^c S$$

$$g_S = \frac{y_1 y_2 v_h}{M}$$

$$g_S = \frac{y \kappa v_h}{M^2}$$

Want this mass
to be high!

2. Singlet explanations of $(g-2)\mu$: High- E

$$g_S S \mu_L \mu^c$$

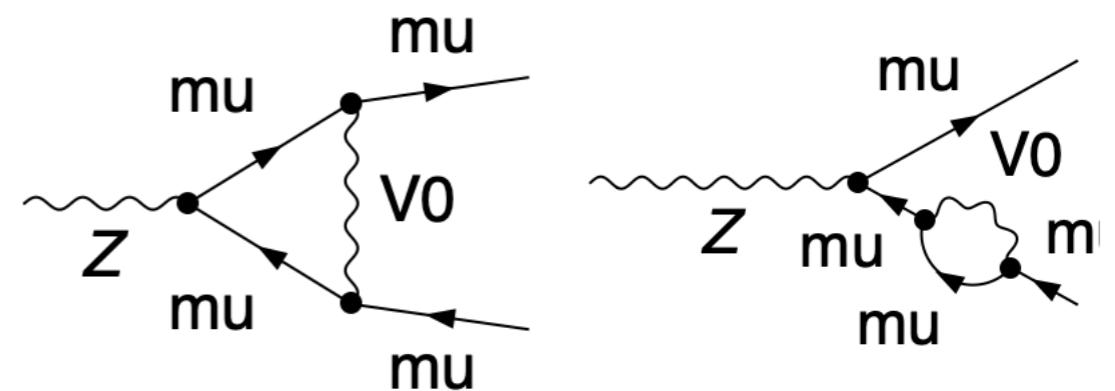
Scalar Singlets

$$g_V (\mu_L^\dagger \bar{\sigma}^\nu \mu_L + \mu^c \sigma^\nu \mu^{c\dagger}) V_\nu$$

Vector Singlets

$$\mathcal{L}_\chi \supset -y_1 L H^\dagger \chi^c - y_2 \mu^c \chi S$$

Mixing!



$$R_{\mu e} = \frac{\Gamma(Z \rightarrow \mu\mu)}{\Gamma(Z \rightarrow ee)} \rightarrow \delta R_{\mu e}$$

$$\delta R_{\mu e} \propto \frac{y_1^2 v_h^2}{M^2}$$

$$\delta R_{\mu e} \propto \frac{g_V^2}{16\pi^2} \frac{m_Z^2}{m_V^2} C_{\text{loop}}$$

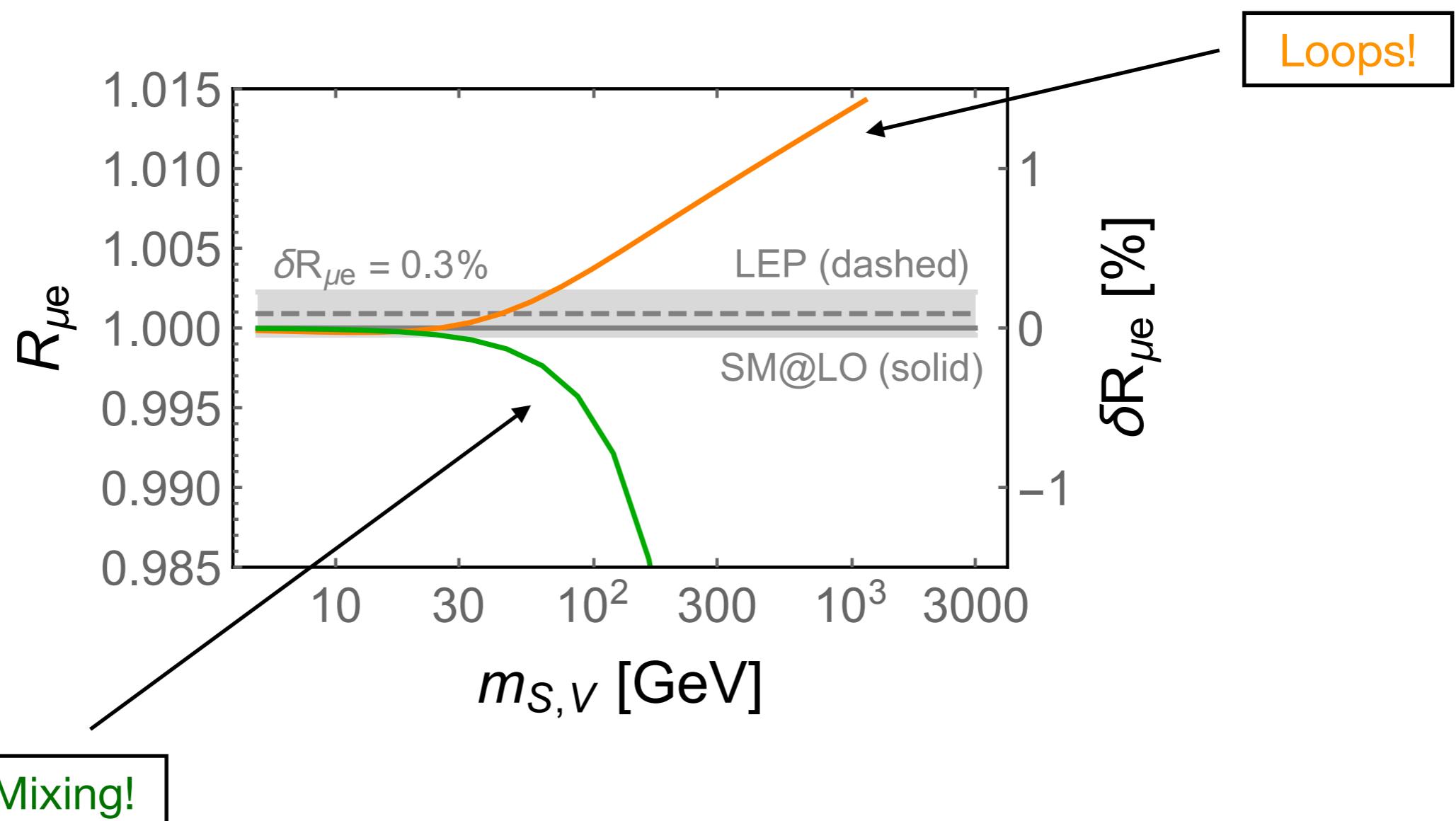
2. Singlet explanations of $(g-2)\mu$: High- E

$$g_S S \mu_L \mu^c$$

Scalar Singlets

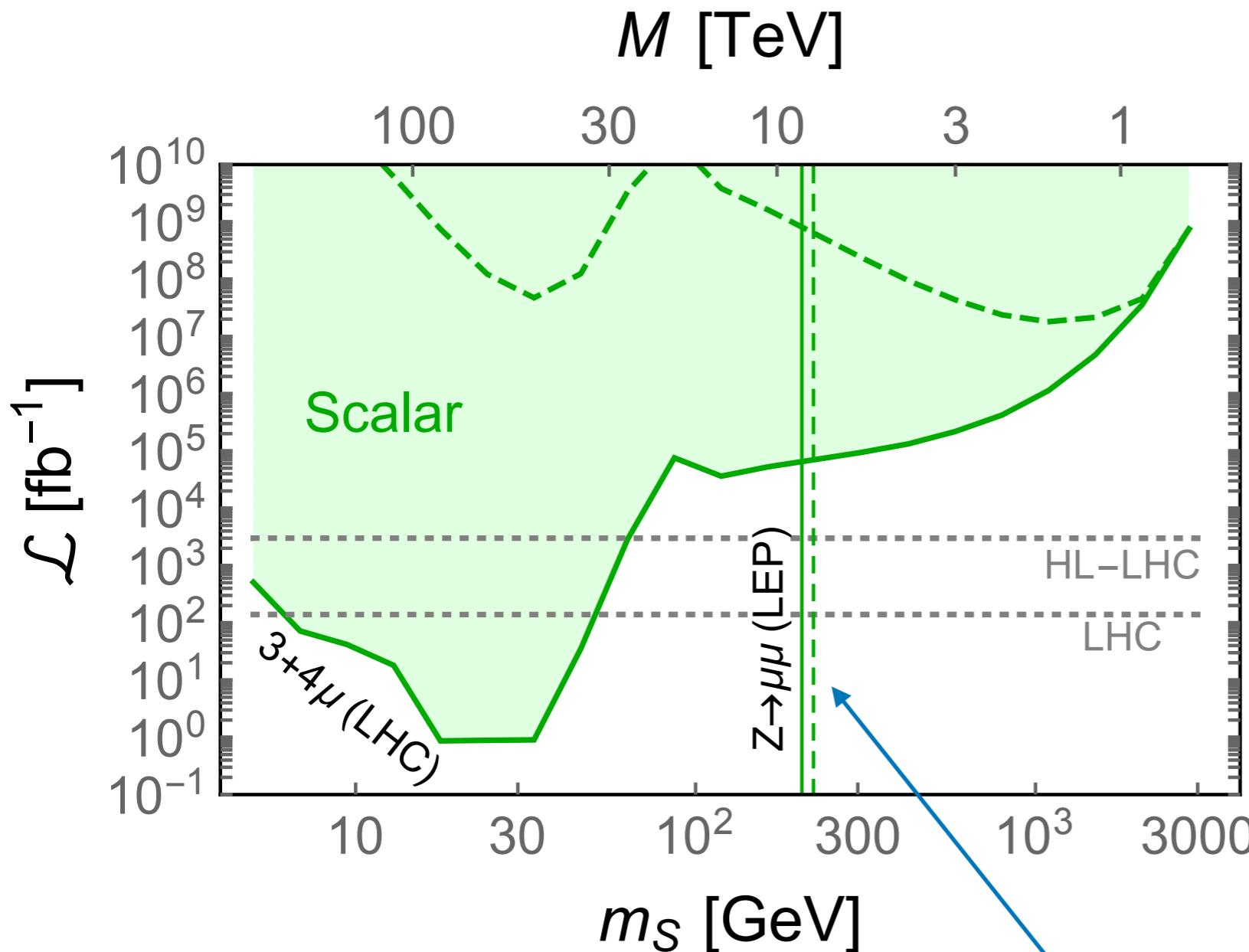
$$g_V (\mu_L^\dagger \bar{\sigma}^\nu \mu_L + \mu^c \sigma^\nu \mu^{c\dagger}) V_\nu$$

Vector Singlets



2. Singlet explanations of $(g-2)_\mu$: High- E

Preliminary!



$$g_S S \mu_L \mu^c$$

Scalar Singlets

Top-left exclusion regions will increase at higher energy hadron colliders like FCC-hh

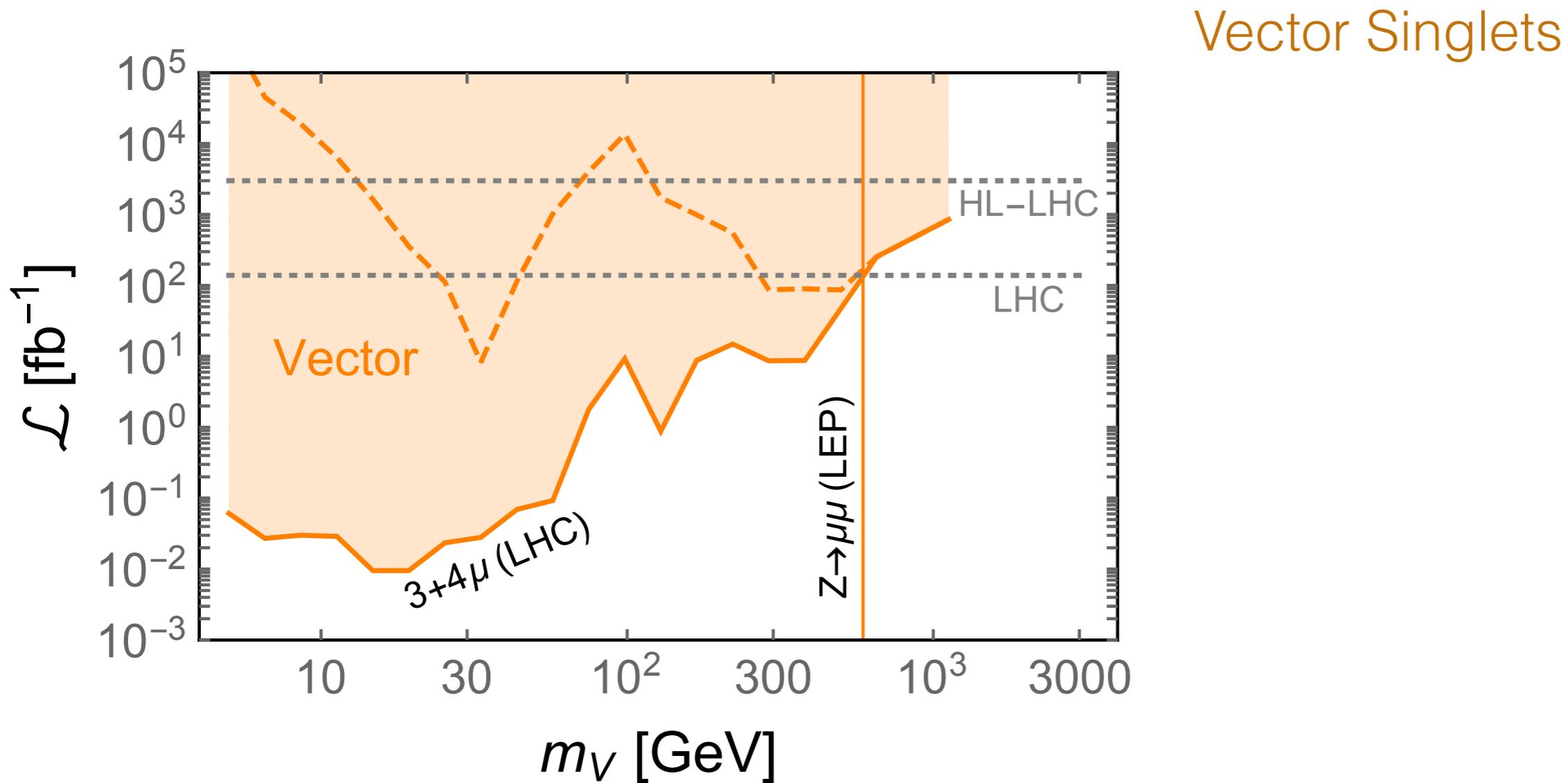
Improved measurement of Z decay modes at FCC-ee will move the vertical lines to the left!

$$\mathcal{L}_\chi \supset -y_1 LH^\dagger \chi^c - y_2 \mu^c \chi S$$

2. Singlet explanations of $(g-2)\mu$: High- E

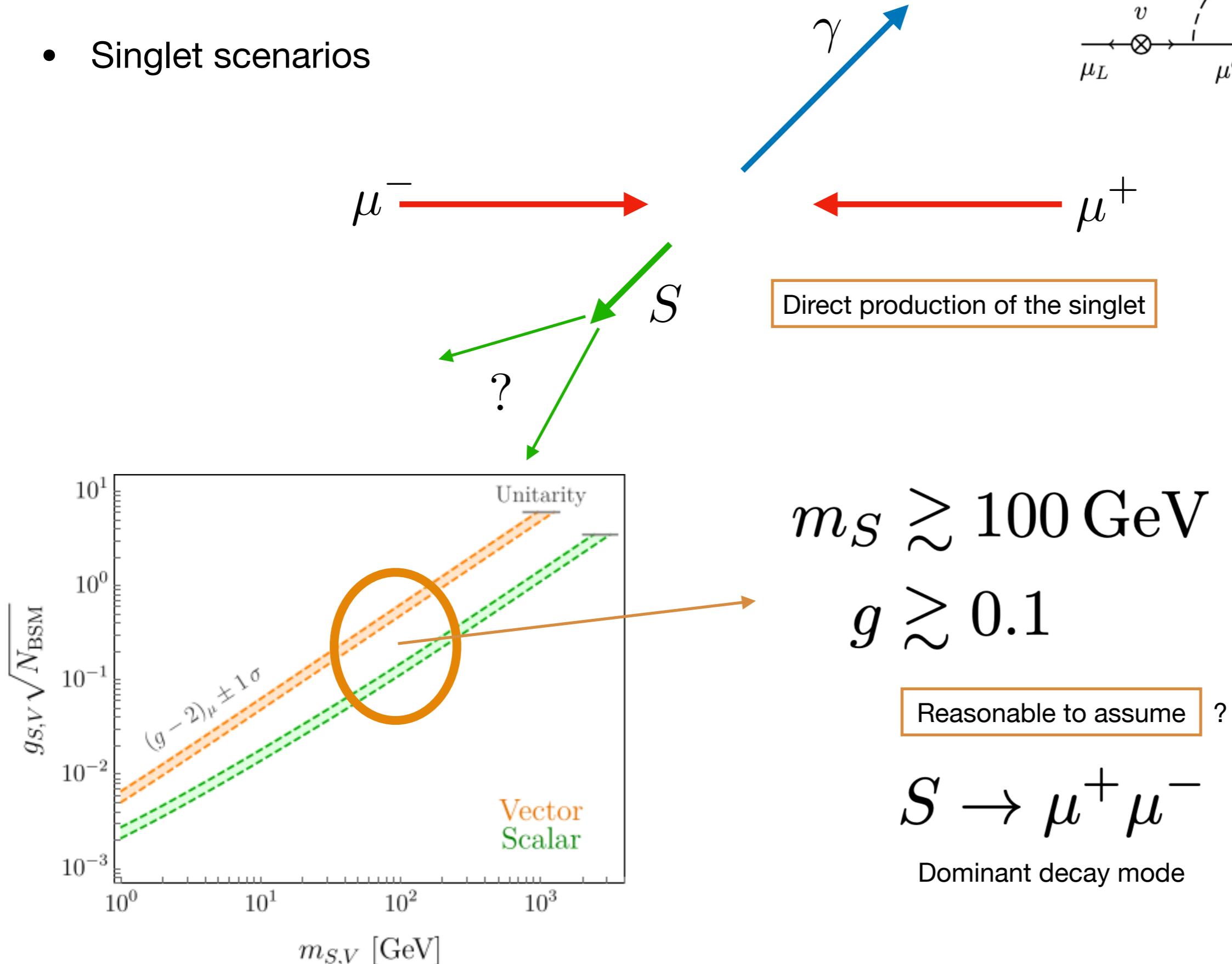
Preliminary!

$$g_V(\mu_L^\dagger \bar{\sigma}^\nu \mu_L + \mu^c \sigma^\nu \mu^{c\dagger}) V_\nu$$



2. Singlet explanations of $(g-2)_\mu$: High- E

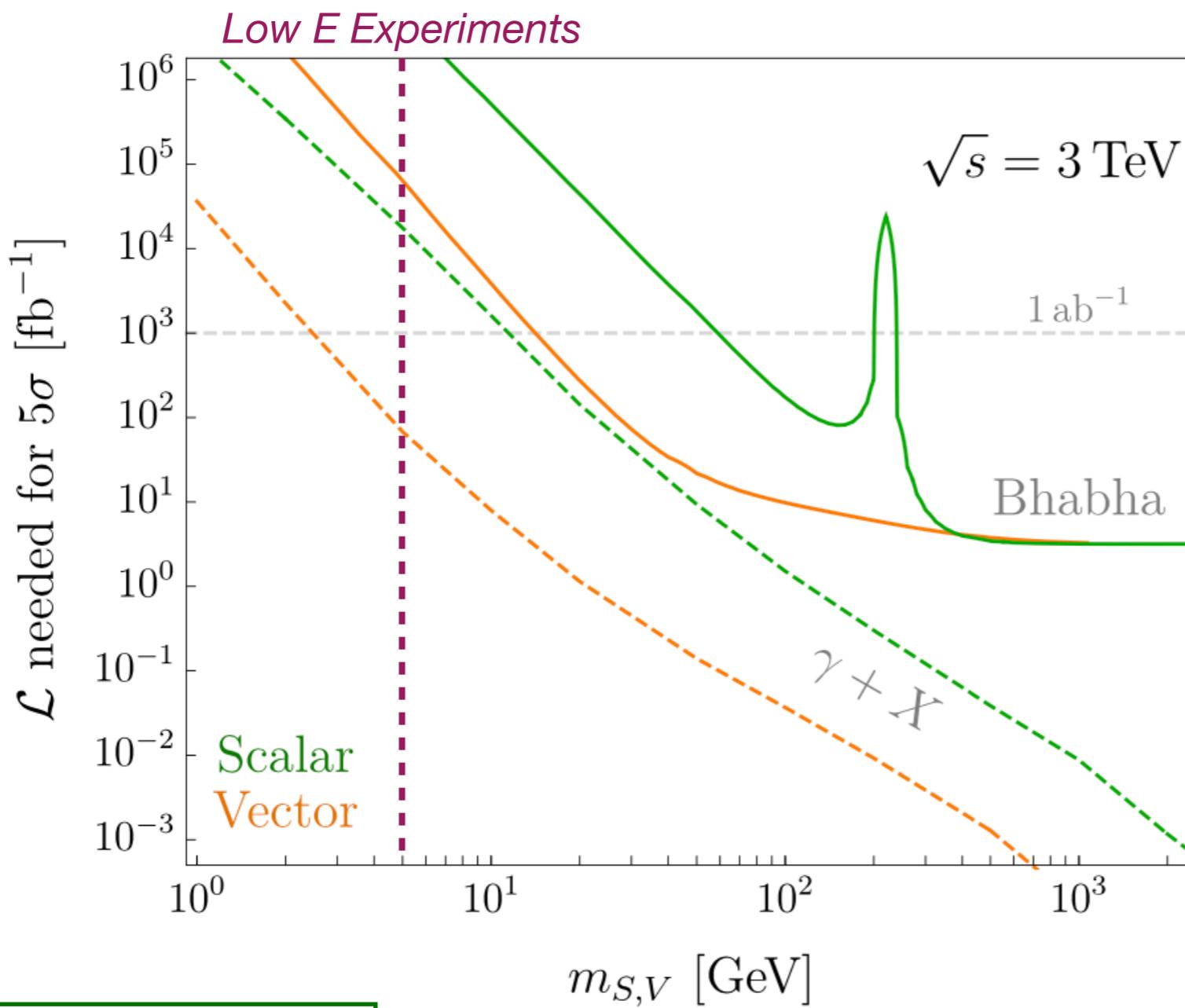
- Singlet scenarios



2. Singlet explanations of $(g-2)\mu$: High- E

“Singlet scenarios”

A 3 TeV Muon Collider
can probe all Singlet
explanations for $g-2$



$$g_S S \mu_L \mu^c$$

Scalar Singlets

$$g_V (\mu_L^\dagger \bar{\sigma}^\nu \mu_L + \mu^c \sigma^\nu \mu^{c\dagger}) V_\nu$$

Vector Singlets

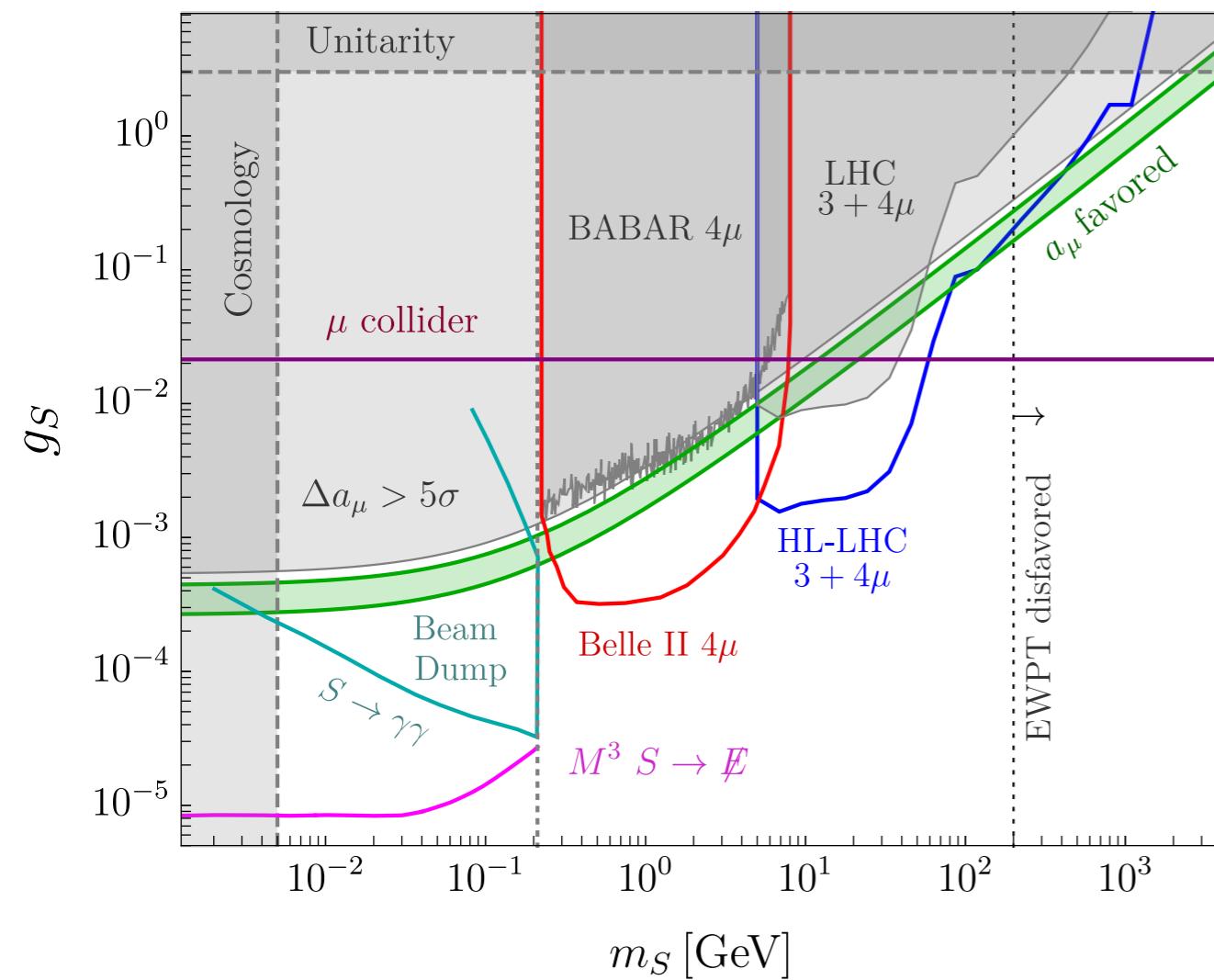
Capdevilla, Curtin, Kahn, Krnjaic,
ArXiv:2006.16277
ArXiv:2101.10334

Luminosity goal
for a 3 TeV MuC

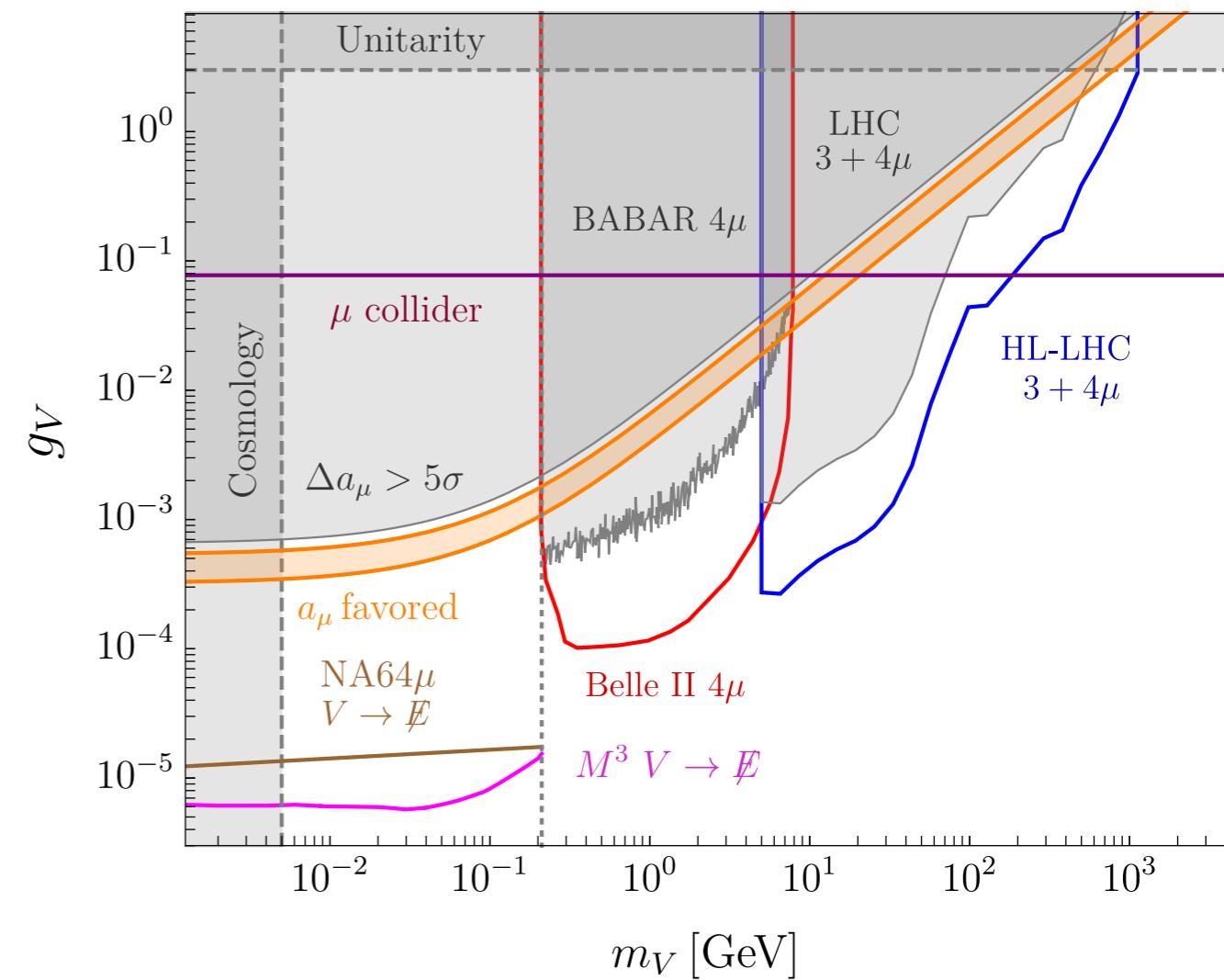
Summary

Preliminary!

Singlet Scalar, $\text{BR}(S \rightarrow \mu^+ \mu^-) = 1$ for $m_S > 2m_\mu$



Singlet Vector, $\text{BR}(V \rightarrow \mu^+ \mu^-) = 1$ for $m_V > 2m_\mu$



Thanks!