Non-Abelian Vector Dark Matter and Lepton Anomalous Magnetic Moments

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Motivation

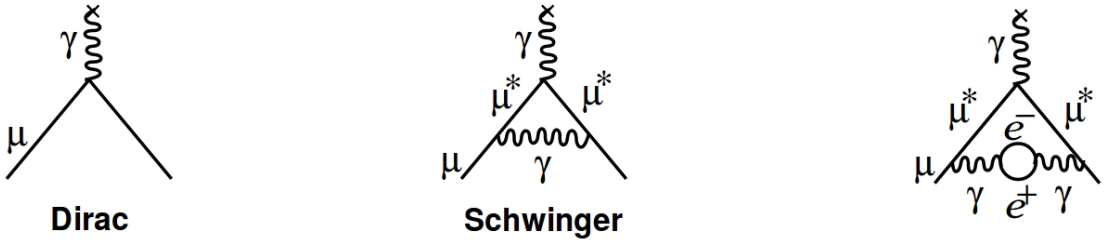
- Origin of Dark Matter?
- Anomalies in the lepton anomalous magnetic moments!
- Possible connections?

$\rightarrow$ Non-Abelian $SU(2)$ gauge model

Anomalies in Lepton AMMs

$(g-2)_\mu$

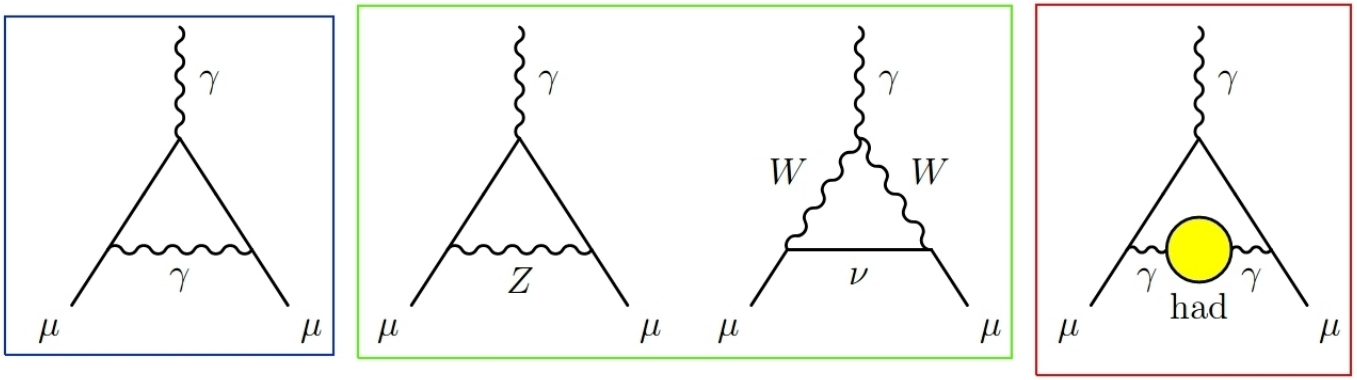
- Quantum loop corrections: $g_\mu \neq 2$



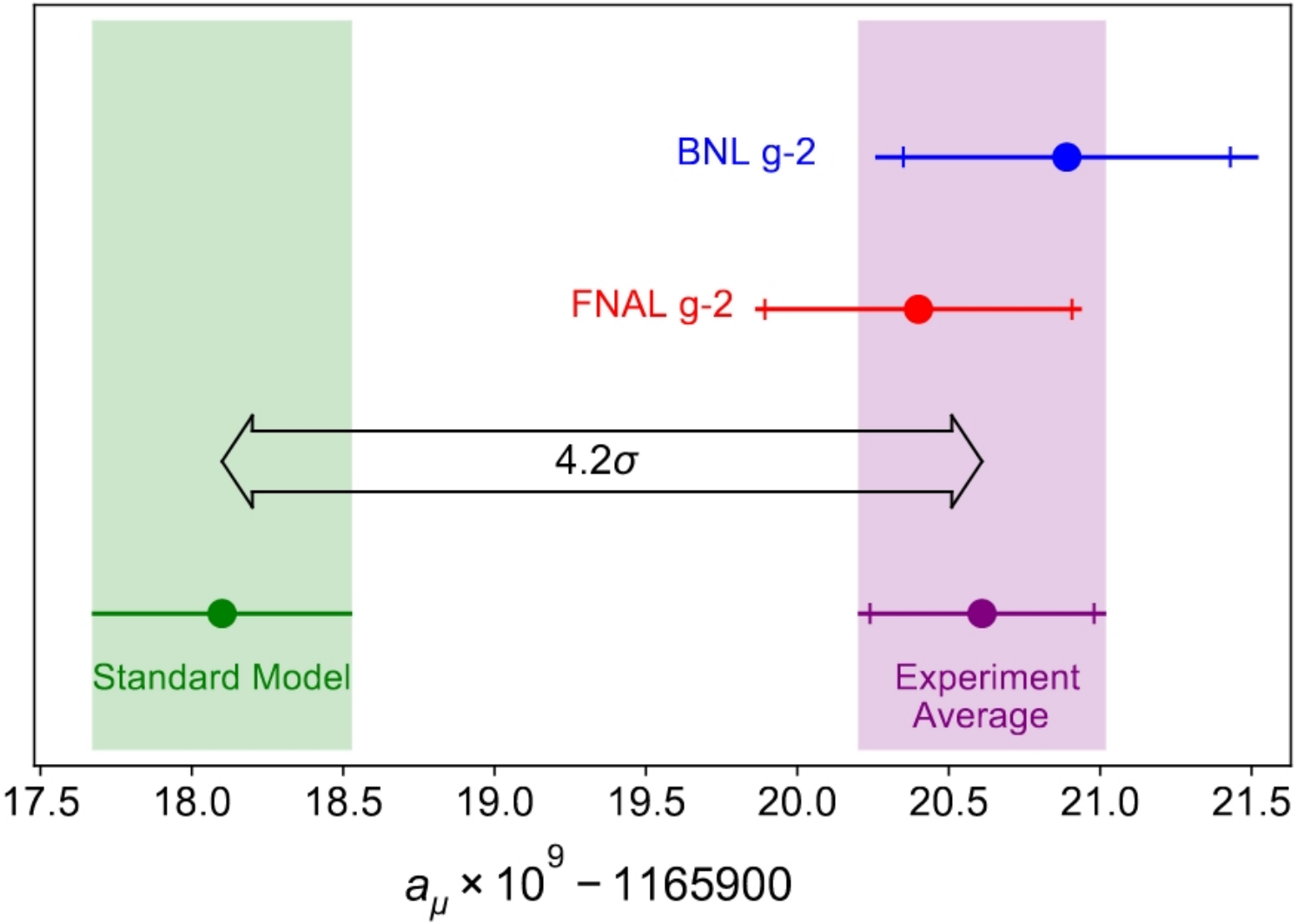
Bethe (1947) [non-relativistic framework], Schwinger (1948)

- Anomalous magnetic moment: $a_\mu = \frac{g_\mu - 2}{2}$

$$a_\mu^{\rm SM} = a_\mu^{\rm QED} + a_\mu^{\rm EW} + a_\mu^{\rm Had}$$

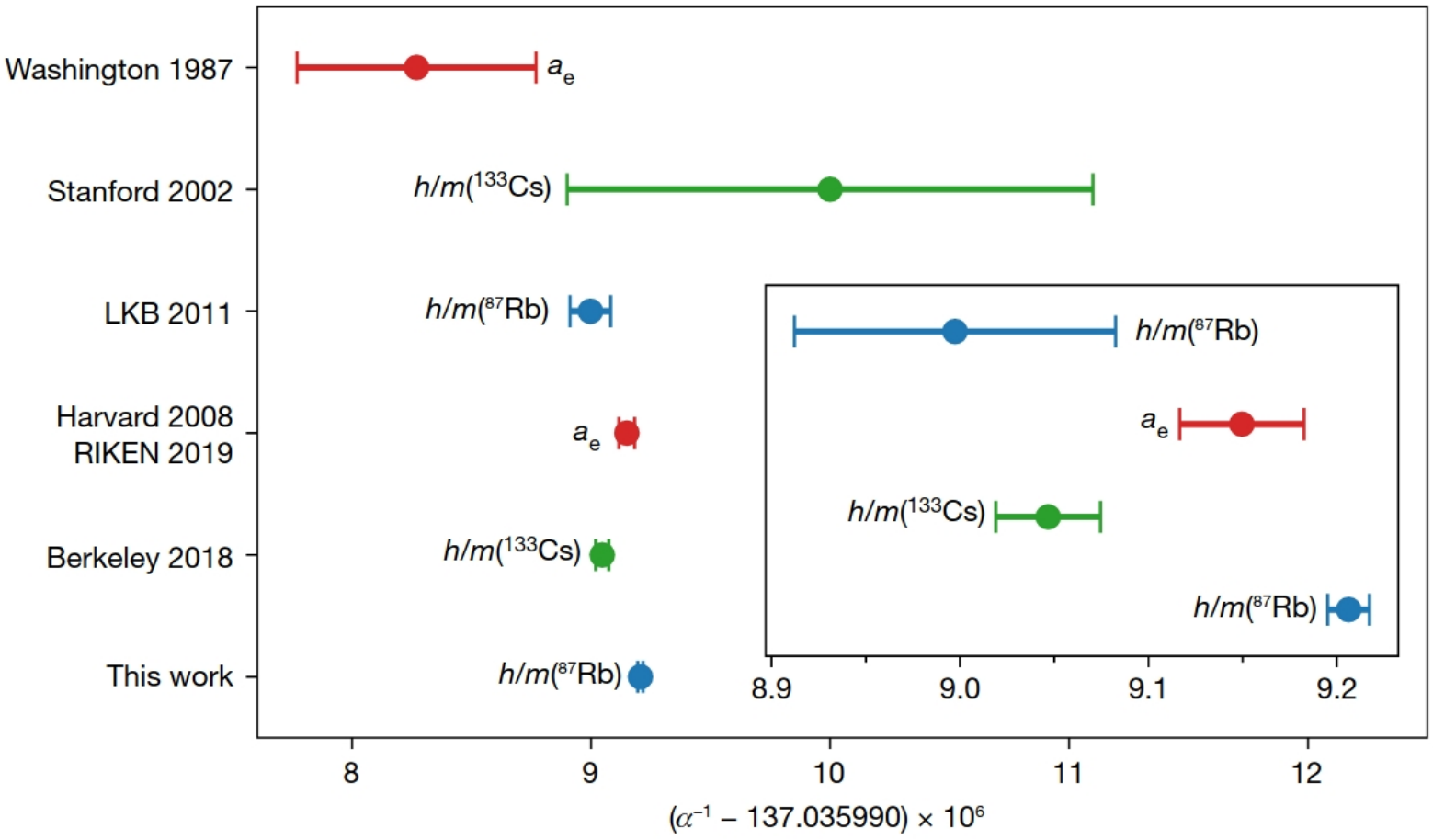


Anomaly in a_μ



Phys. Rev. Lett. 126, 141801

Anomaly in a_e

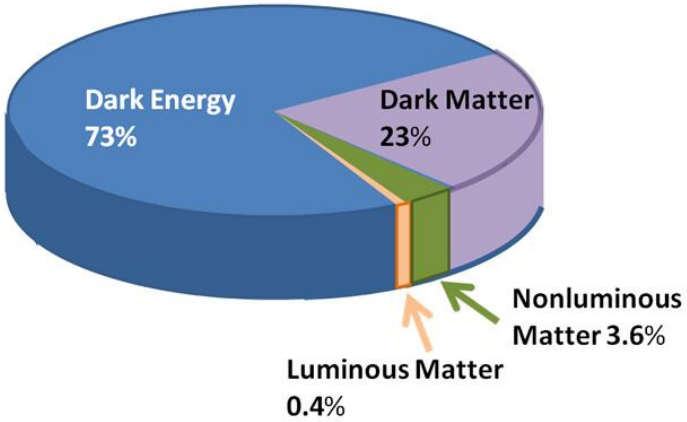


$\sim 5.4\sigma$ discrepancy between recent two measurements

Nature 588 (2020) no.7836, 61-65

Goal: simultaneous explanation

- Dark Matter candidate?



- BNL (2006)+ FNAL (2021):
  $a_\mu^{exp} - a_\mu^{SM} \equiv \Delta a_\mu = +(251 \pm 59) \times 10^{-11}$ $\sim +4.2\sigma$

- Berkeley (2018):
  $a_e^{exp} - a_e^{SM} \equiv \Delta a_e = -(87 \pm 36) \times 10^{-14}$ $\sim -2.5\sigma$

Non-Abelian Extension of the SM

Model

- Gauge group: $SU(3)_c \times SU(2)_L \times U(1)_Y \times SU(2)_X$
- Fermions:

$$
\begin{aligned}
L_L &= \begin{pmatrix} \nu_L & N_L \\ e_L & E_L \end{pmatrix} \sim (1, 2, -\frac{1}{2}, 2), \\
\widetilde{e}_R &= (e_R \; E'_R) \sim (1, 1, -1, 2), \\
\widetilde{\nu}_R &= (\nu_R \; N'_R) \sim (1, 1, 0, 2), \\
\widetilde{\ell}_R &= \begin{pmatrix} N_R \\ E_R \end{pmatrix} \sim (1, 2, -\frac{1}{2}, 1), \\
E'_L &\sim (1, 1, -1, 1), \quad N'_L \sim (1, 1, 0, 1).
\end{aligned}
$$

◇ Neutrinos $\sim$ Dirac mass

◇ $\cancel{SU(2)_X}$ $\sim$ vectorlike masses for $E^{(\prime)}, N^{(\prime)}$

B. Fornal et. al. 2017; E. Ma 2021

Model

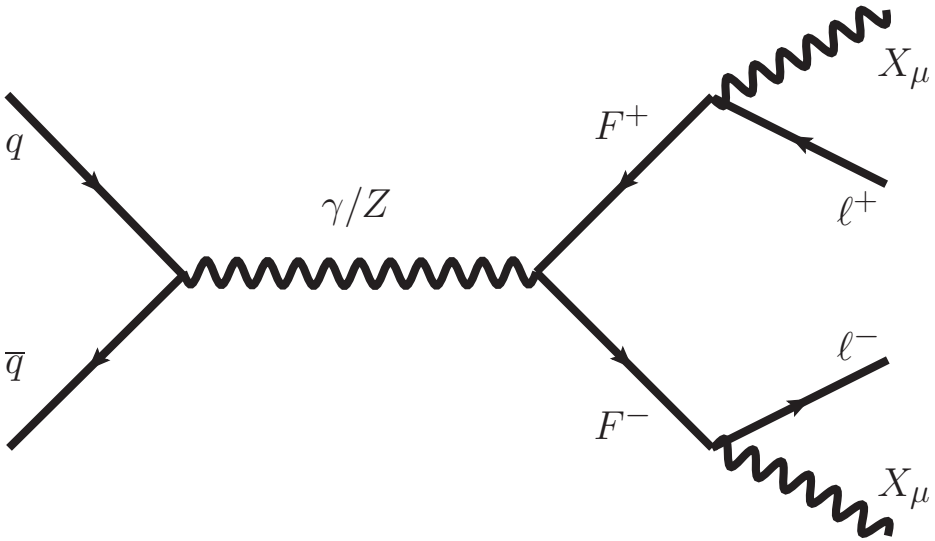
- Gauge group: $SU(3)_c \times SU(2)_L \times U(1)_Y \times SU(2)_X$
- Scalars: $\phi = (\phi_1, \phi_2)^T \sim (1, 1, 0, 2)$; $\cancel{SU(2)_X}$
- Gauge sector: $X, \overline{X}, Z'$

$$\mathcal{L}_G \supset \frac{g_X}{2} Z'_\mu \Big\{ \overline{e}\gamma^\mu e + \overline{\nu}\gamma^\mu \nu - \overline{E_L}\gamma^\mu E_L - \overline{E'_R}\gamma^\mu E'_R - \overline{N_L}\gamma^\mu N_L - \overline{N'_R}\gamma^\mu N'_R \Big\} + \frac{g_X}{\sqrt{2}} X_\mu \Big\{ \overline{\nu_L}\gamma^\mu N_L + \overline{e_L}\gamma^\mu E_L + \overline{\nu_R}\gamma^\mu N'_R + \overline{e_R}\gamma^\mu E'_R + h.c. \Big\}.$$

◇ Dark charge: $E, E', N, N', \overline{X}$ $\qquad Q_X = 1$

Collider constraints and prospects

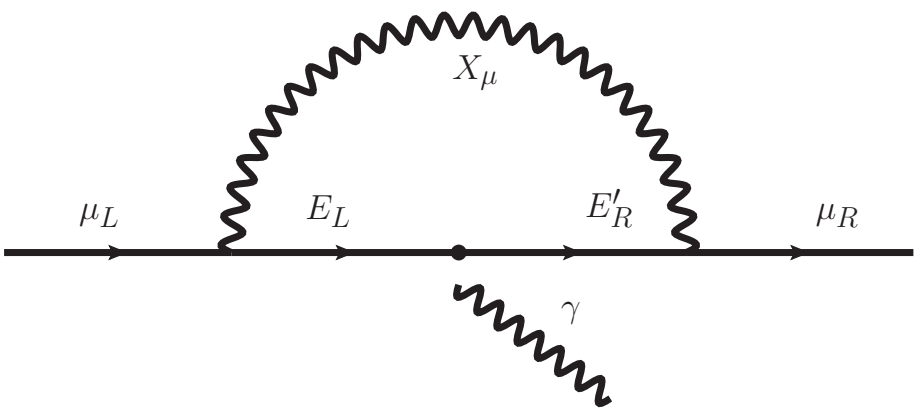
- LHC: non-standard DM signals with multi-lepton signature
  (current bounds $M_F \gtrsim 450$ GeV)

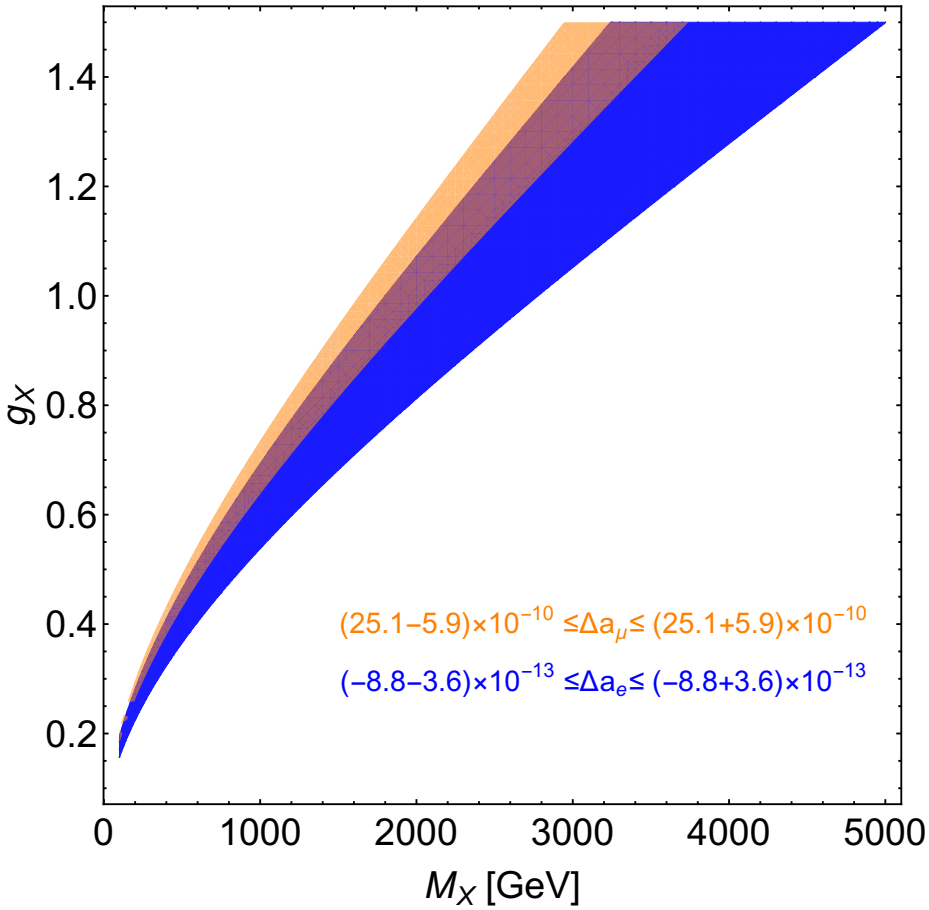


- LEP-II: direct and indirect search ($e^+e^- \to f\overline{f}$).
- EW precision data: T parameter.

Dark Matter and $g - 2$

$(g-2)_{\mu,e}$

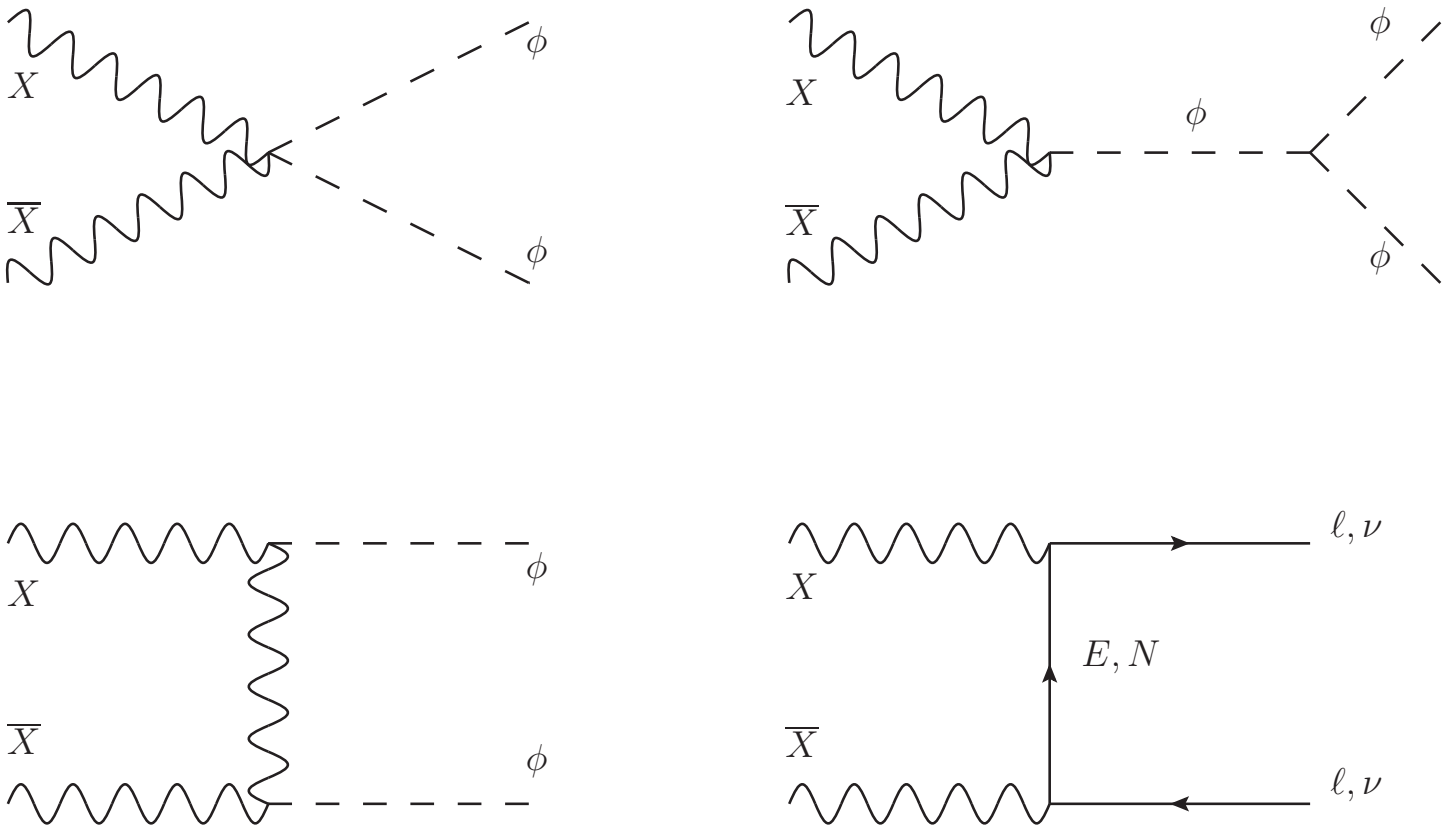




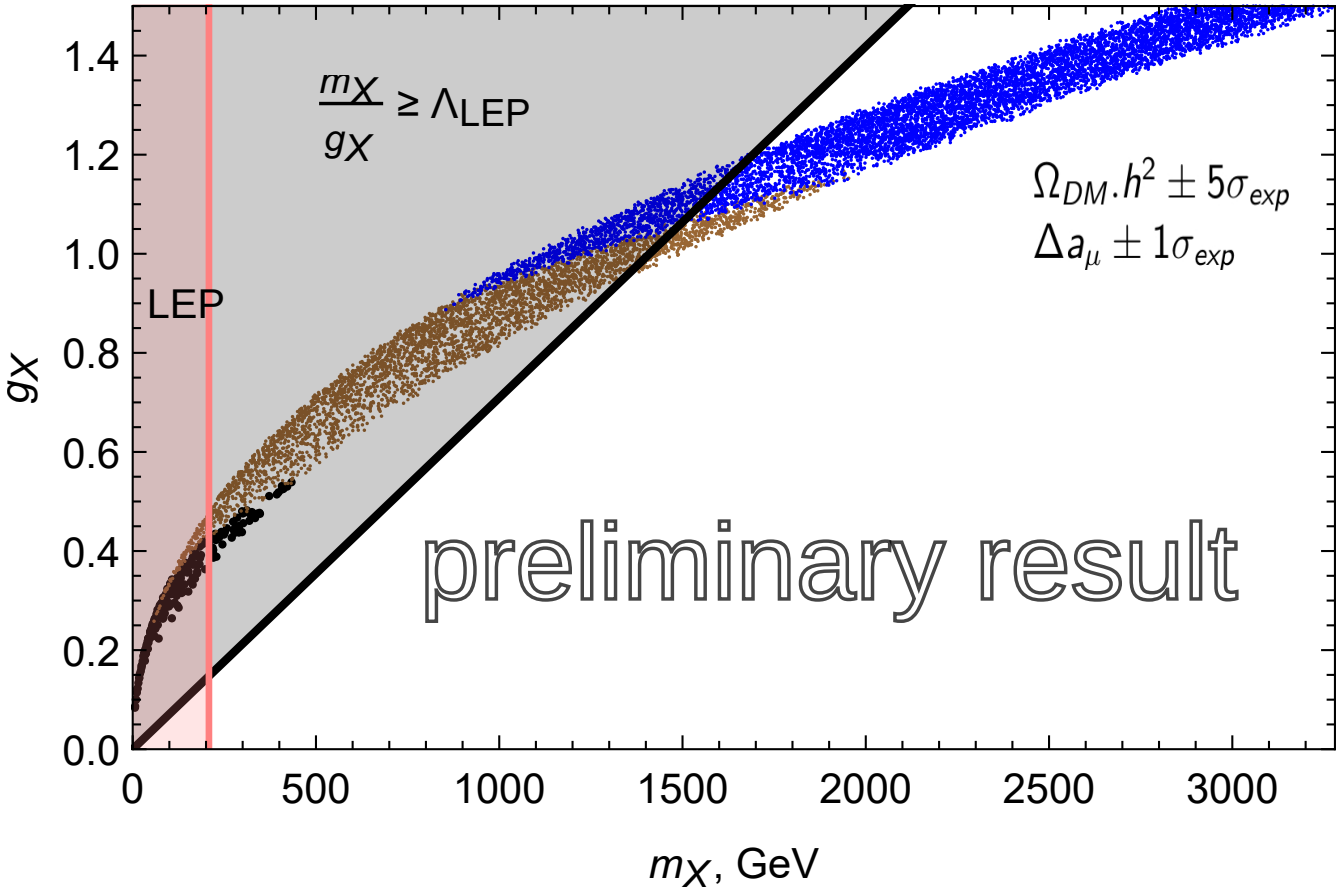
- Dark Matter X in loop

$y_{11} = y_{22} = 1.5 = -3y_{12}$
$(y^{\mu}_{12} = -10y^{e}_{12})$

Dark Matter Annihilation



$(g-2)_\mu$ and Dark Matter



$m_{E_1} \leq 450$ GeV, $450 < m_{E_1} \leq 2000$ GeV, $m_{E_1} > 2000$ GeV $(y, g_X \leq 1.5)$

Summary

Summary

- Strong evidence of new physics:

◇ $\sim 23\%$ of the Universe is Dark Matter!

◇ BNL+FNAL: $\Delta a_\mu = +(2.51 \pm 0.59) \times 10^{-9}$ $\sim +4.2\sigma$

◇ Berkeley: $\Delta a_e = -(8.7 \pm 3.6) \times 10^{-13}$ $\sim -2.5\sigma$

- New physics solution:

✓ Non-Abelian $SU(2)$ gauge model

✓ Simultaneous explanation and possible deep connection

✓ Neutrino mass

✓ Collider prospects

THANK YOU!