Dark Sector Searches via Muon Beam-Dump Experiments

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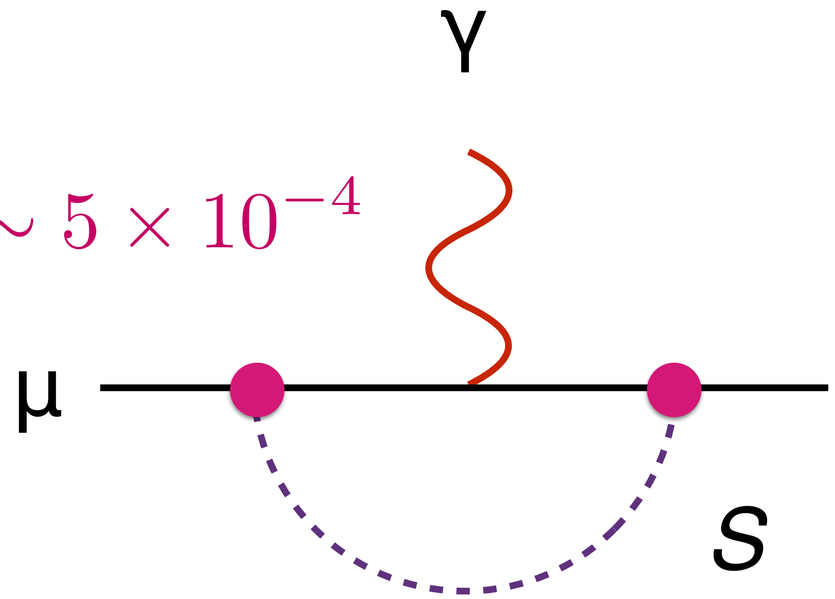
Fermilab ACE Science Workshop

Minimal model to solve muon g-2 anomaly

- Introduce a **new** light scalar S
  ($\mathrm{MeV} < m_S < 2m_\mu$)
- Couples to muons, not quarks, not dark matter

$$\Delta a_\mu \sim \frac{g_\mu^2}{16\pi^2}\frac{m_\mu^2}{m_S^2} \sim 10^{-9}$$

$g_\mu \sim 5 \times 10^{-4}$



Minimal model to solve $(g\text{-}2)_\mu$ anomaly

model A

$$\mathcal{L} \supset -g_e S\bar{e}e - g_\mu S\bar{\mu}\mu - g_\tau S\bar{\tau}\tau$$

w/ $g_\ell \propto m_\ell$

model B

$$\mathcal{L} \supset -g_\mu S\bar{\mu}\mu$$

Originated from $\mathcal{O}_5 = \frac{c_i}{\Lambda} S\bar{L}_i H E_i$ Batell+ ‘18

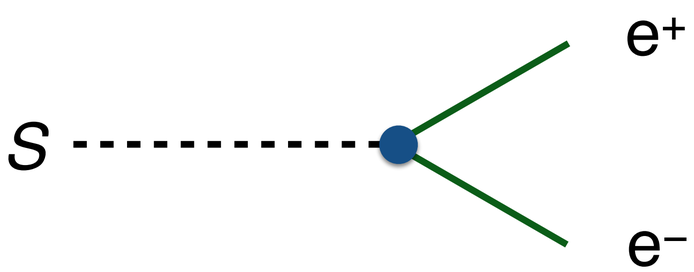
with Minimal Flavor Violation

under “flavor-specific” hypothesis

Dominant decay channels

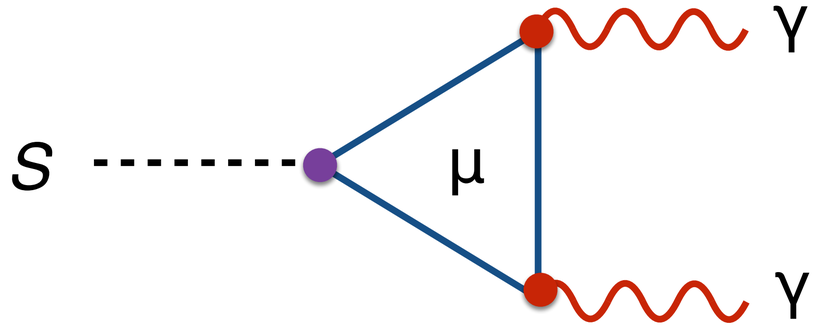
$$\mathrm{MeV} < m_S < 2m_\mu$$

model A



m_e-suppressed

model B



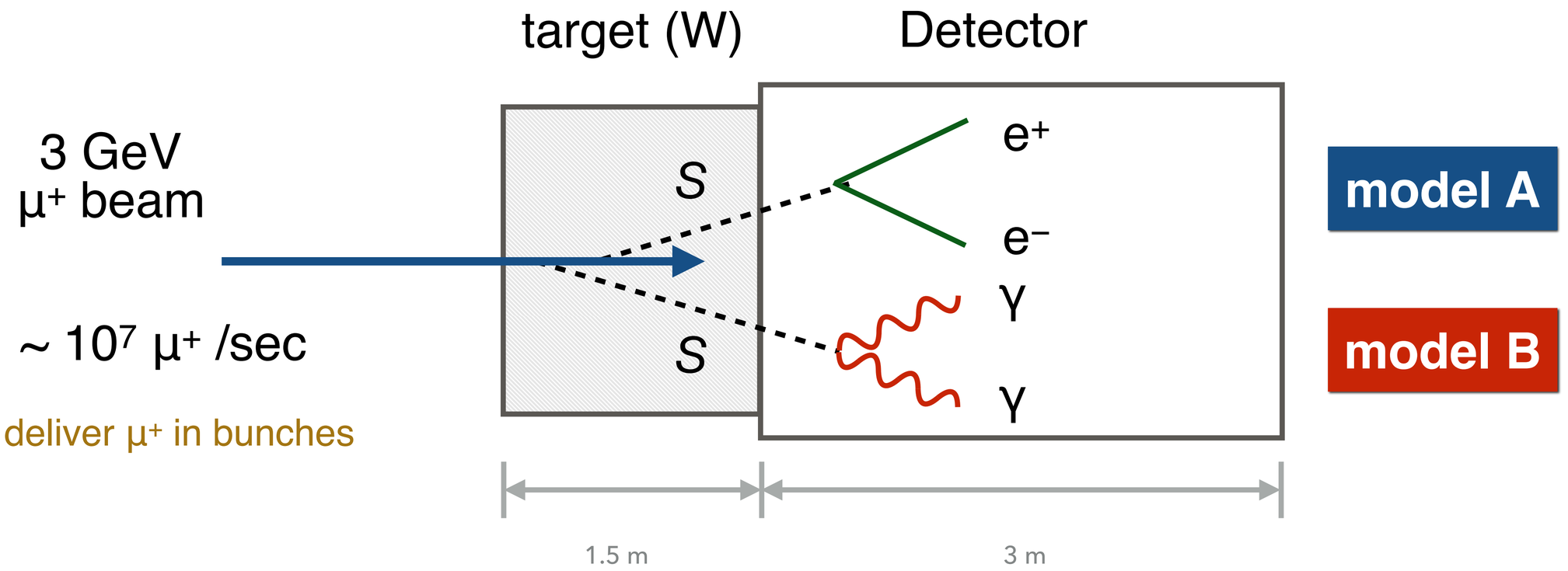
loop-suppressed

for $g_\mu \sim 10^{-4}$, $m_S \sim 100$ MeV, decay length: O (10 cm) ~ O (10 m)

Look at muon-beam dump experiments

- Muon-beam dump experiments are good place to look for dark scalars (and other light dark particles):
  - focus on the couplings to muons
  - sensitive to displaced decays
  - can be integrated to other muon experiments
- We look into two searches

Fermilab setup (FNAL-μ)



Tracks from displaced vertices/anomalous energy deposit

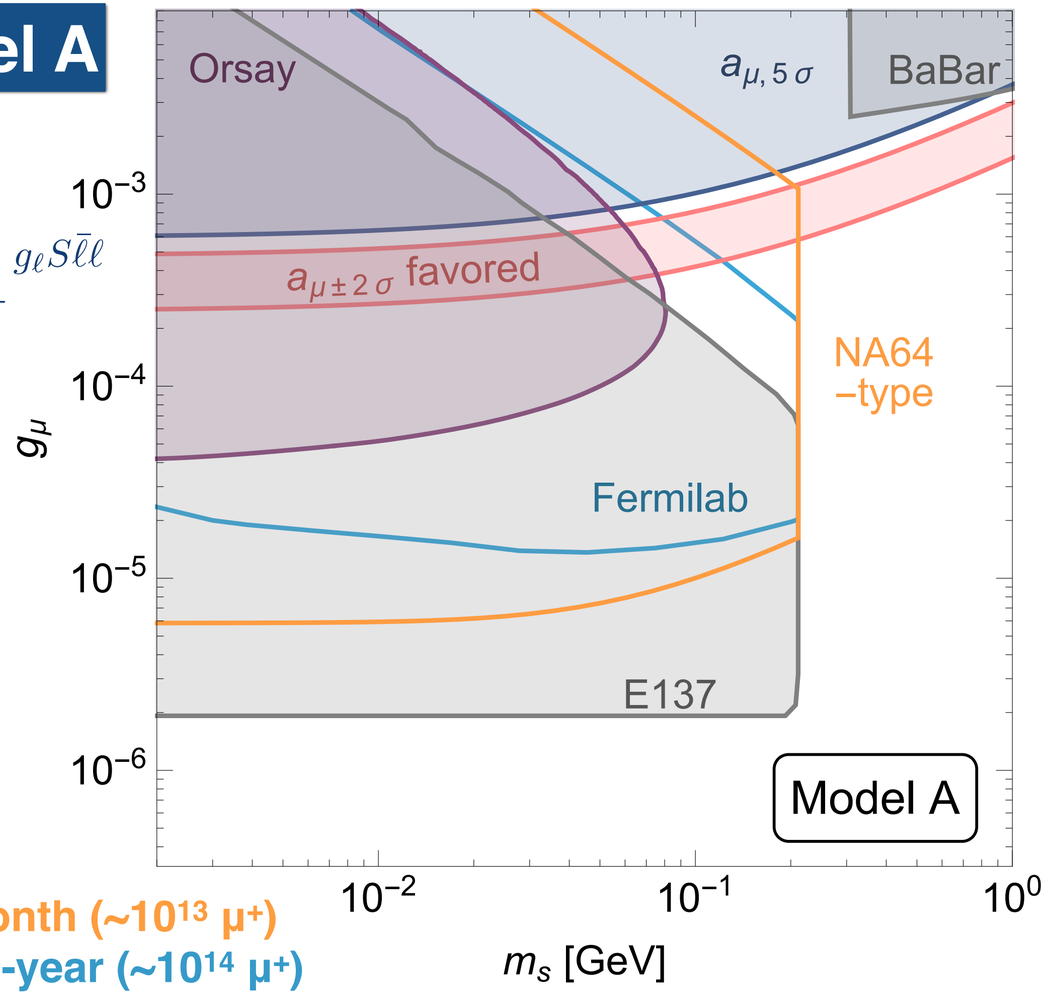
Fermilab setup (FNAL-μ)

- Simple
- Compact (could go into g-2 hall)
- Could run in parallel w/ other muon experiments
- Muon beam source is similar to what was delivered to muon g-2 experiment

Projected sensitivity to dark scalar

model A

$$\mathcal{L} \supset -\sum_{\ell=e,\mu,\tau} g_\ell S\bar{\ell}\ell$$



model B

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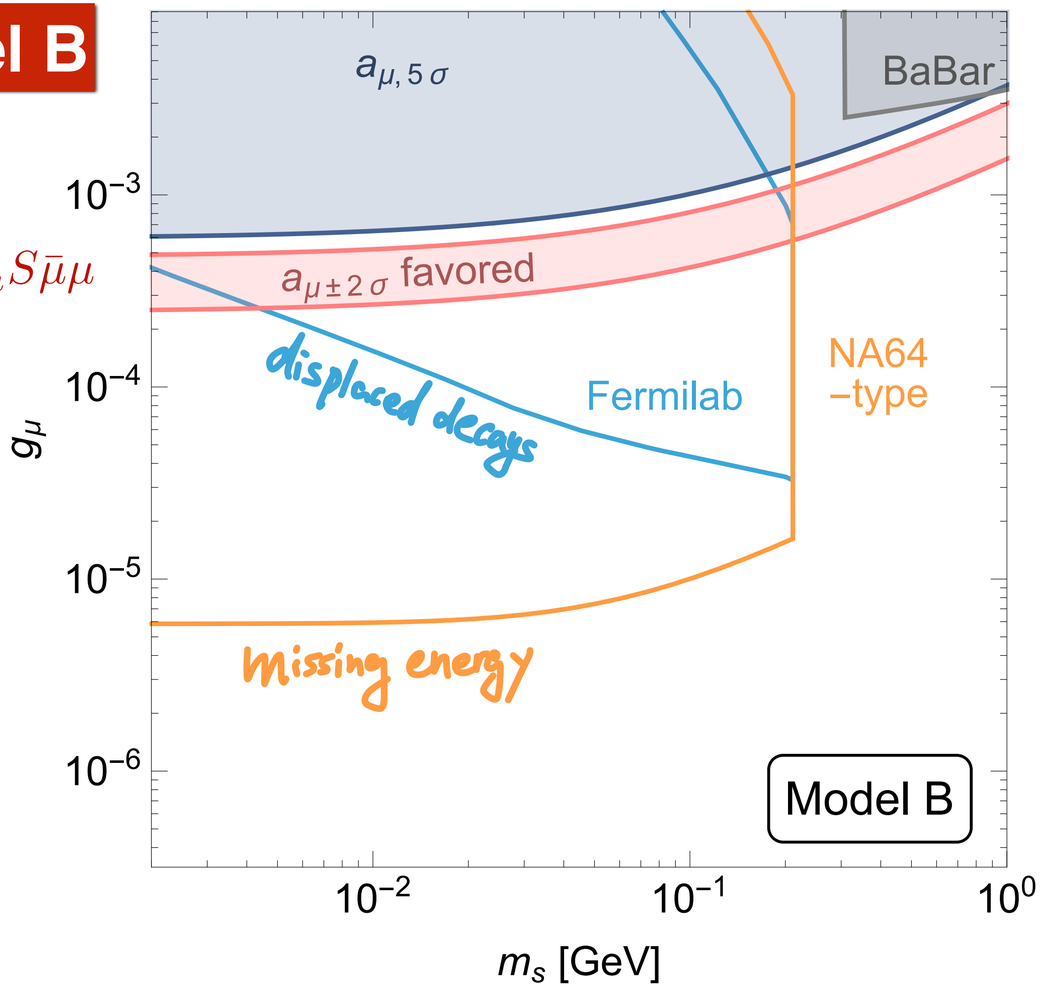
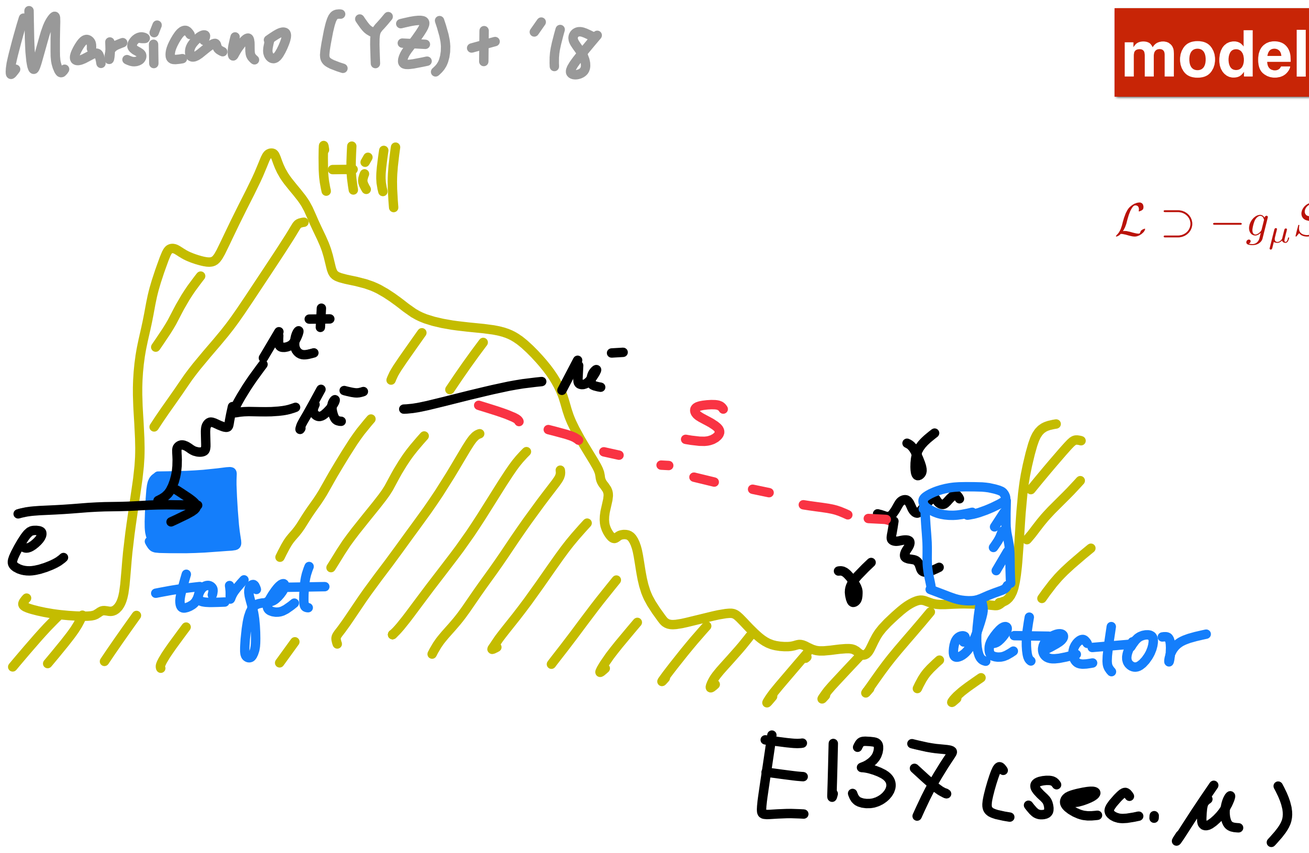


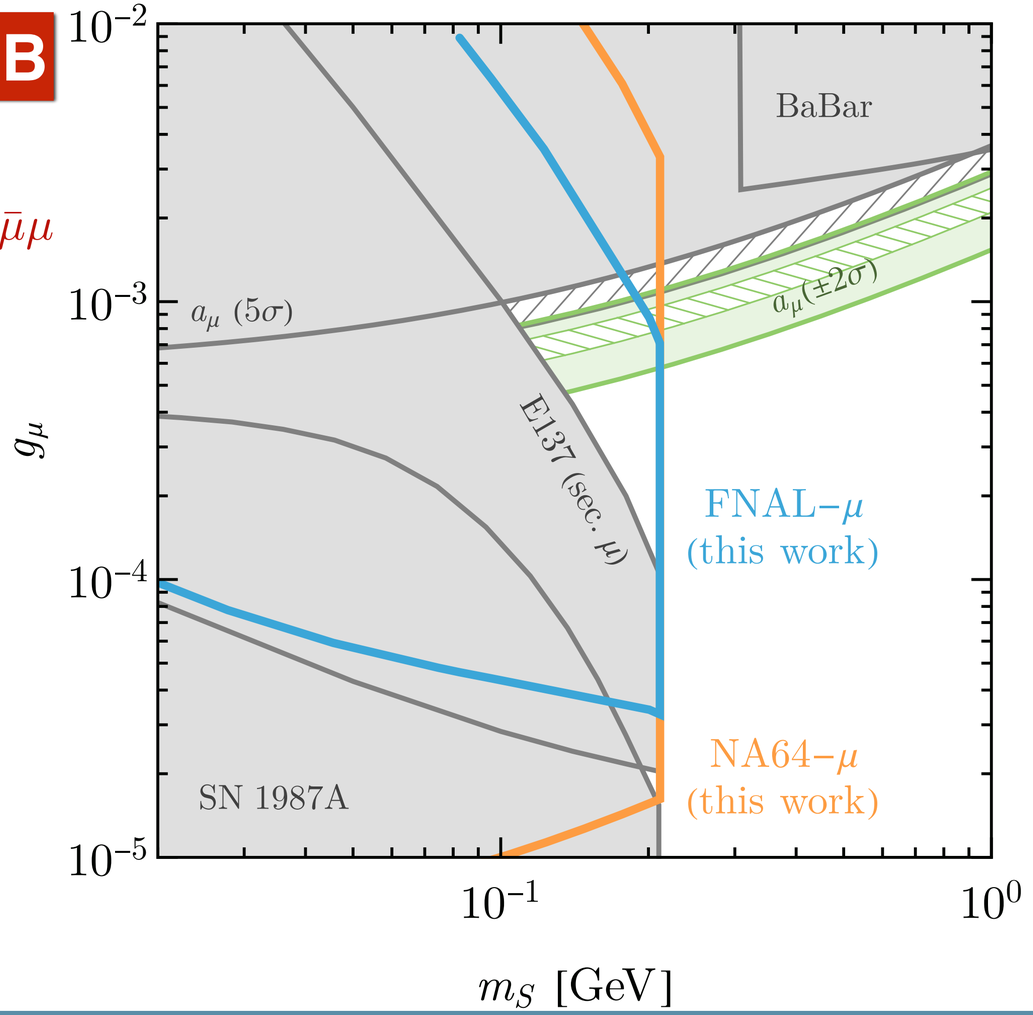
NA64: 3-month (~10^{13} μ⁺)
Fermilab: 1-year (~10^{14} μ⁺)

Projected sensitivity to dark scalar



model B

$\mathcal{L} \supset -g_\mu S \bar{\mu} \mu$



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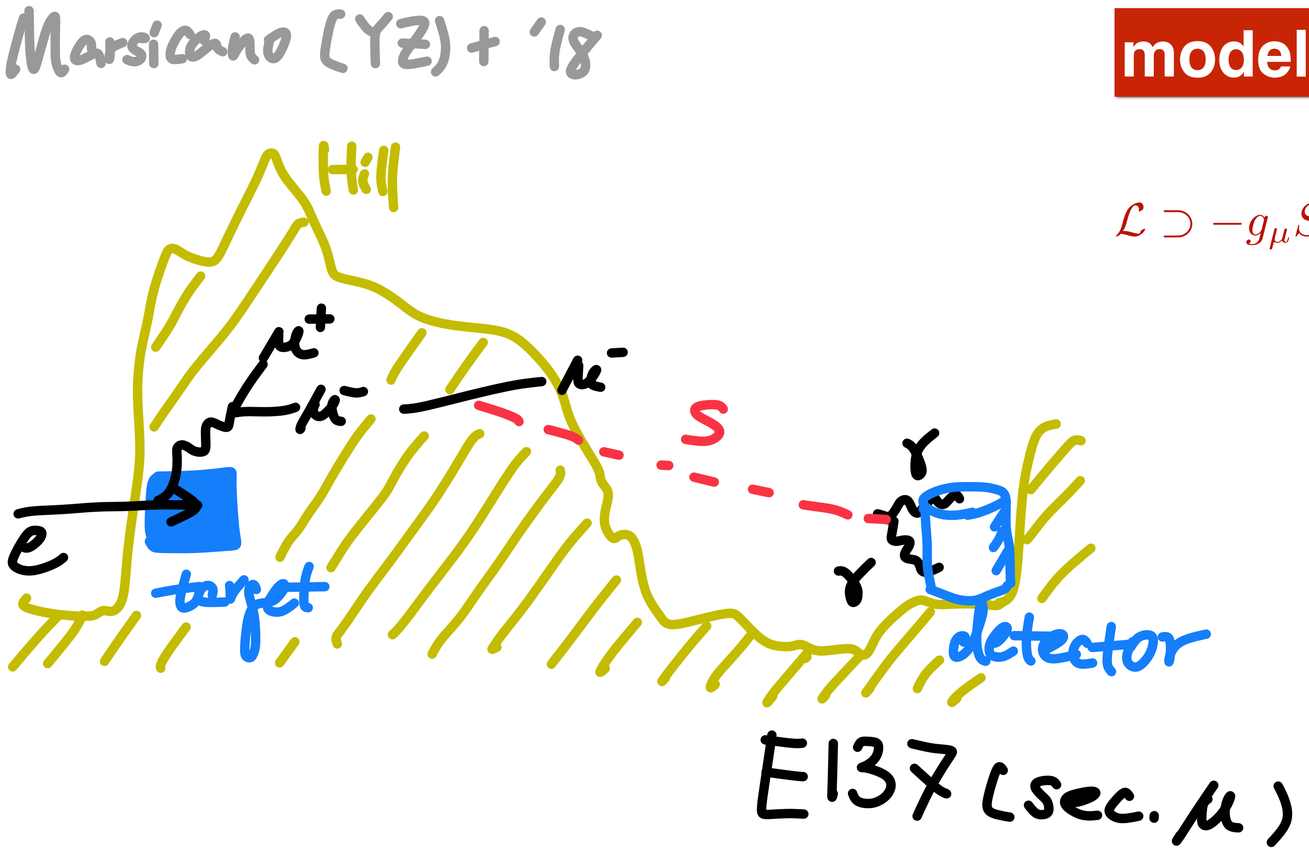

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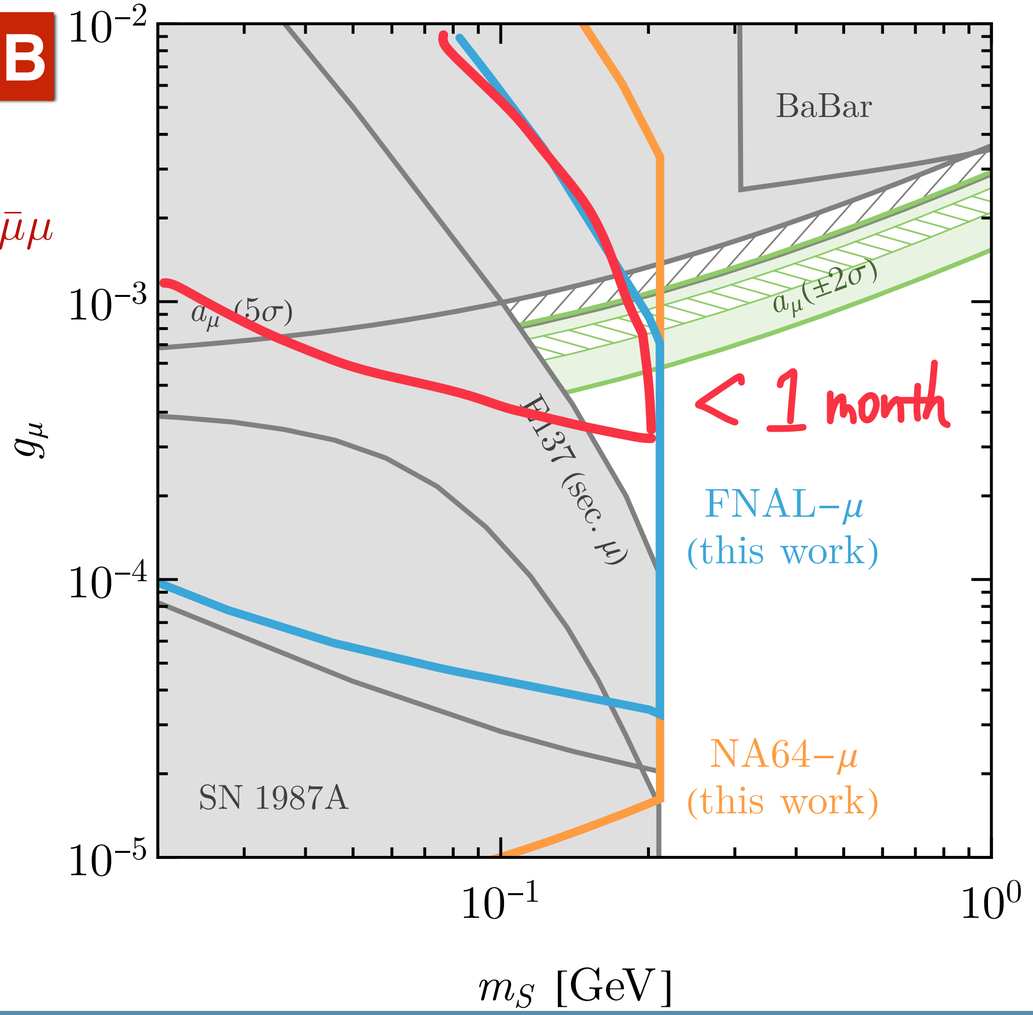

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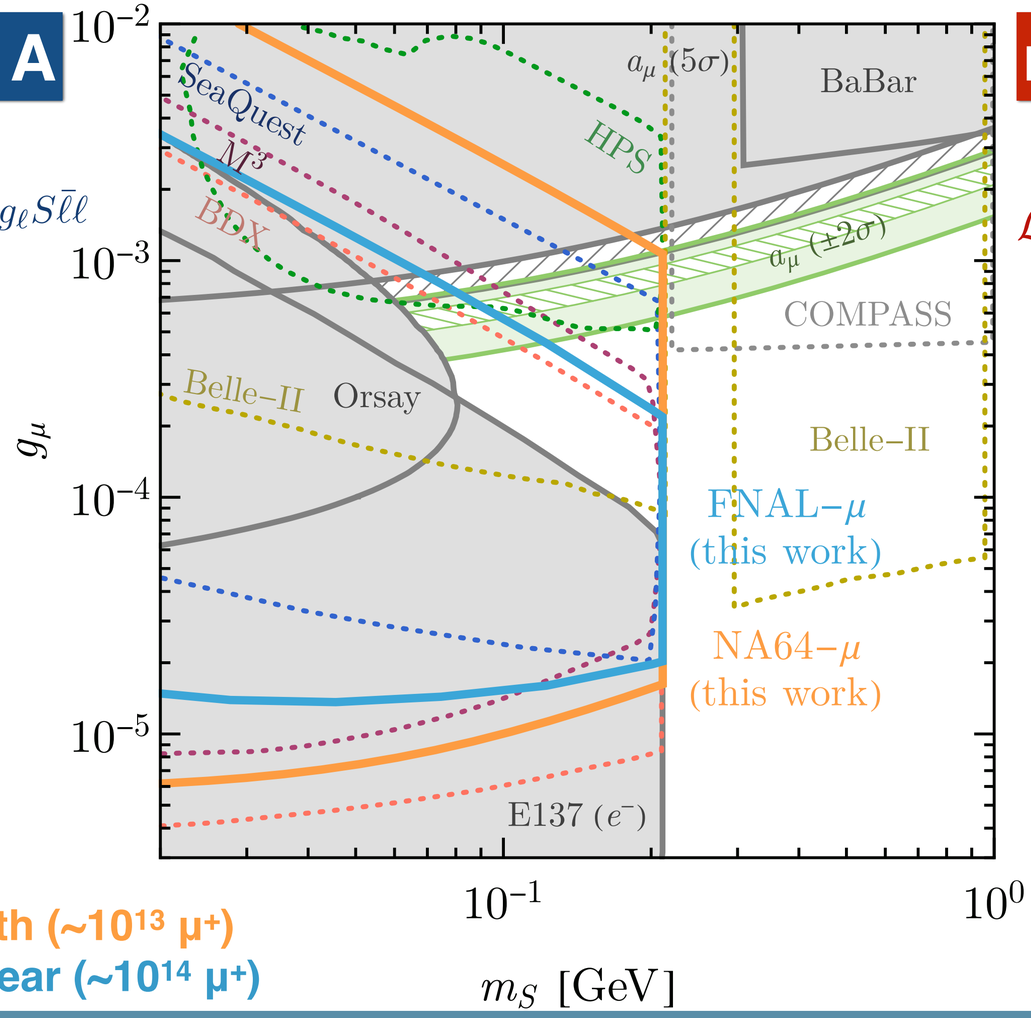

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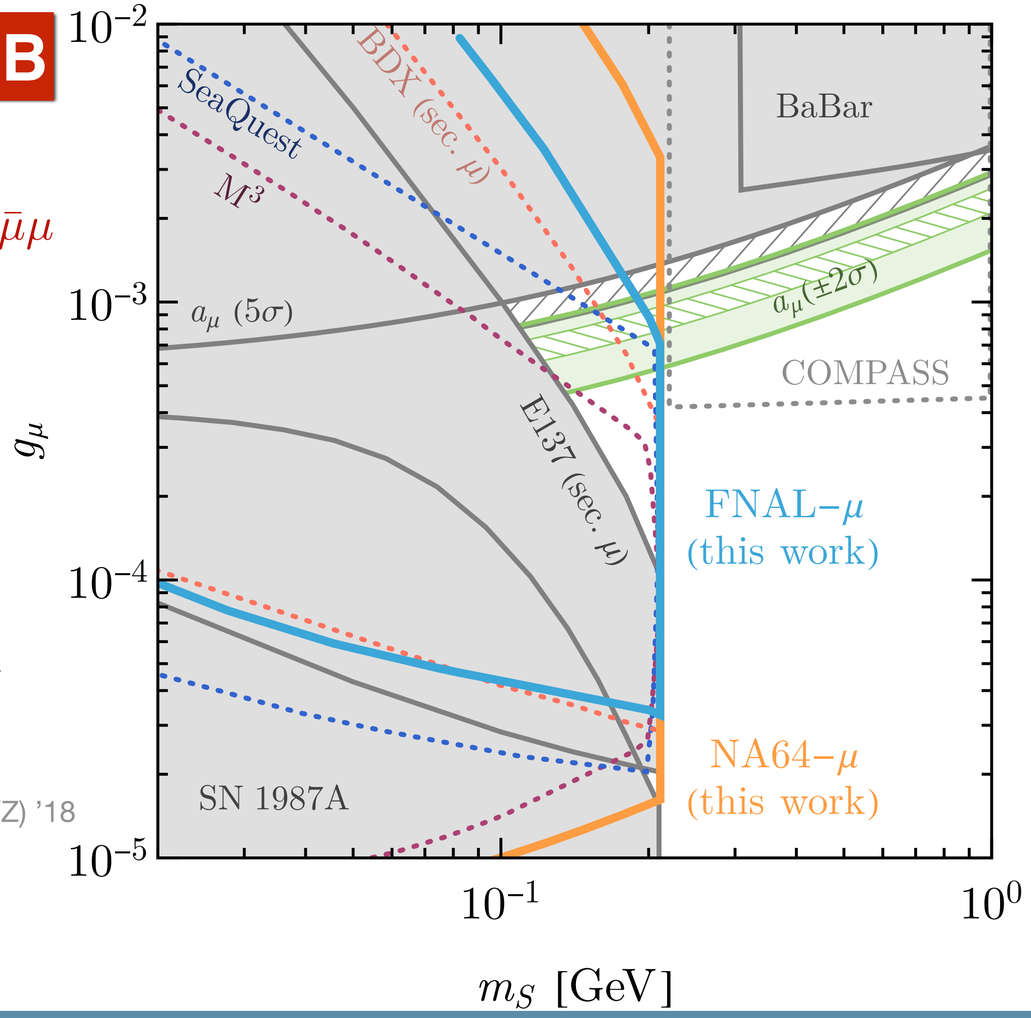

Essig+ ’10
Battaglieri+ ’14
Batell+ ‘16
Kahn+ ’18
Berlin+ ‘18
Marsicano + (YZ) ’18

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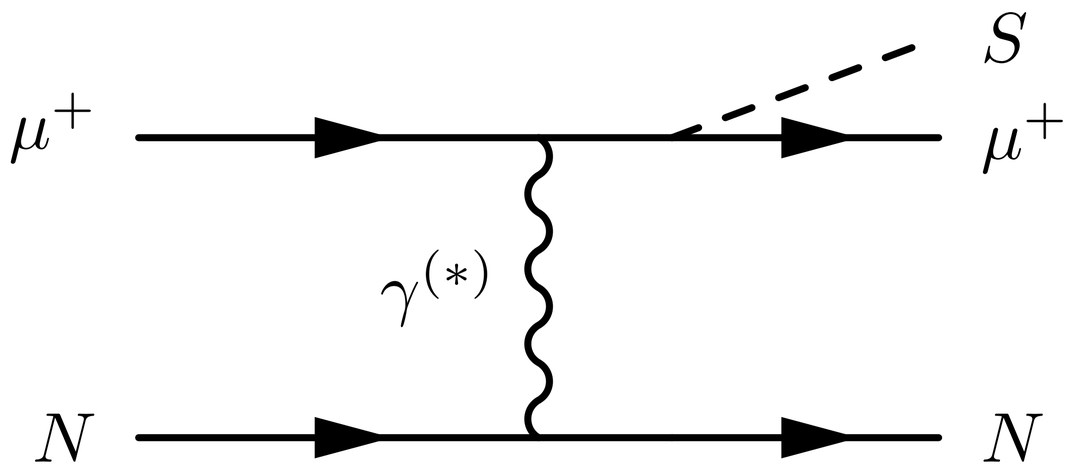
Summary

- Muonic dark sector can explain muon related anomalies.
- Muon beam-dump experiments can effectively probe muonic dark sector, w/ predominant muon coupling, that explain muon g-2 anomaly.
- FNALμ can be easily implemented at existing FNAL infrastructure w/ modest modifications/additions.

Backup

Signal

$$\mathrm{MeV} < m_S < 2m_\mu$$



(+ another diagram)

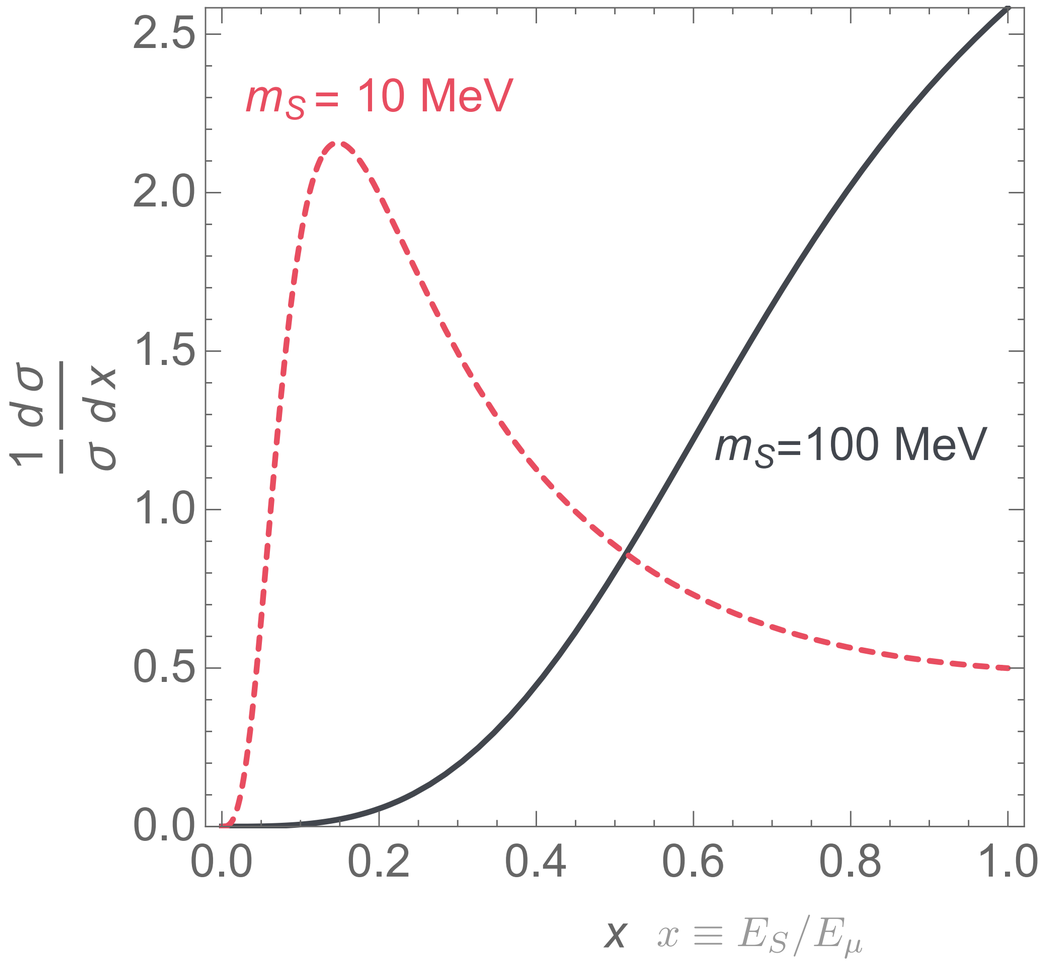
S takes a larger amount of muon beam energy as m_S grows

Backgrounds

- Long-lived neutral particles / accidental backgrounds
- Negligible backgrounds for our search setups
  - NA64-μ w/ the requirement $E_{miss} > 50$ GeV Gninenko+ ’15 Banerjee+ ’17
  - FNAL-μ: We estimate K_L decays are negligible during one-year run

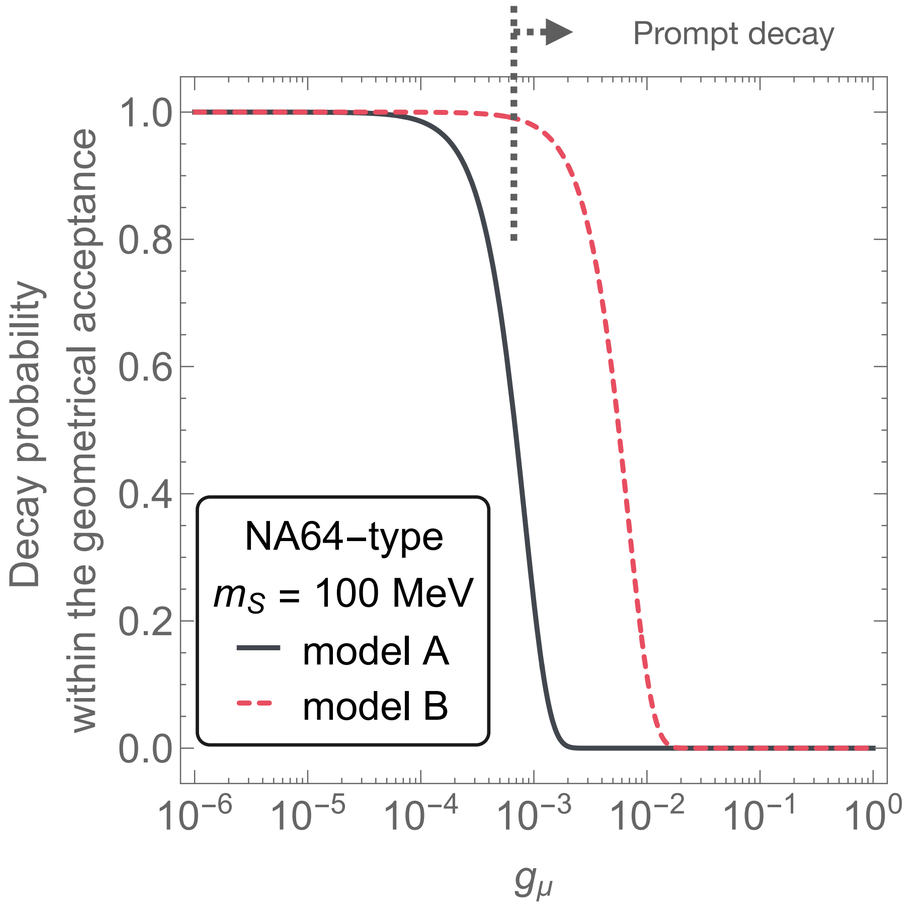
Signal

- Energy of S changes w/ m_S
- Take significant amount of beam energy when m_S becomes larger

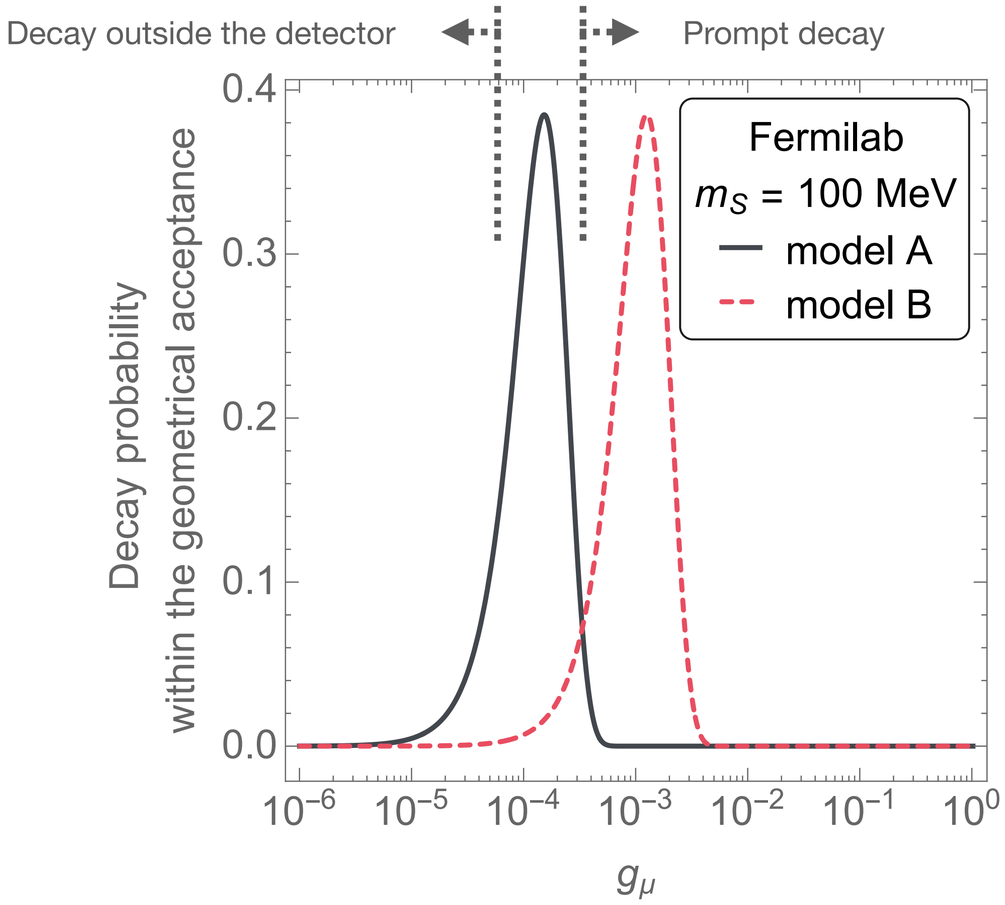


Signal

NA64-μ: missing energy



FNAL-μ: displaced decays



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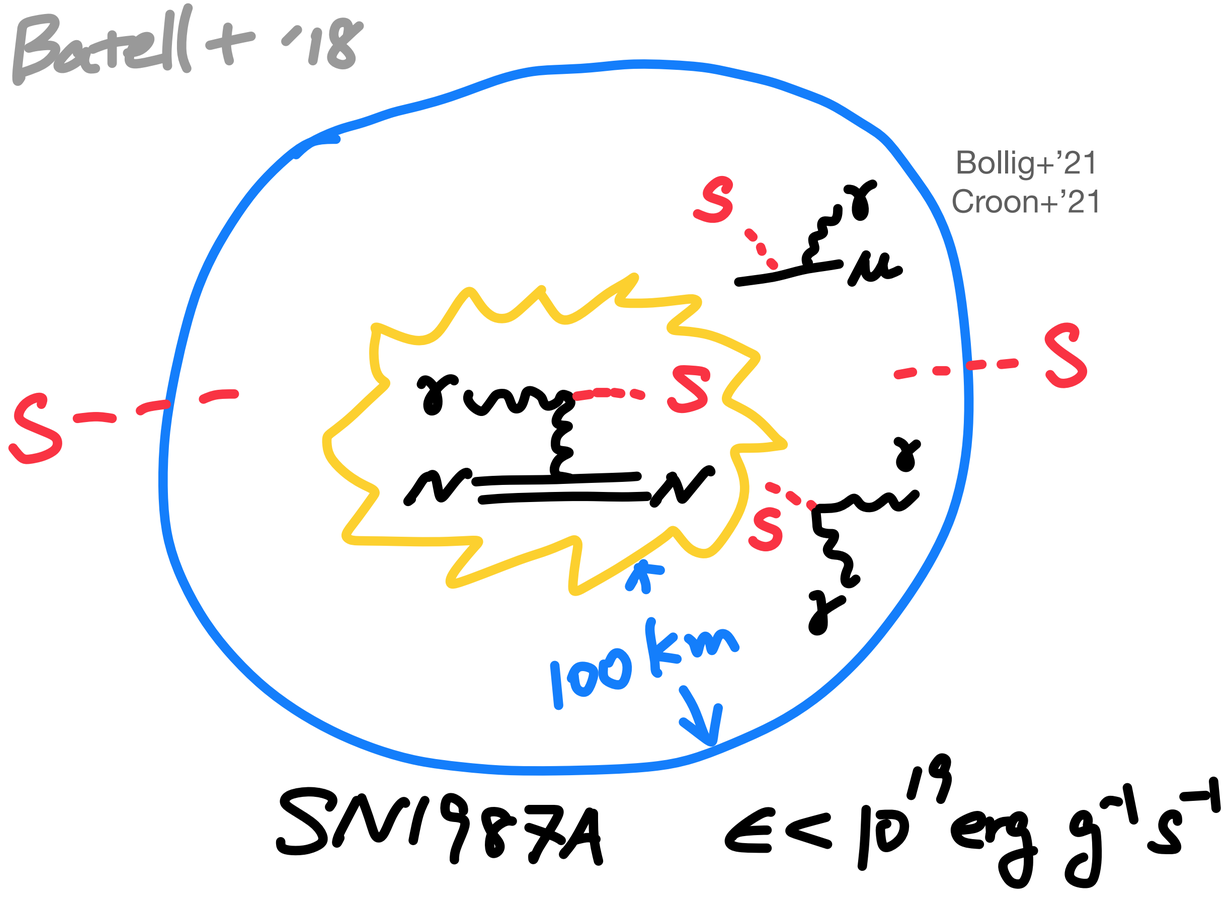

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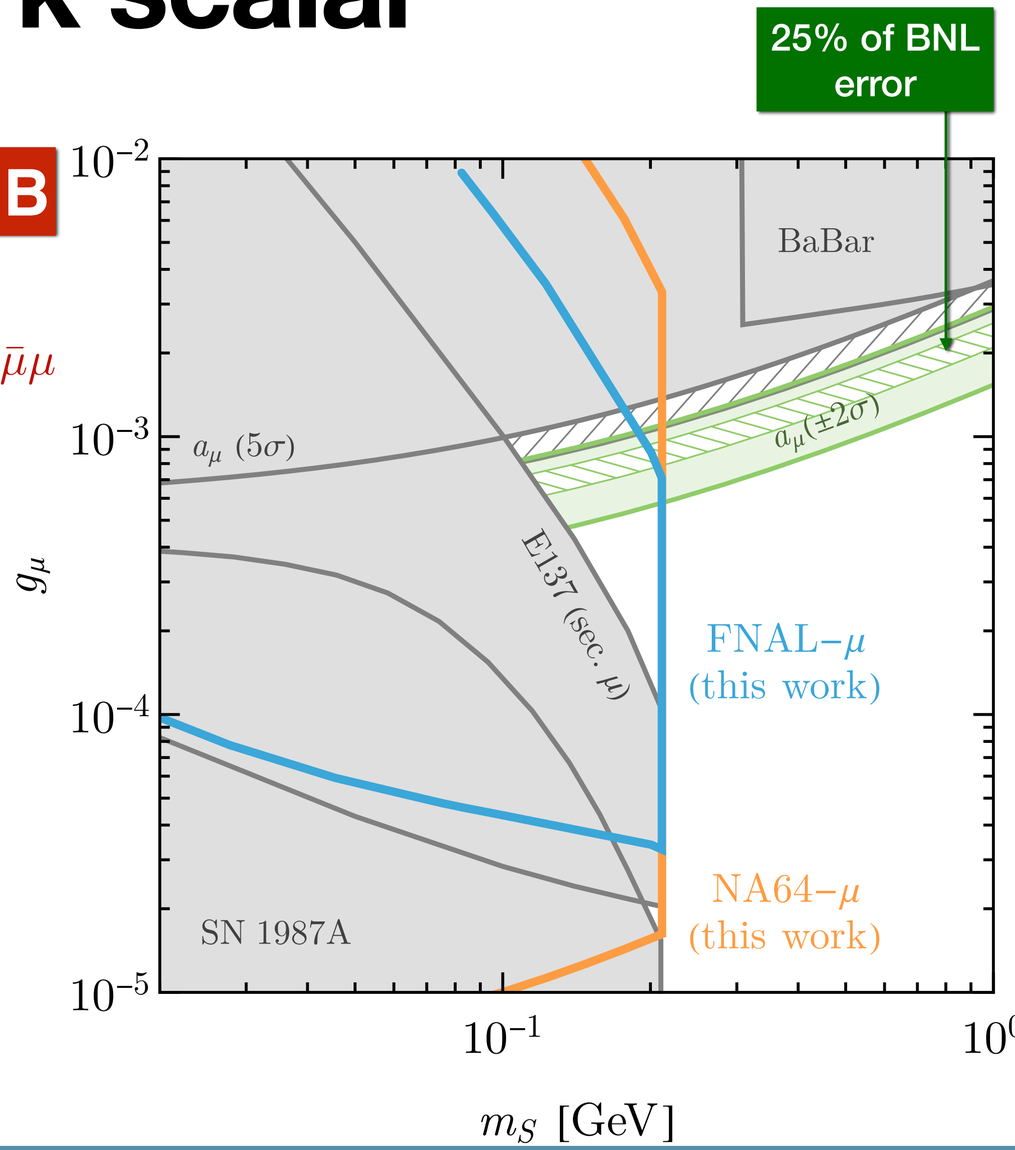

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