

Dark Sector Searches via Muon Beam-Dump Experiments

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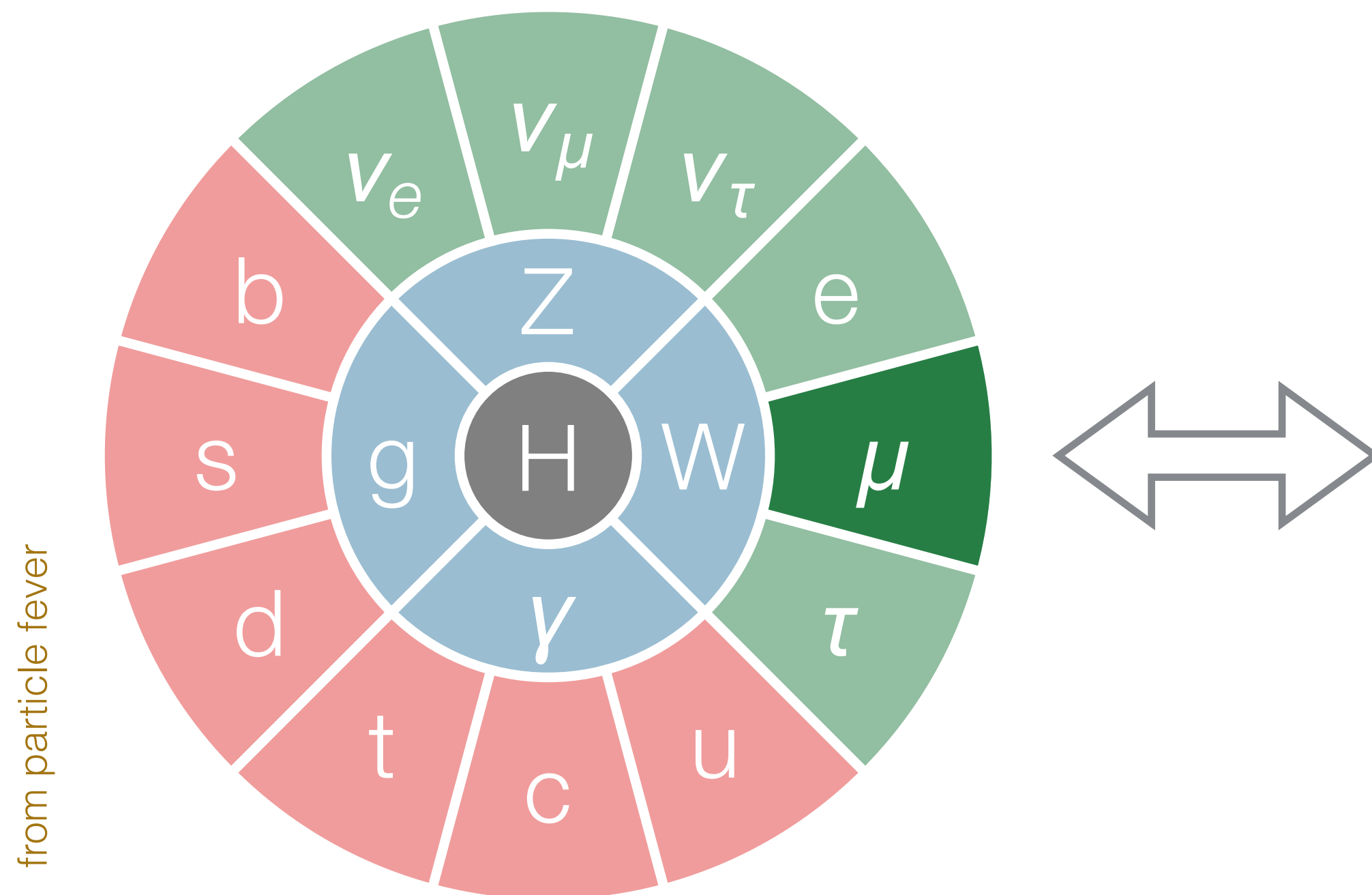
w/ Chien-Yi Chen and Maxim Pospelov

PRD 95, 115005 (2017), arXiv:[1701.07437](https://arxiv.org/abs/1701.07437)

Workshop on discovering the new physics of $g-2$ with fixed target muon facilities at Fermilab

Accumulated muon anomalies

- Muon $g-2$, R_K , proton charge radius...
- Statistics/experimental/theoretical systematics or ***muonic dark sectors***

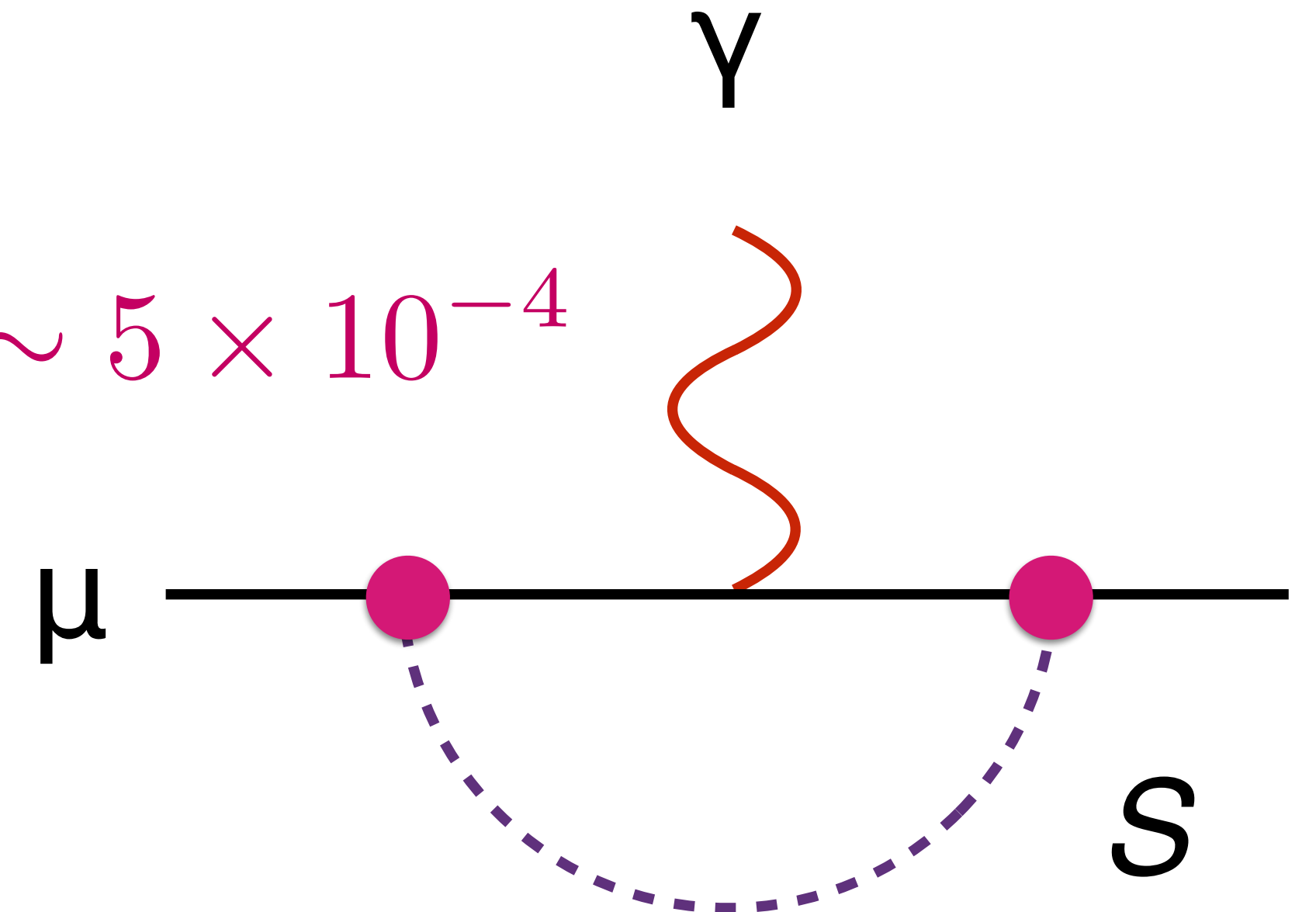


Minimal model to solve muon g-2 anomaly

- Introduce a **new** light scalar S
($\text{MeV} < m_S < 2m_\mu$)
- 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 $(g-2)_\mu$ 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 $\mathcal{O}_5 = \frac{c_i}{\Lambda} S \bar{L}_i H E_i$

with Minimal Flavor Violation

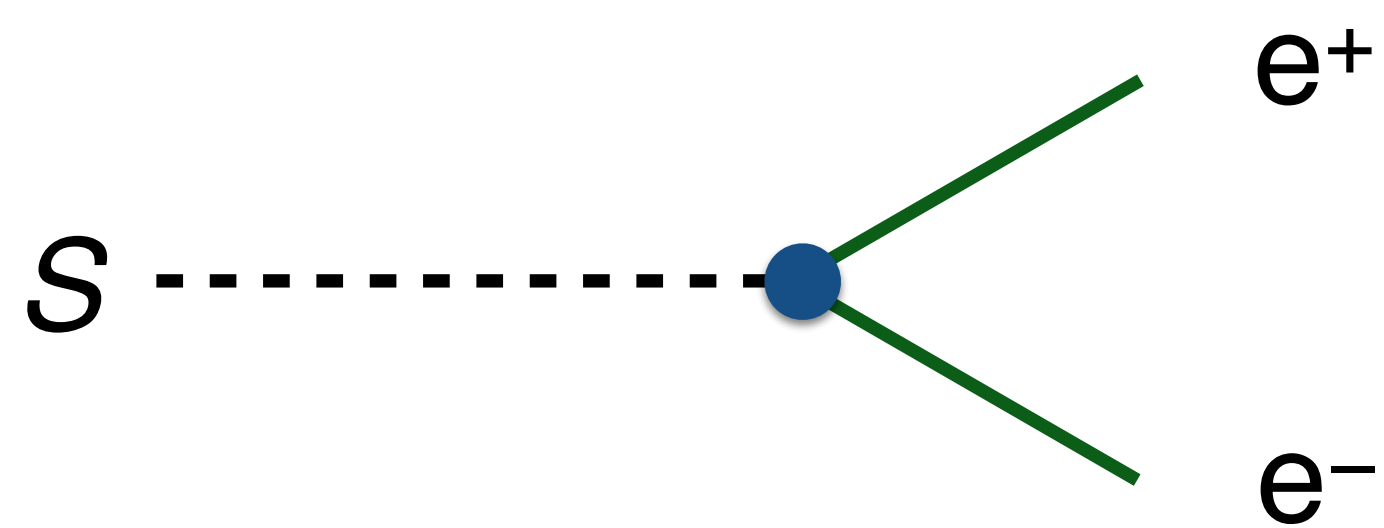
under “flavor-specific” hypothesis

Batell+ '18

Dominant decay channels

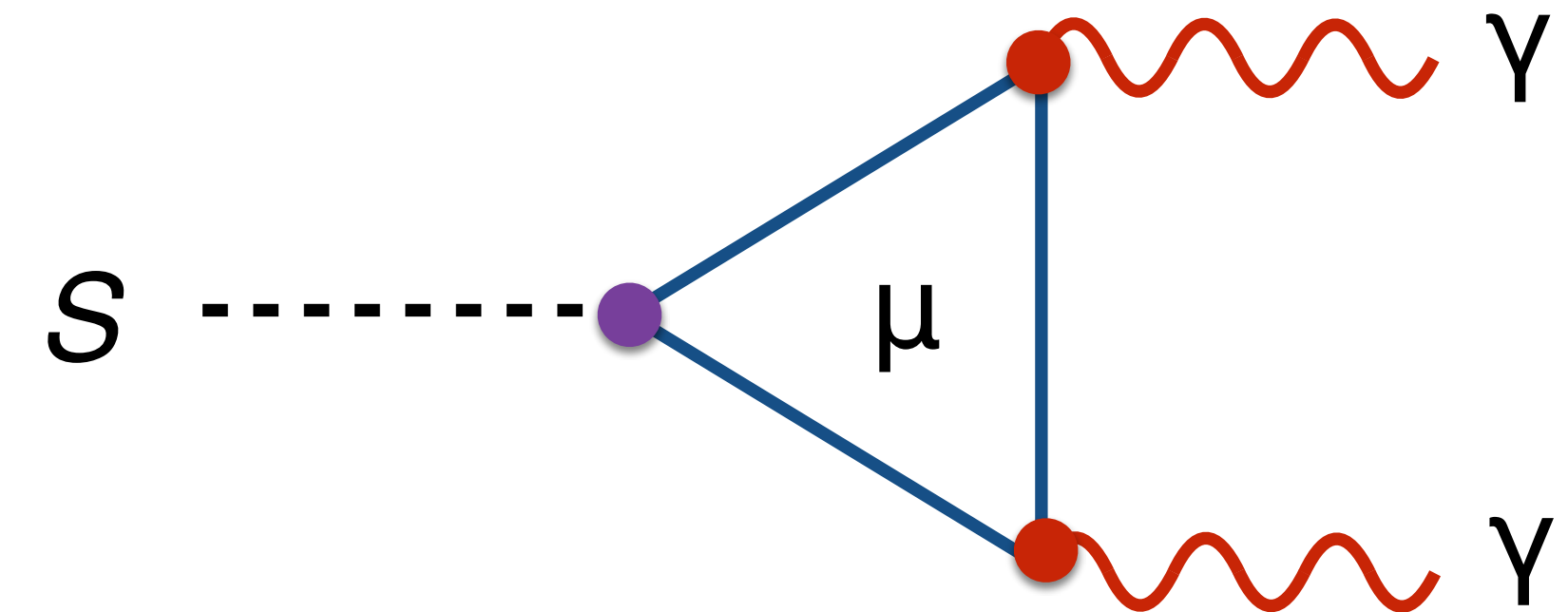
$$\text{MeV} < m_S < 2m_\mu$$

model A



m_e -suppressed

model B



loop-suppressed

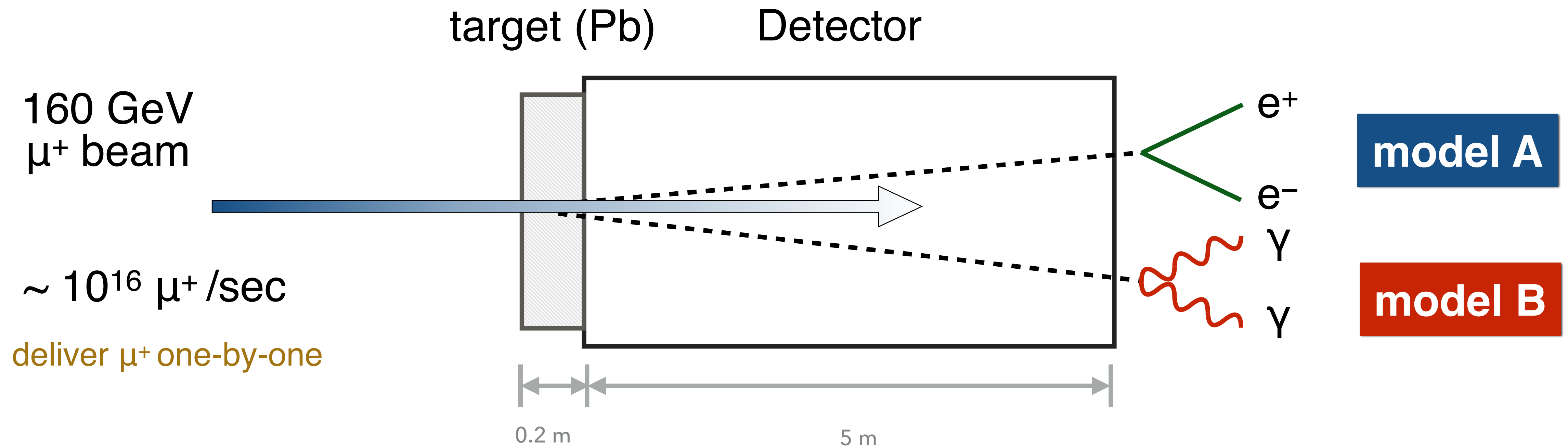
for $g_\mu \sim 10^{-4}$, $m_S \sim 100$ MeV, decay length: $O(10 \text{ cm}) \sim O(10 \text{ m})$

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**

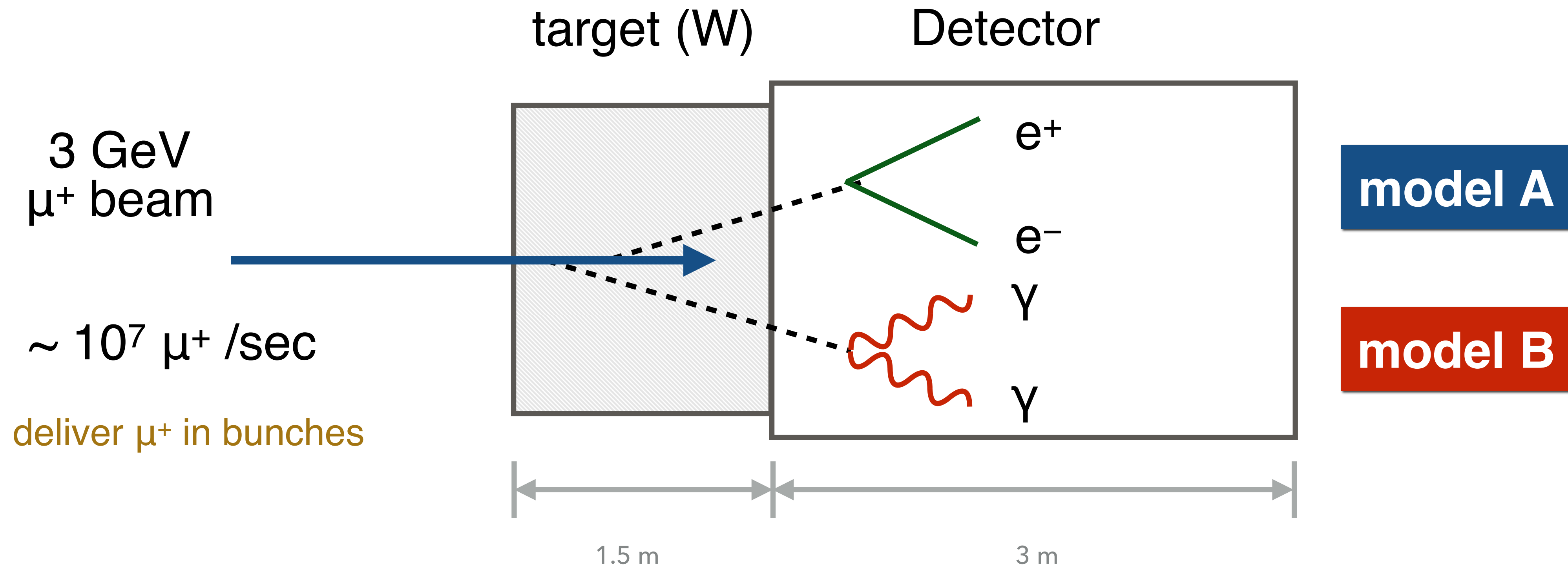
NA64 setup (NA64 μ)

NA64 μ is a fixed-target experiment at CERN (test run will start soon)



large missing energy of μ beam ($E_{\text{miss}} \gtrsim E_{\text{beam}}/3$)

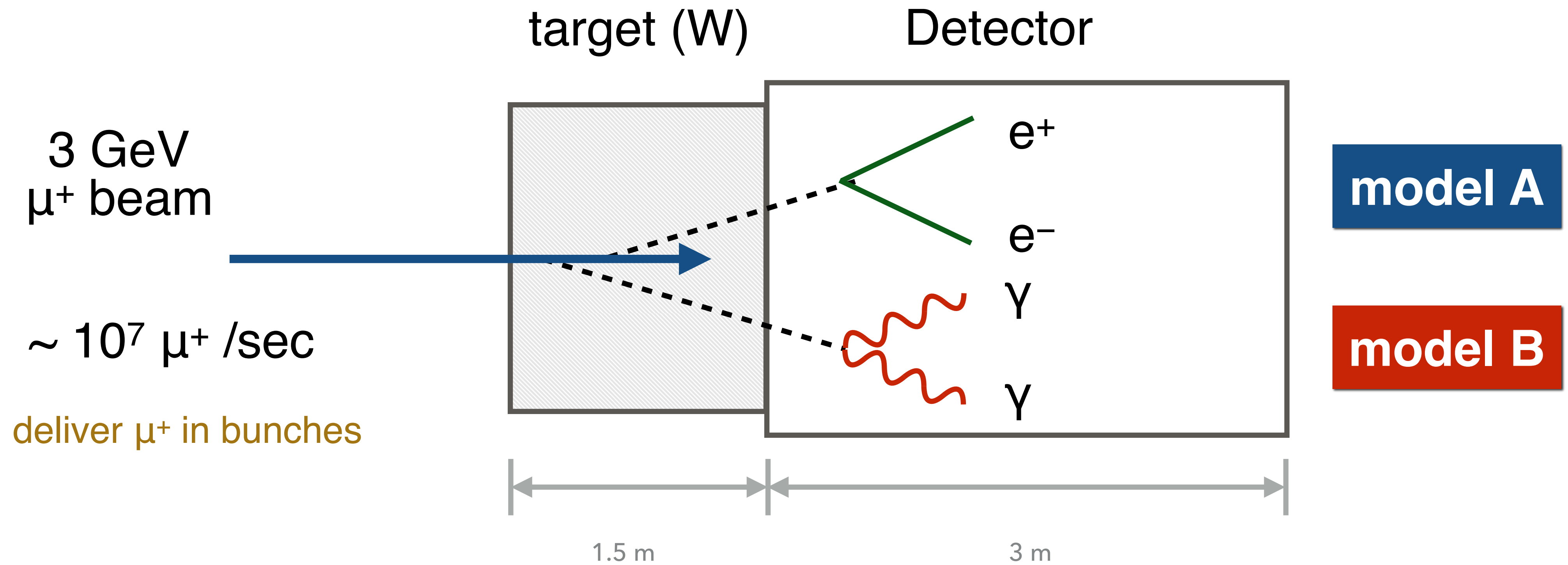
Fermilab setup (FNAL μ)



Tracks from displaced vertices/anomalous energy deposit

Fermilab setup

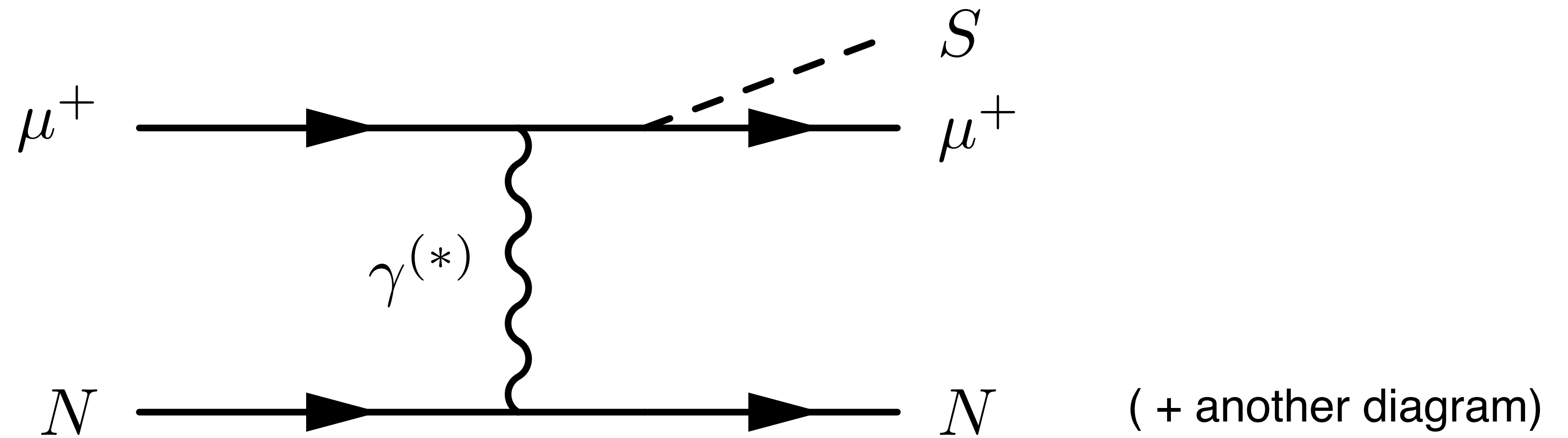
1. *Simple*
2. *Compact (could go into g-2 hall)*
3. *Could run in parallel w/ g-2 exp.*



Tracks from displaced vertices/anomalous energy deposit

Signal

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



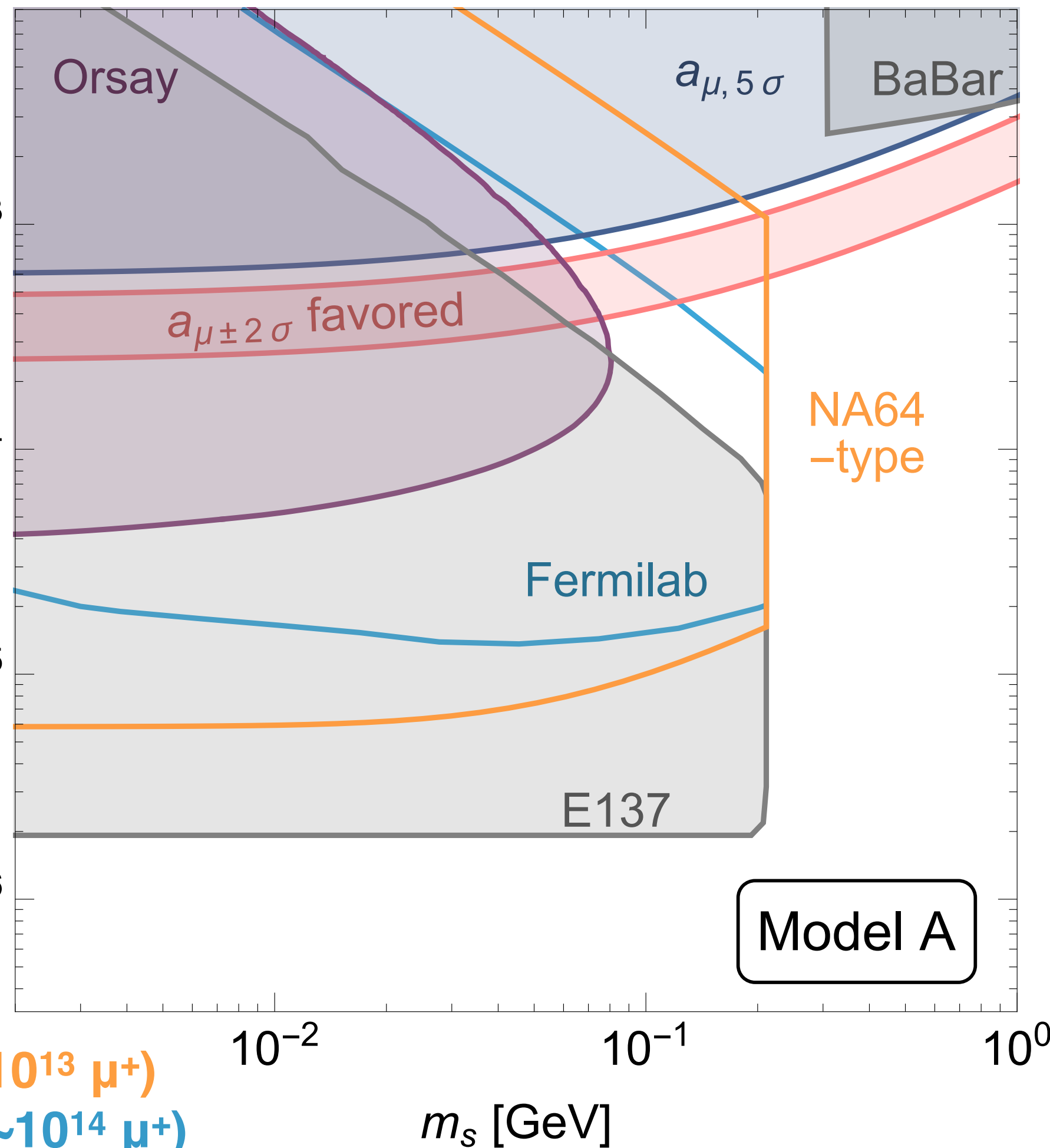
S takes a larger amount of muon beam energy as m_S grows

Backgrounds

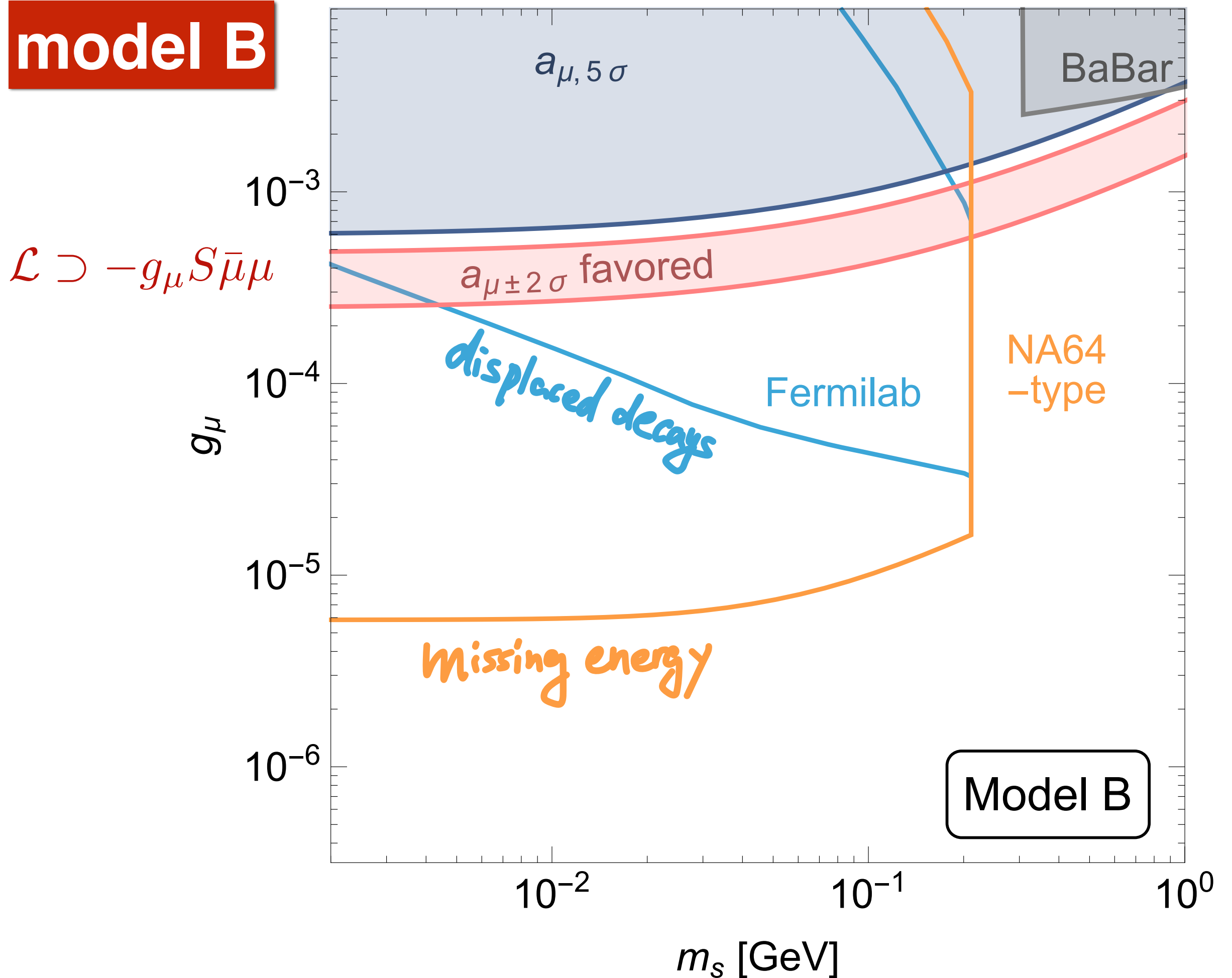
- Long-lived neutral particles / accidental backgrounds
- Negligible backgrounds for our search setups
 - NA64- μ w/ the requirement $E_{\text{miss}} > 50 \text{ GeV}$ Gninenko+ '15
Banerjee+ '17
 - FNAL- μ : We estimate K_L decays are negligible during one-year run

Projected sensitivity to dark scalar

model A



model B



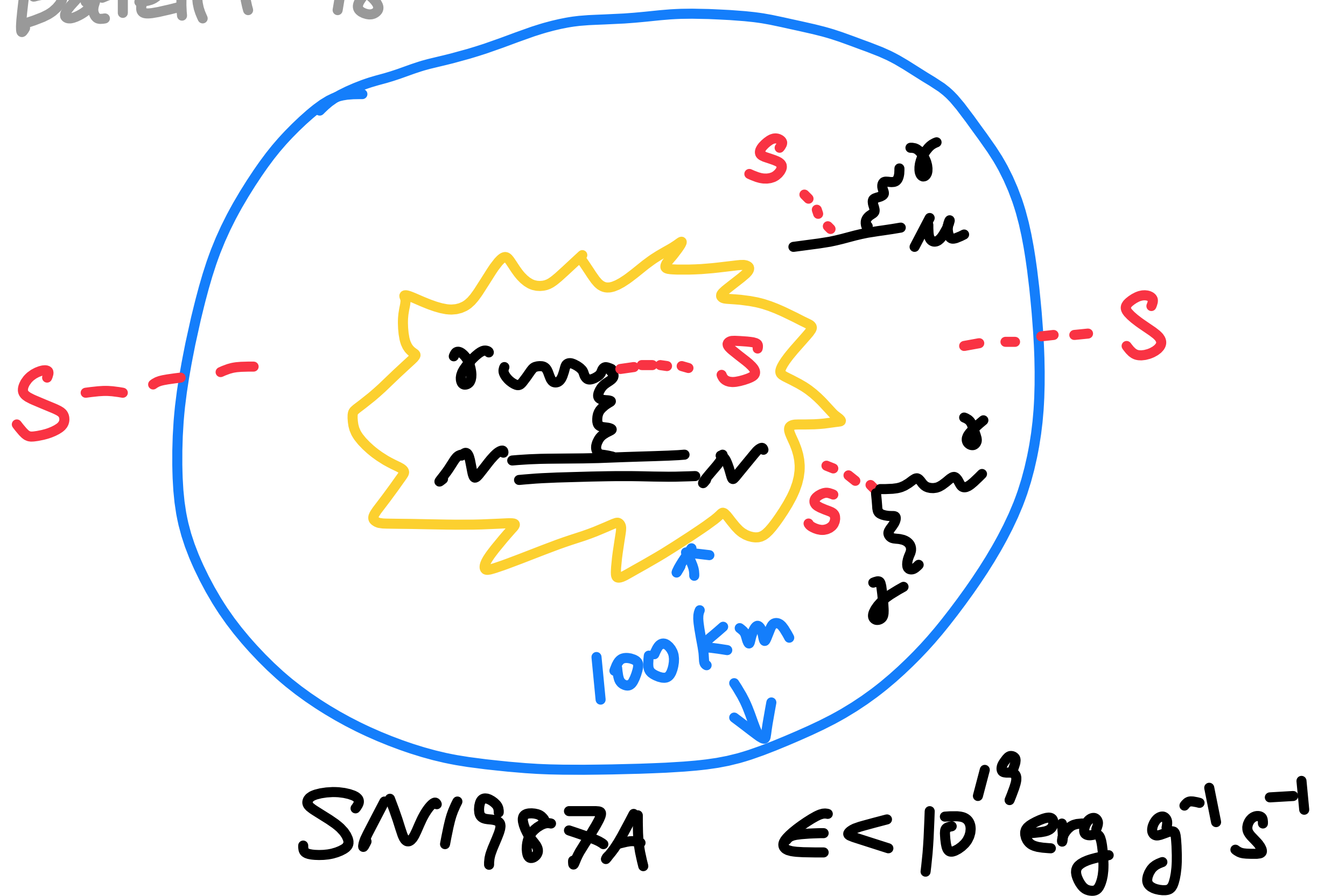
$$\mathcal{L} \supset - \sum_{\ell=e,\mu,\tau} g_\ell S \bar{\ell} \ell$$

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

NA64: 3-month ($\sim 10^{13} \mu^+$)
 Fermilab: 1-year ($\sim 10^{14} \mu^+$)

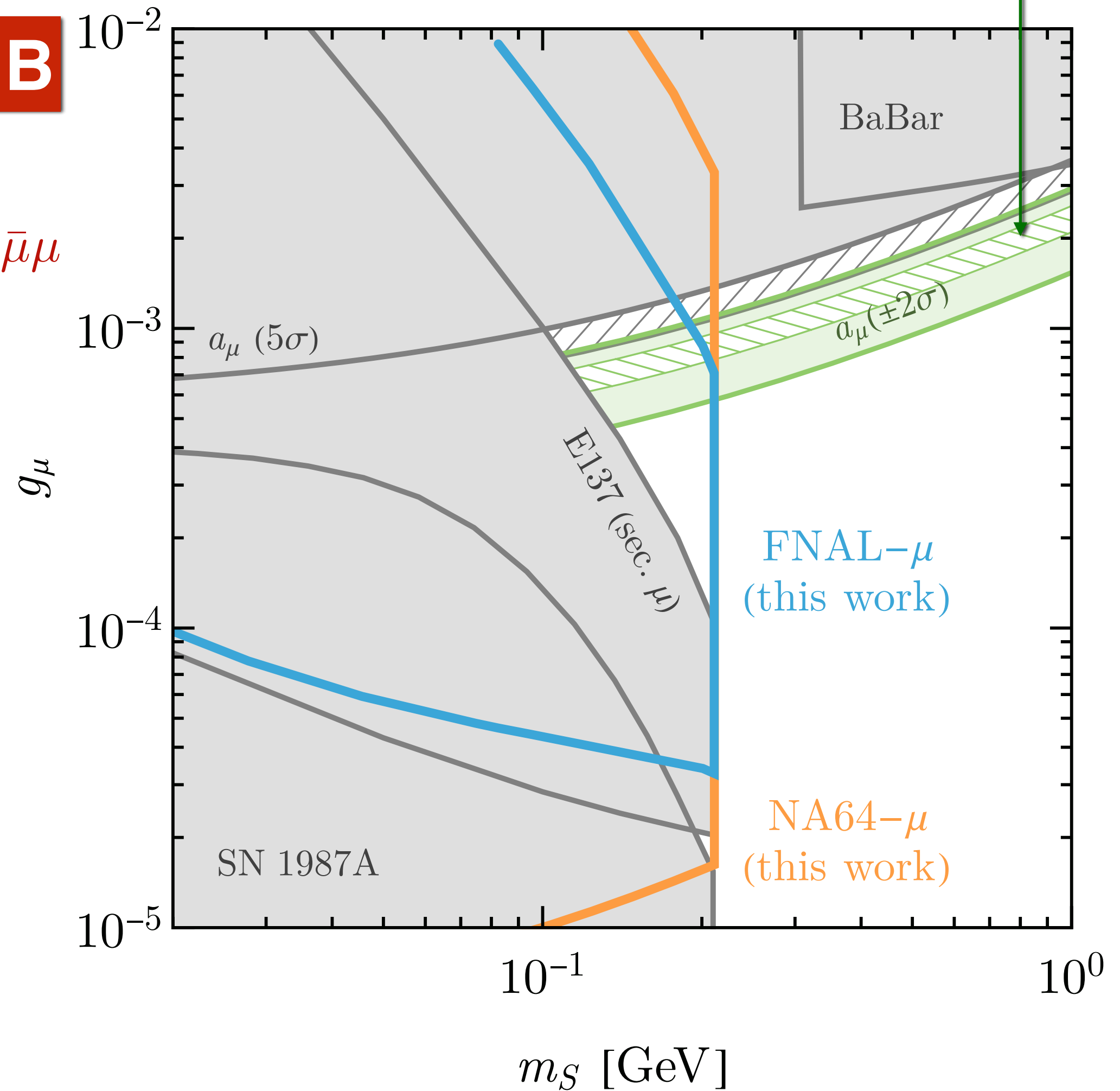
Projected sensitivity to dark scalar

Battell + '18



model B

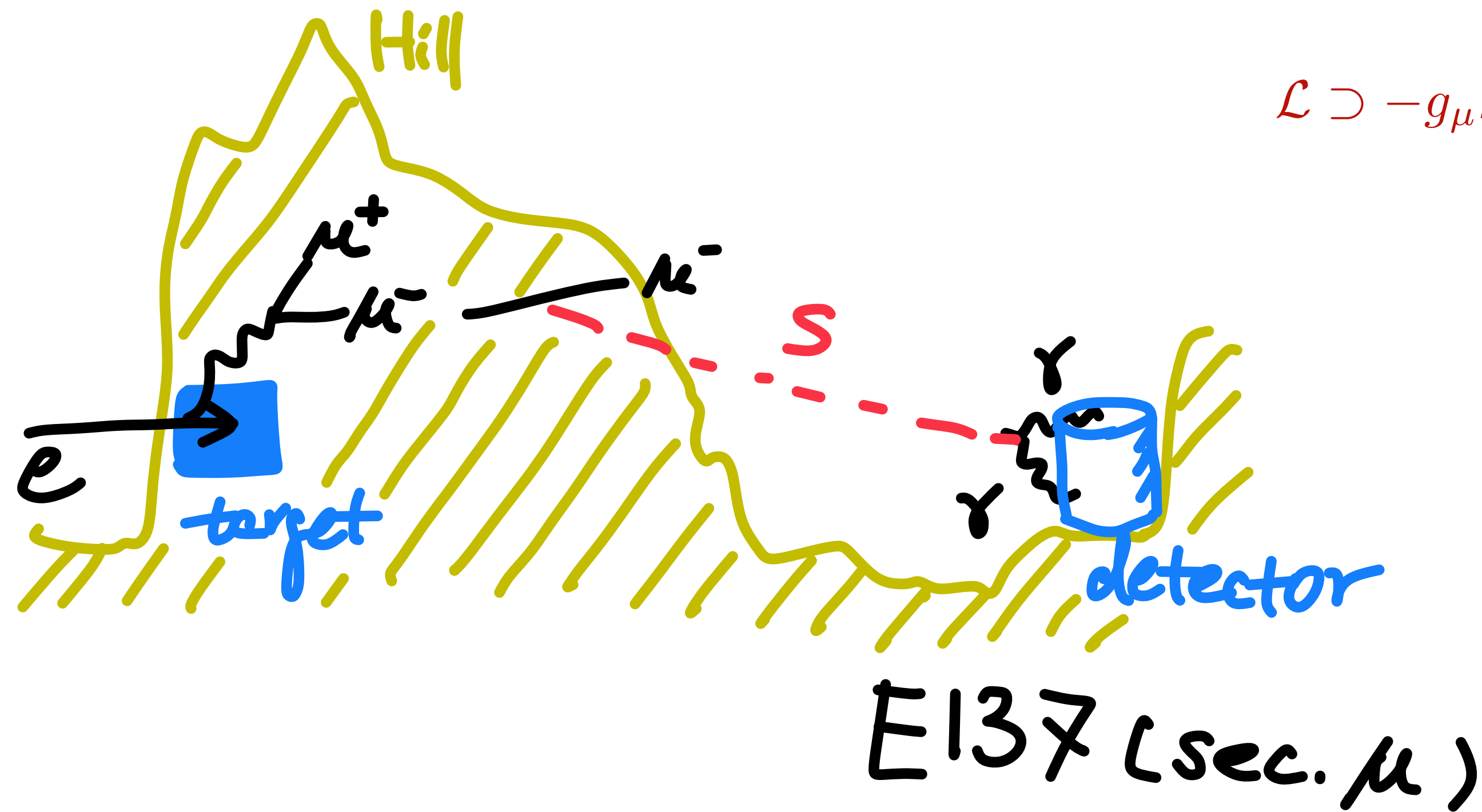
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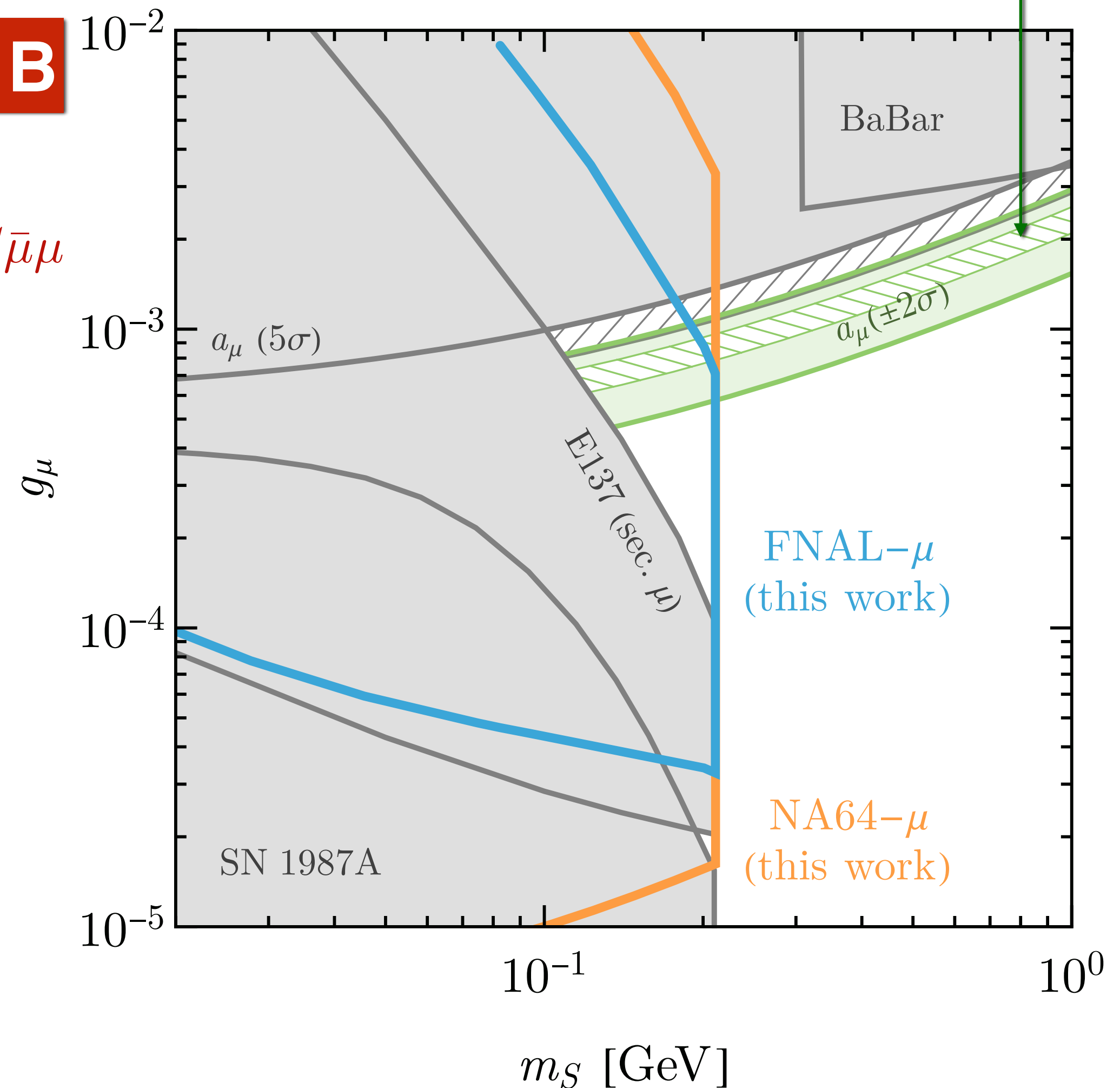
Projected sensitivity to dark scalar

Marsicano (YZ) + '18



model B

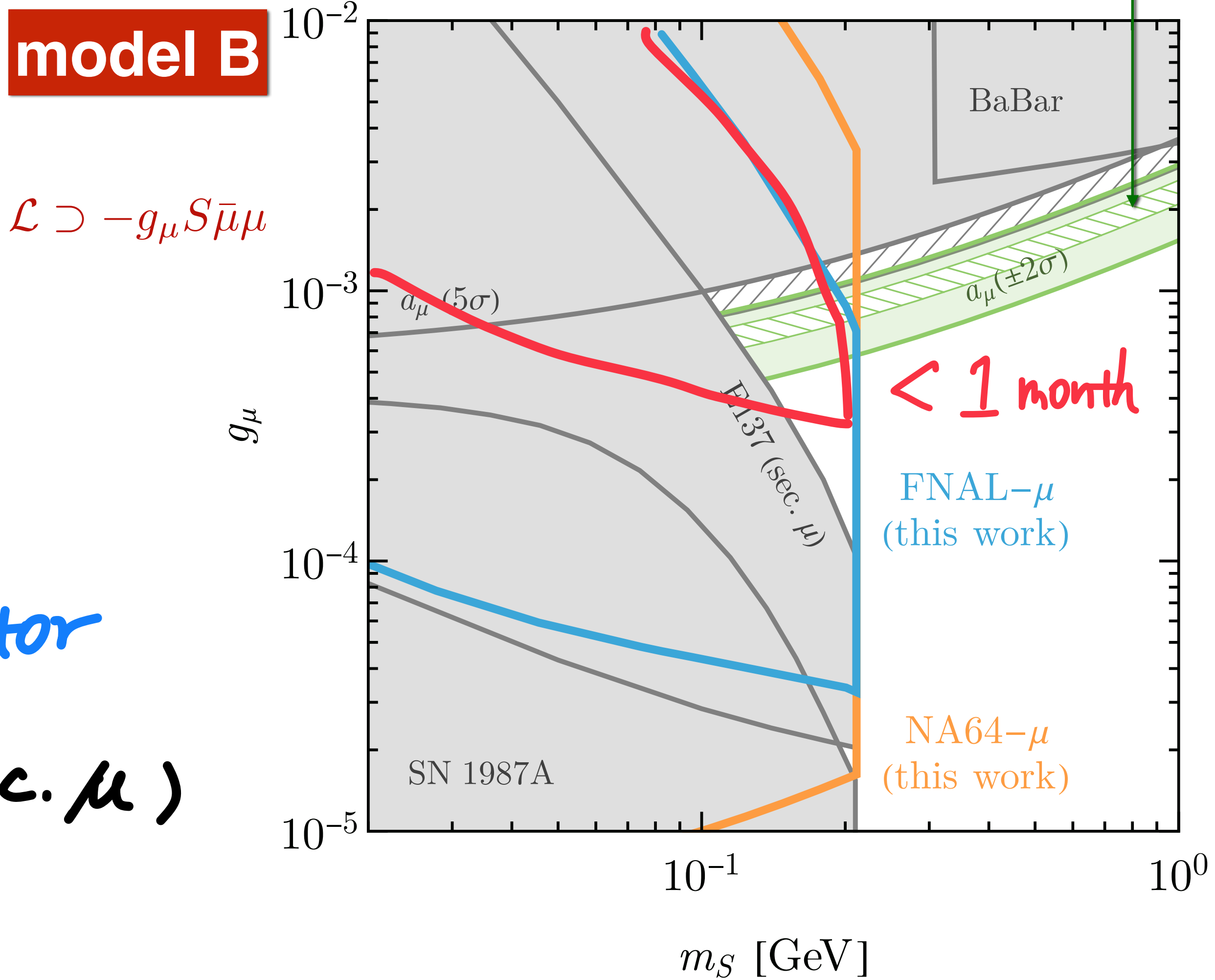
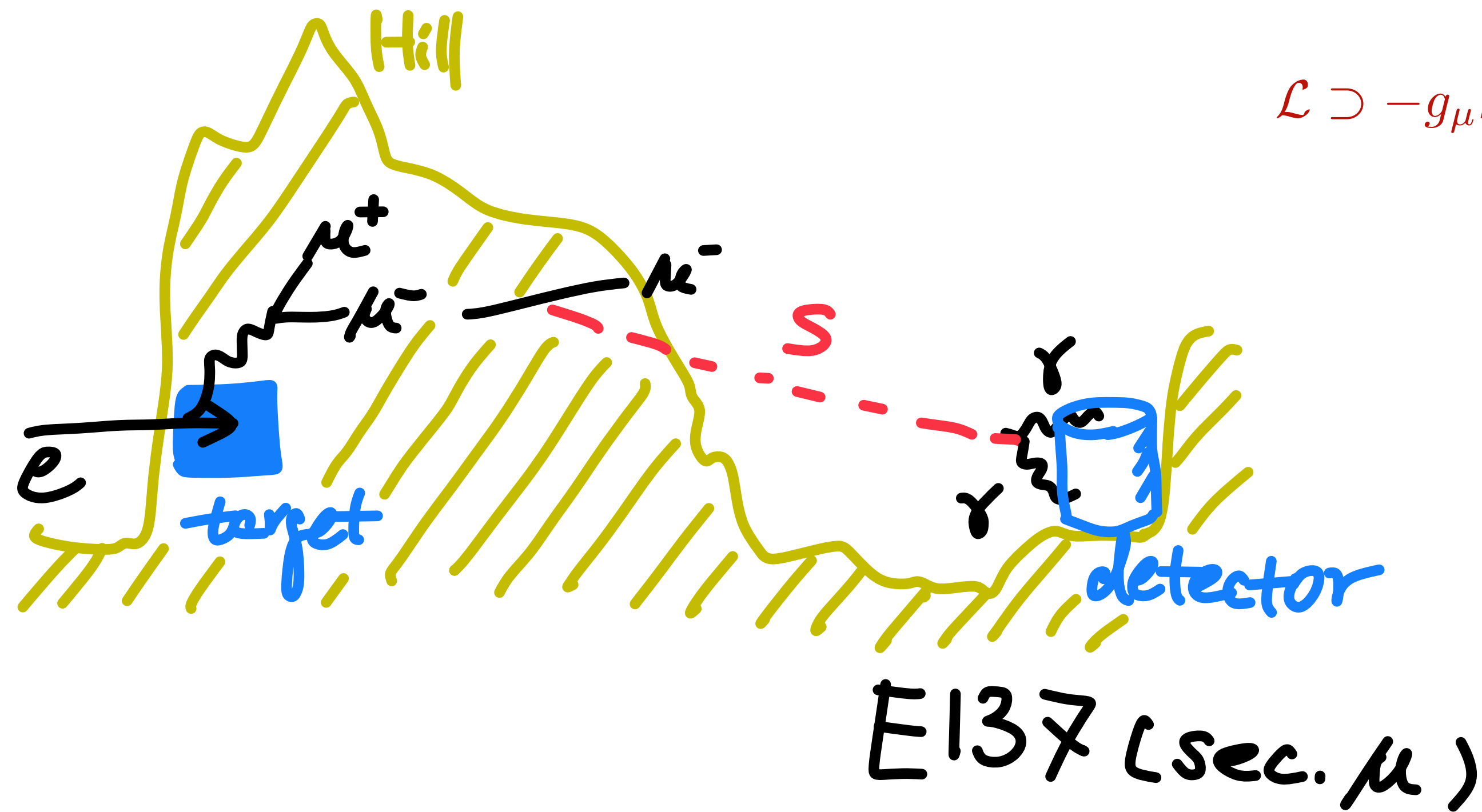
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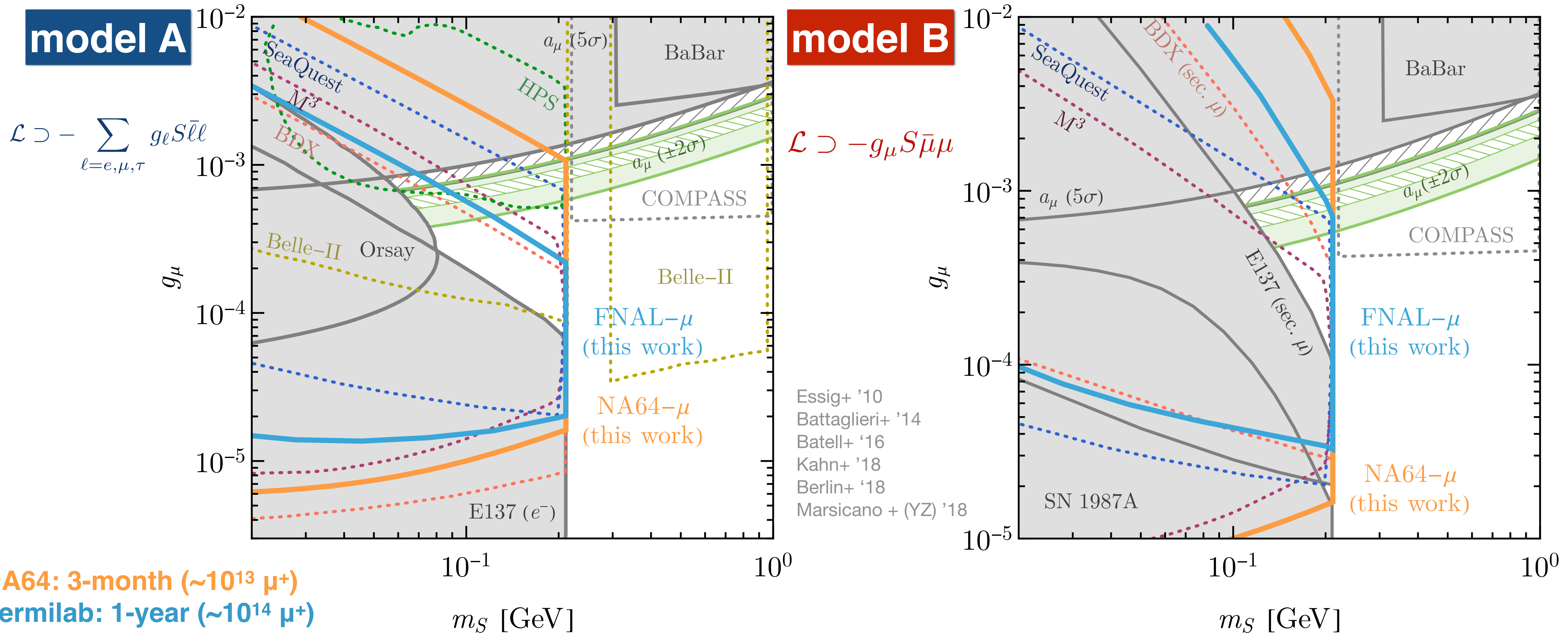
Projected sensitivity to dark scalar

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Projected sensitivity to dark scalar



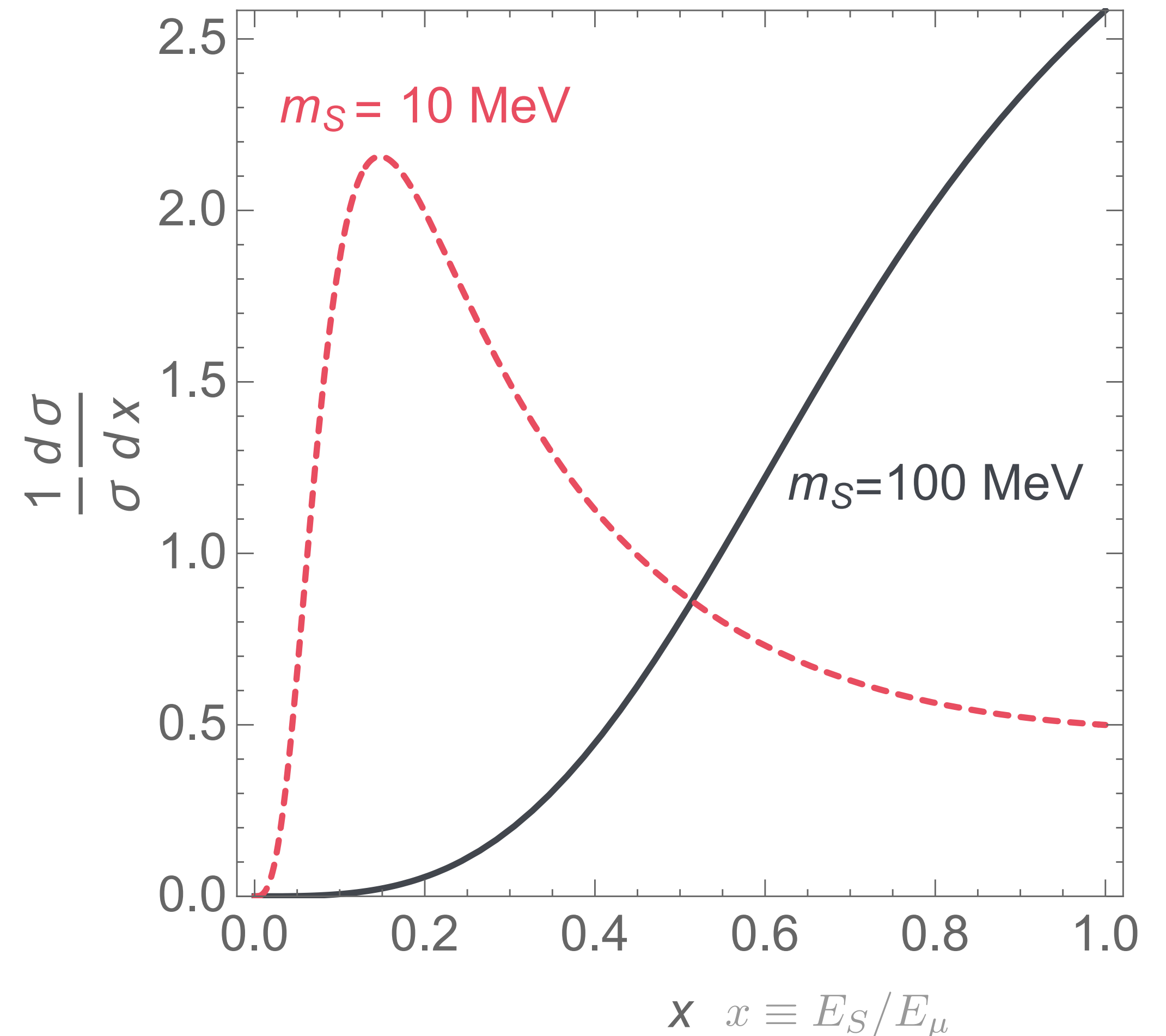
Summary

- 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.
- FNAL μ can be easily implemented at existing FNAL muon campus infrastructure w/ modest modifications/additions.

Backup

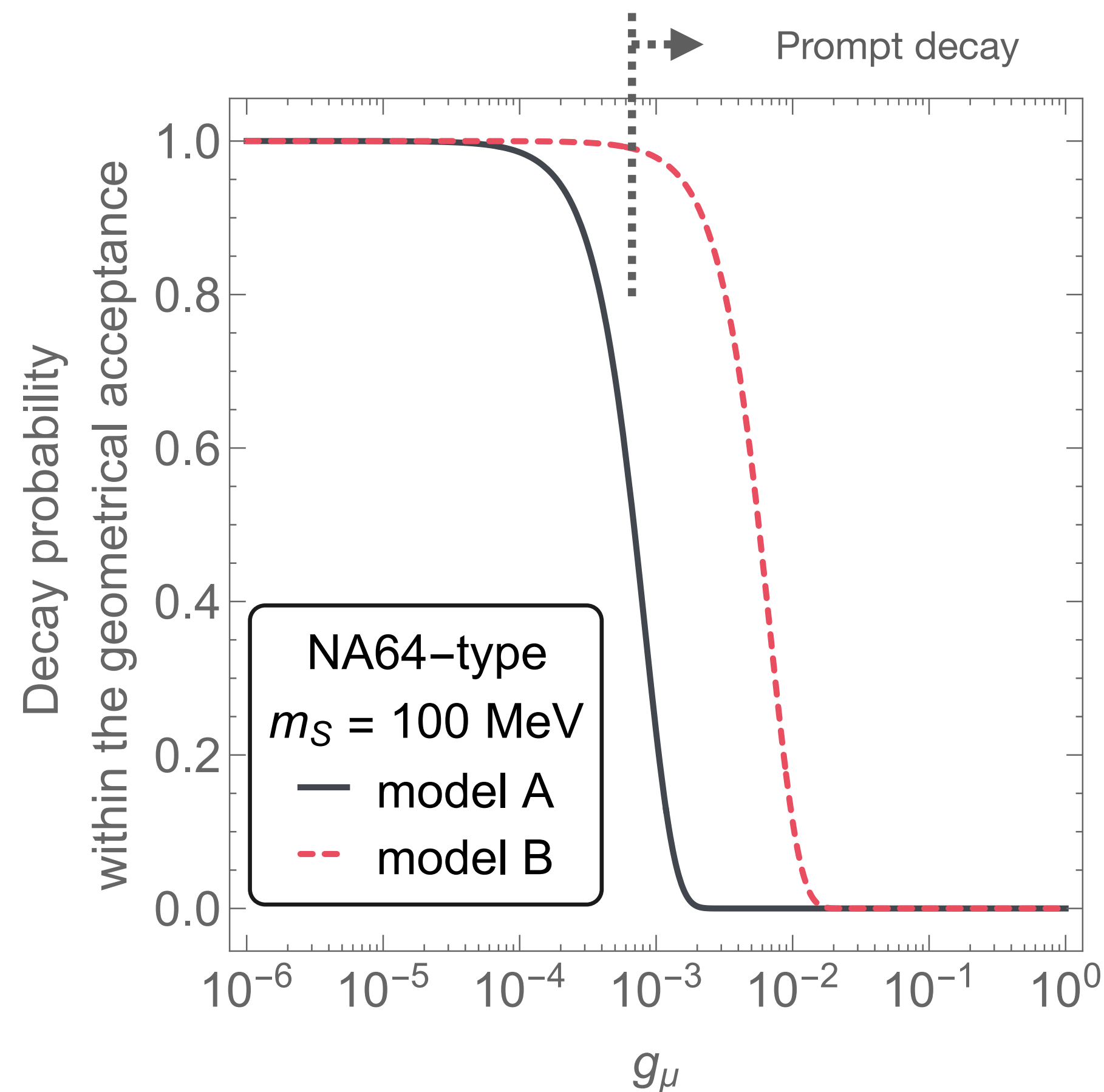
Signal

- 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

