Dark Sector Searches via Muon Beam-Dump Experiments

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Accumulated muon anomalies

Muon related-anomalies appear in several low-energy experiments:

- Muon anomalous magnetic moment (a_μ) — Bennett et al '06, Davier et al '09, Hagiwara et al '11, Blum et al '13
- Muonic hydrogen Lamb shift — Pohl et al '10, Mohr et al '15
- Lepton flavor non-universality in B-decays — LHCb '14

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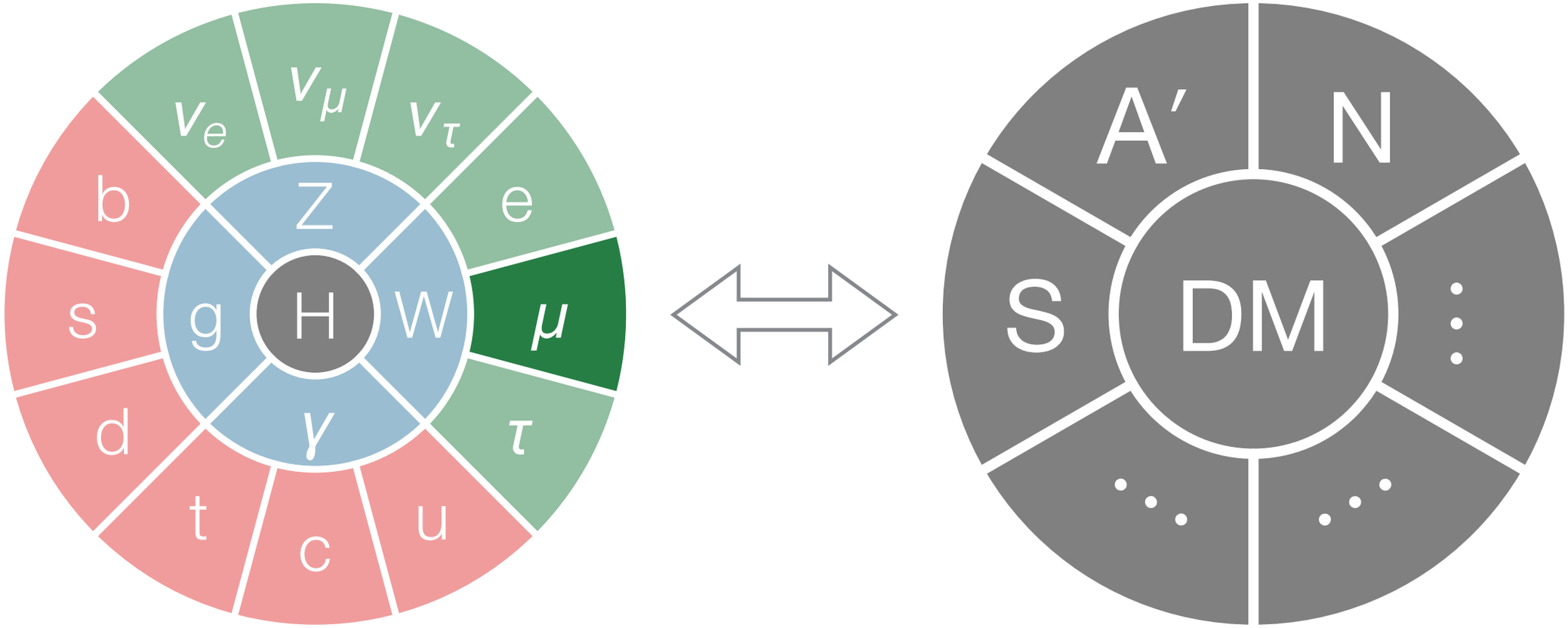
How to interpret?

- from statistical/systematical/theoretical uncertainties…

e.g. Randolf et al ’13, Carlson ‘15

- or

from particle fever

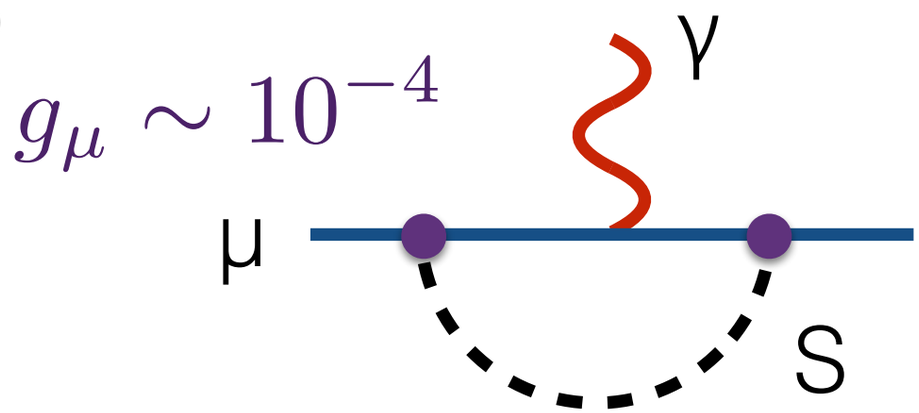


e.g. Pospelov ’09, Tucker-Smith & Yavin ’10, Sierra et al ’15, Crivellin et al ’15, Liu et al ’16

Minimal model to solve a_μ anomaly

- Introduce a **new** light scalar S
  $(\mathrm{MeV} < m_S < 2m_\mu)$

- Couples to μ's, not quarks



model A

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

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

lepton-specific two-Higgs-doublet model (2HDM)

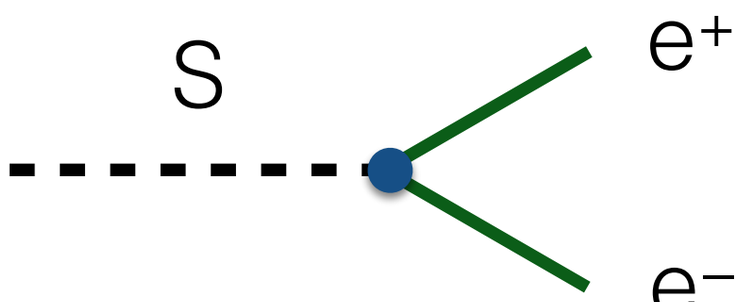
model B

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

can be realized in lepton-specific 2HDM
w/ min flavor violation
Cirigliano et al '05, Liu et al '16

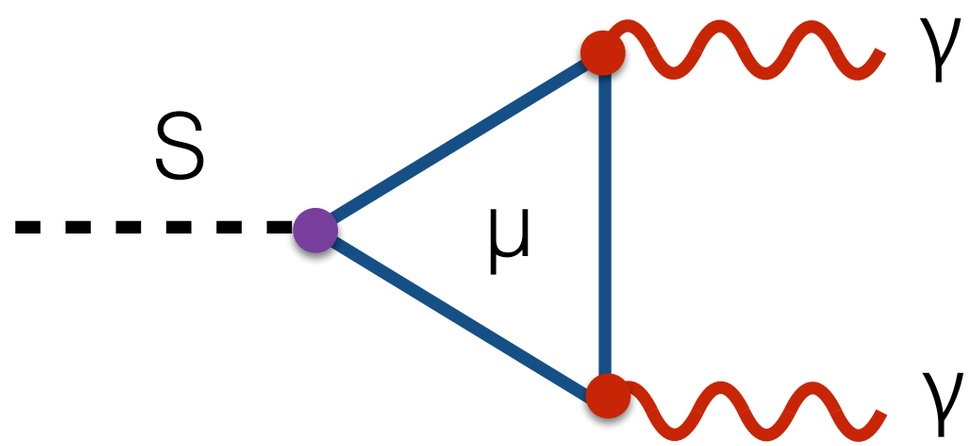
Dominant decay mode ($m_s < 2m_\mu$)

model A



m_e-suppressed

model B



loop-suppressed

for $g_\mu \sim 10^{-4}$, $m_S \sim 100$ MeV

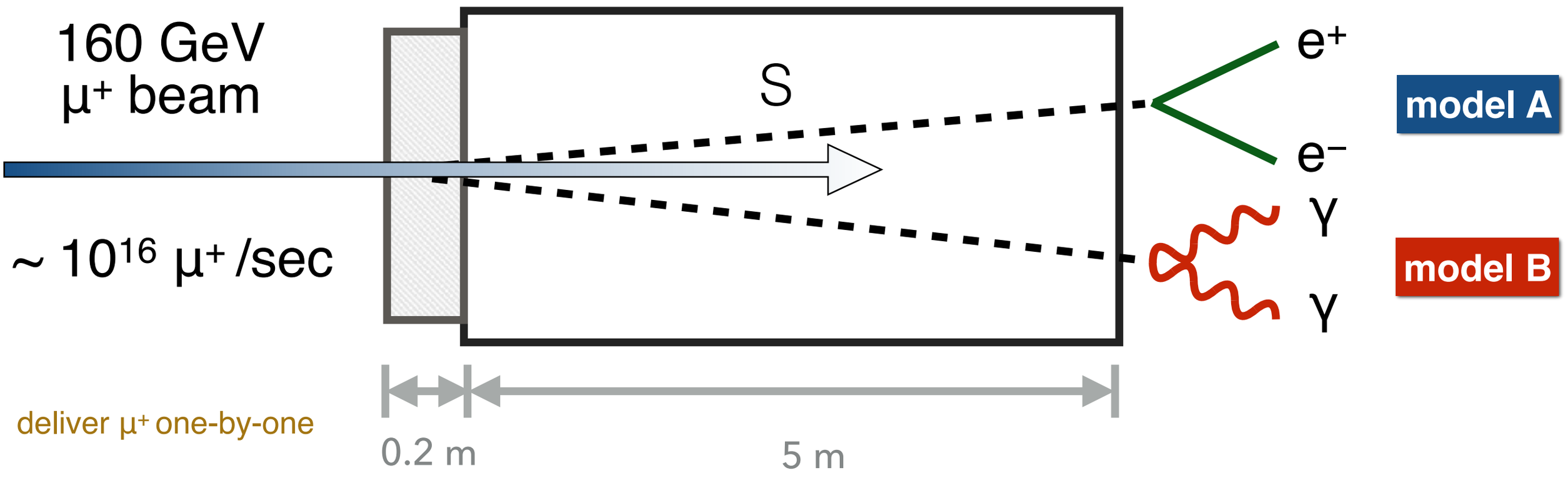
decay length: O (10 cm) ~ O (10 m)

Look at muon-beam dumps

- Muon-beam dump experiments are good place to look for dark scalars in model A & B:
  - focus on the couplings to muons
  - sensitive to displaced decays
  - can be integrated to other muon experiments
- **We look into two searches**

NA64 setup

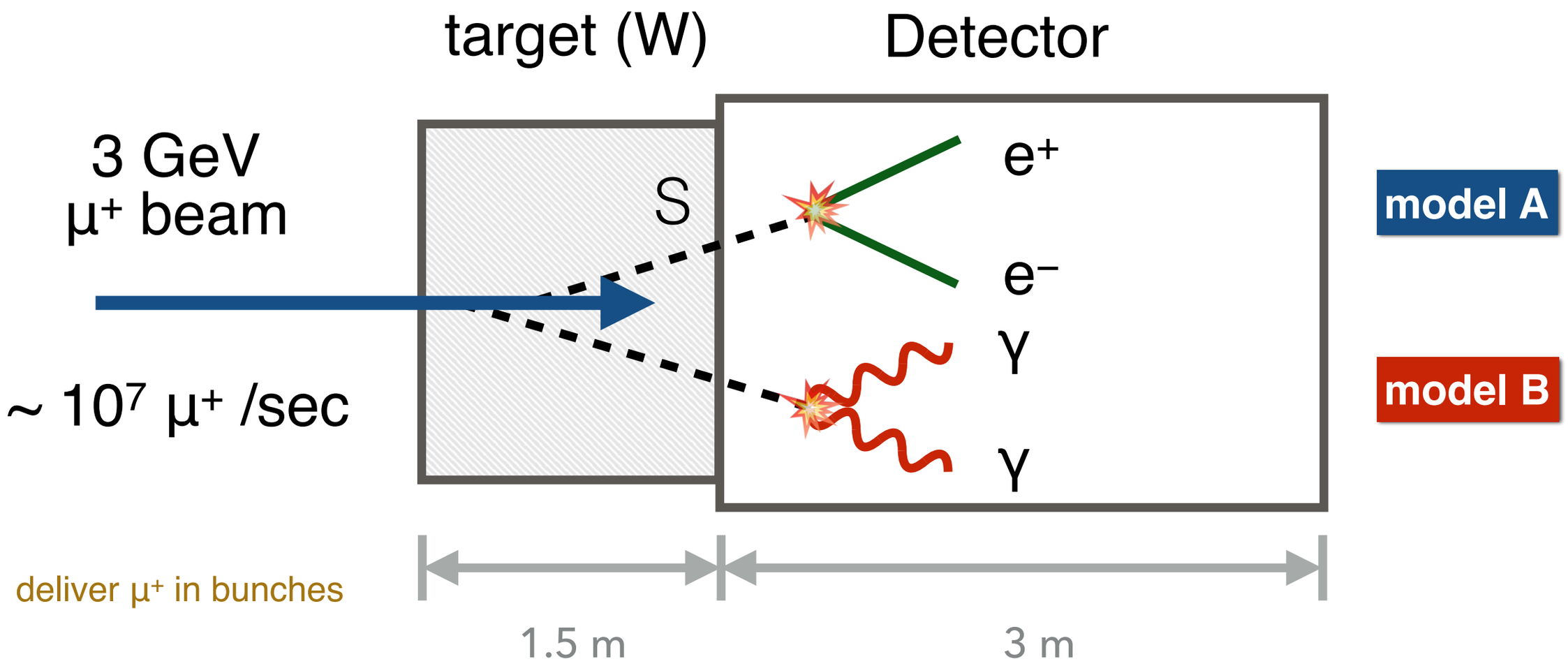
NA64 is a fixed-target experiment at CERN



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

Fermilab setup

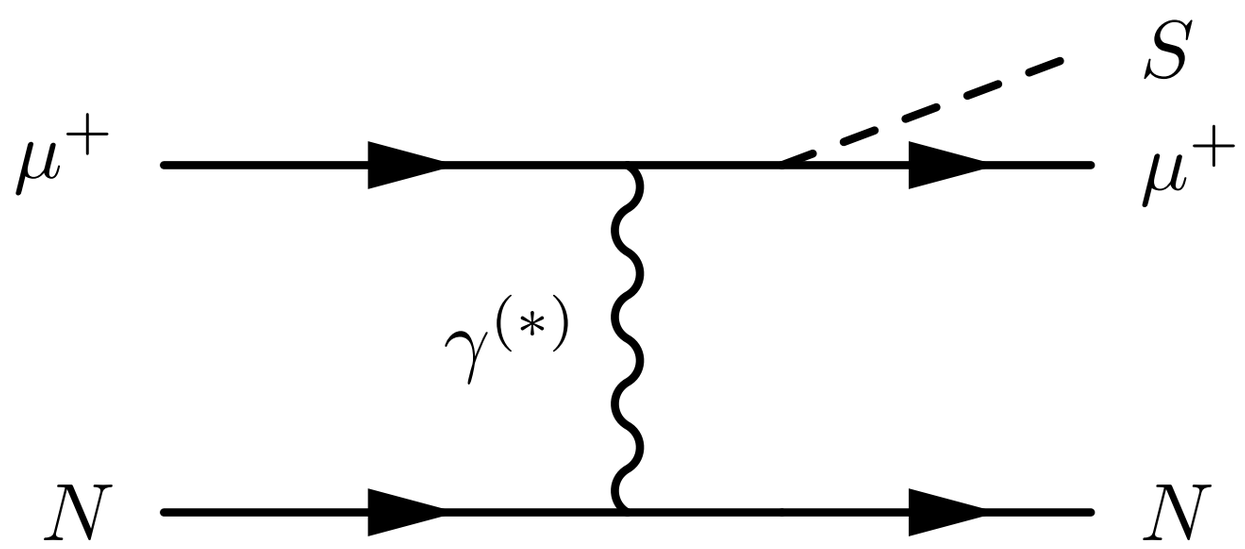
Fermilab runs several muon experiments (e.g. muon g-2)



Tracks from displaced vertices/anomalous energy deposit

Signal & backgrounds

- Signal:



MeV < m_s < $2m_\mu$

(+ another diagram)

- Backgrounds: kaon decays, accidental bkgs
  - NA64: require E_{miss} > 50 GeV

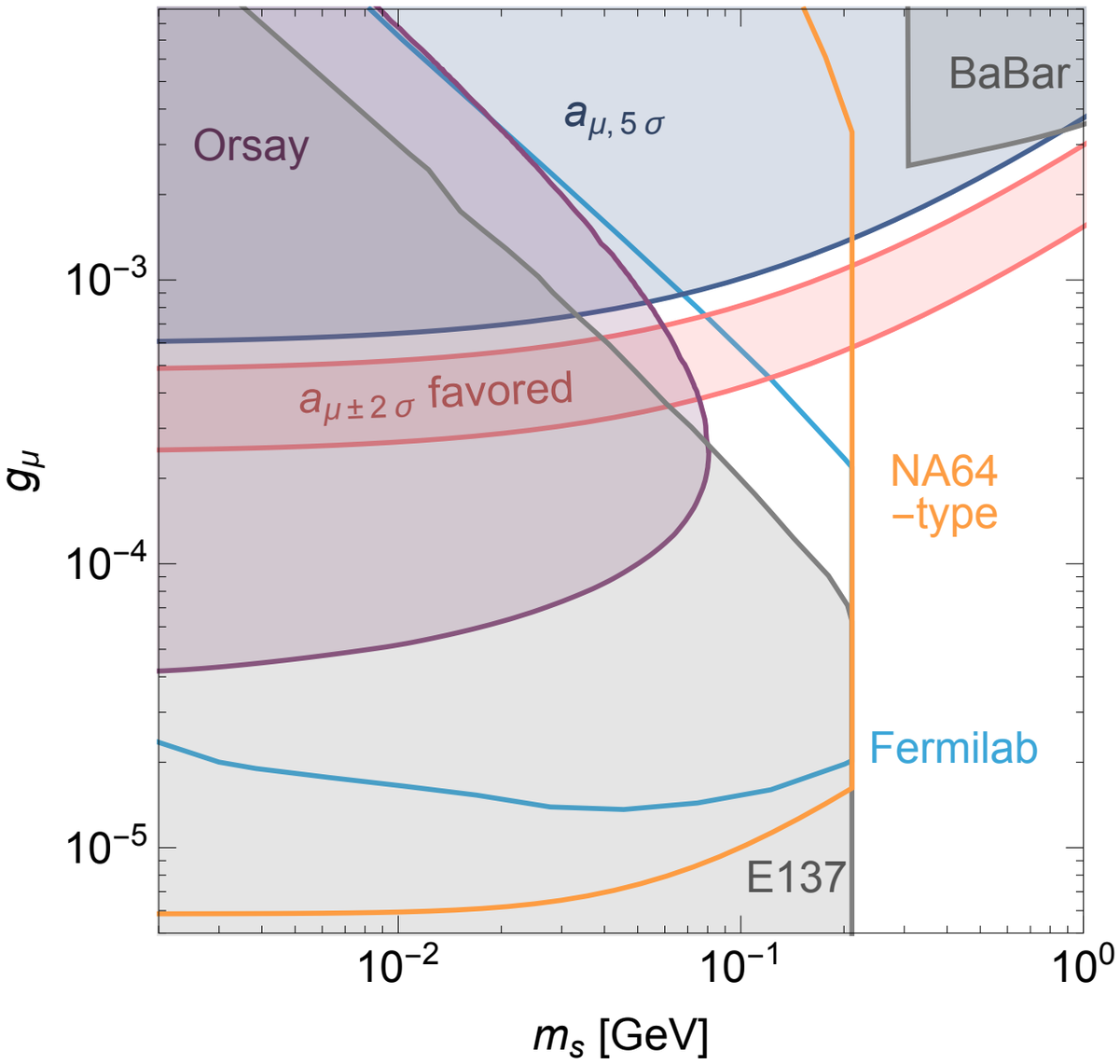
Gninenko et al ’15
Banerjee et al ’17

  - Fermilab: kaon decays are negligible

Projected sensitivity to dark scalar

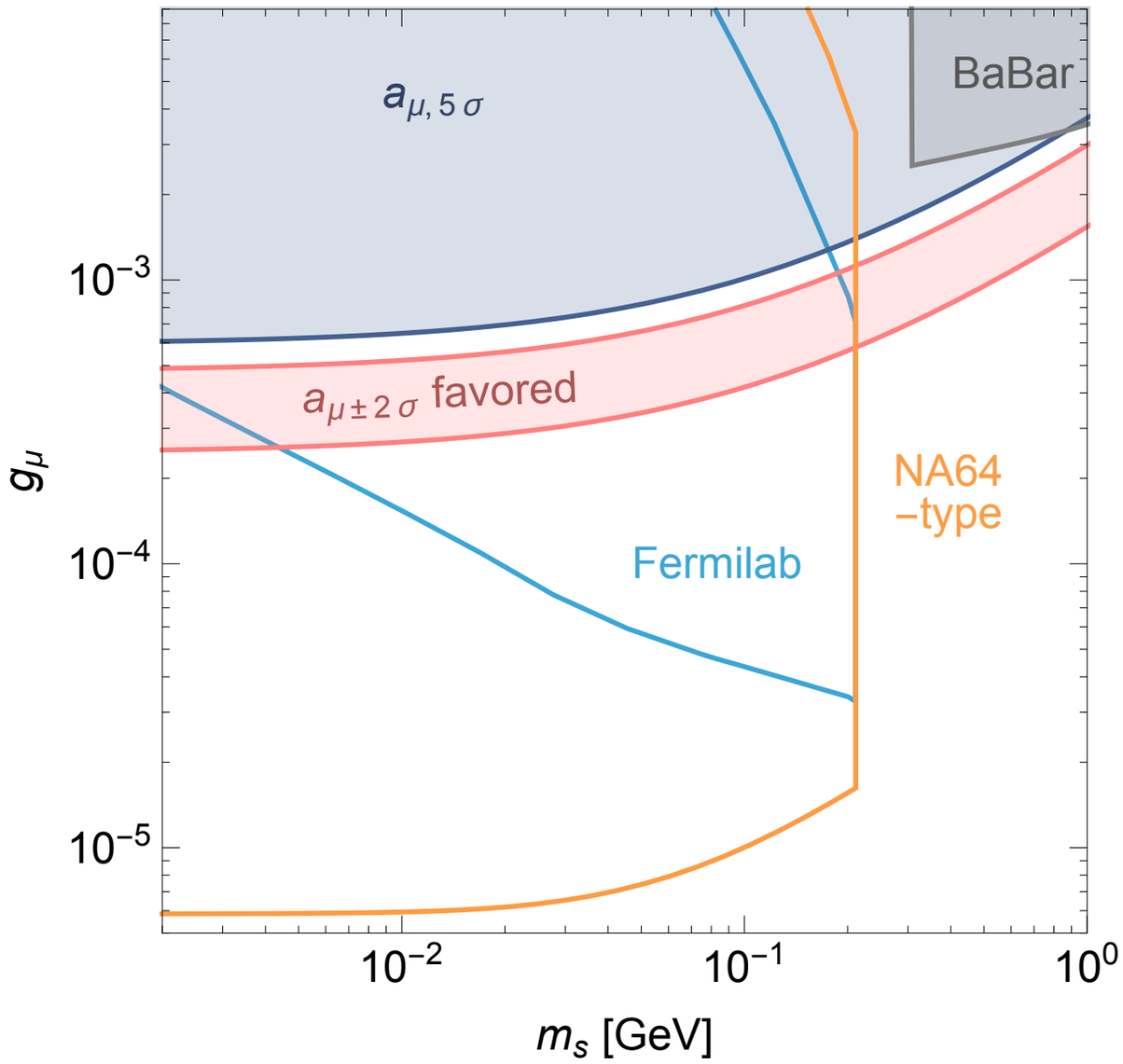
model A

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



model B

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



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

Summary

- Several anomalies in low-energy experiments point to muons. They may imply the existence of light dark particles w/ muon coupling.

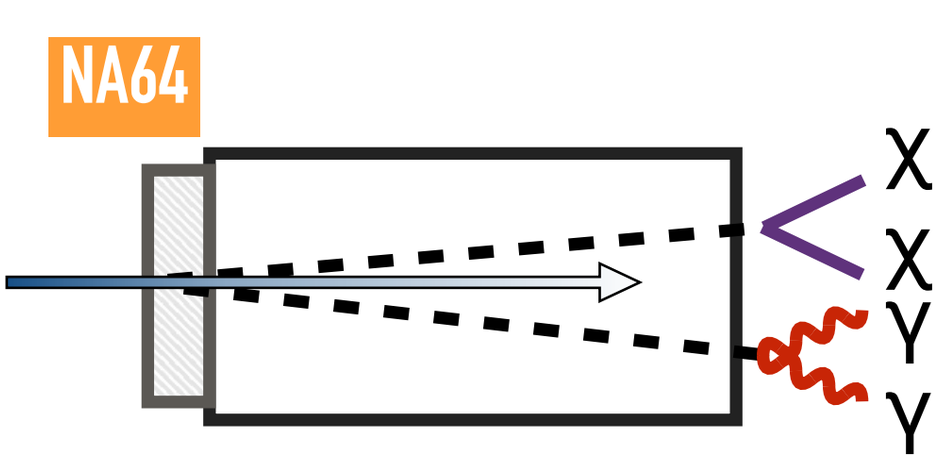
- Muon beam-dump experiments can effectively probe dark scalars, w/ predominant muon coupling, that explain a_μ anomaly

- Muon beam-dump experiments can be integrated into other muon experiments

Backup

Projected sensitivity to light DM

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



$$(m_S, m_\chi, g_\mu, g_\chi)$$