New Muon Beam Missing Momentum Experiments @ FNAL

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

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arXiv:1803.XXXXX

Precision Science Discussion Mar 20, 2018

Overview & Motivation

1) Model independent test of g-2 anomaly

2) Probe models of muon-philic dark matter

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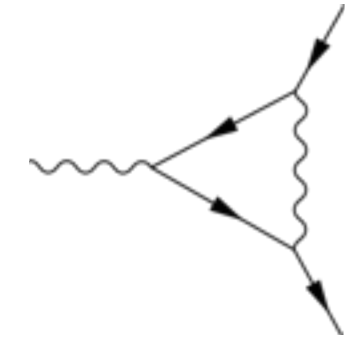
Muon Anomalous Magnetic Moment



Longstanding $\sim 3.7 - 4.1\sigma$ anomaly in $(g-2)_\mu$

Theory updates have only widened disagreement

$$a_\mu \equiv a_\mu(\text{obs}) - a_\mu(\text{SM}) = (28.8 \pm 8.0) \times 10^{-10}$$

Mangano, Keshavarzi, Nomura, Teubner 1802.02995

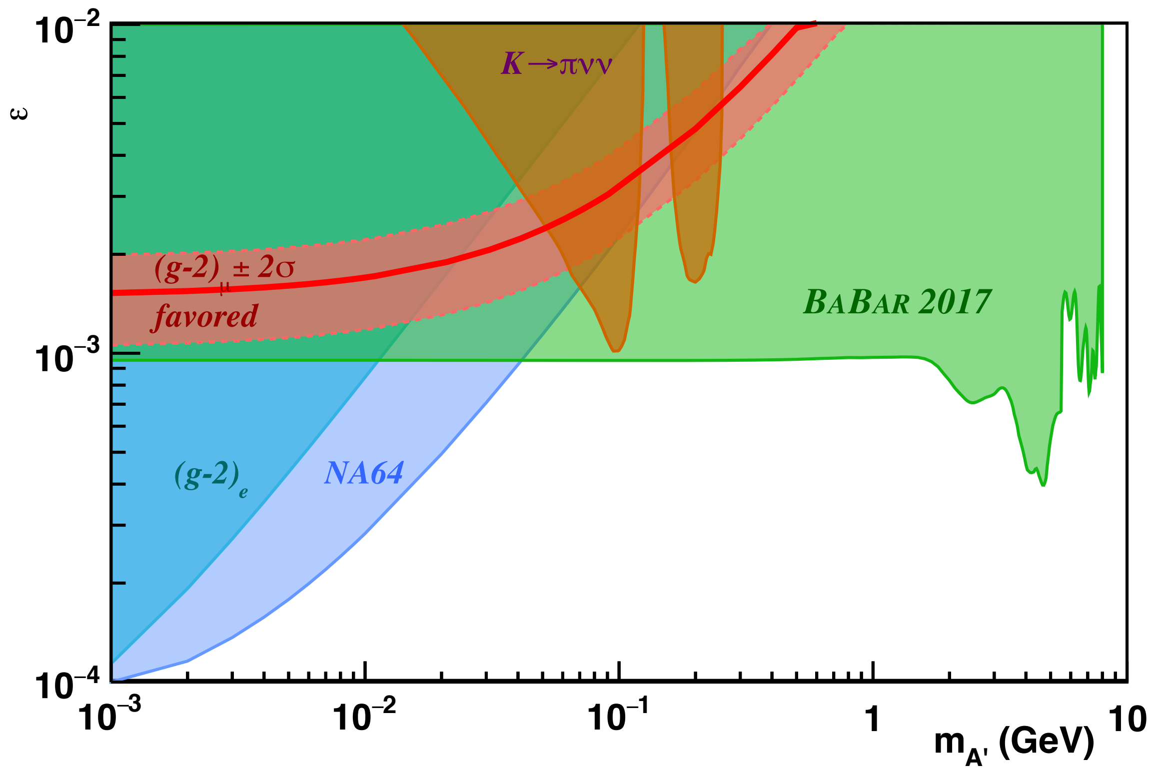
$$a_\mu \equiv a_\mu(\text{obs}) - a_\mu(\text{SM}) = (31.3 \pm 7.7) \times 10^{-10}$$

Jegerlehner 1705.00263

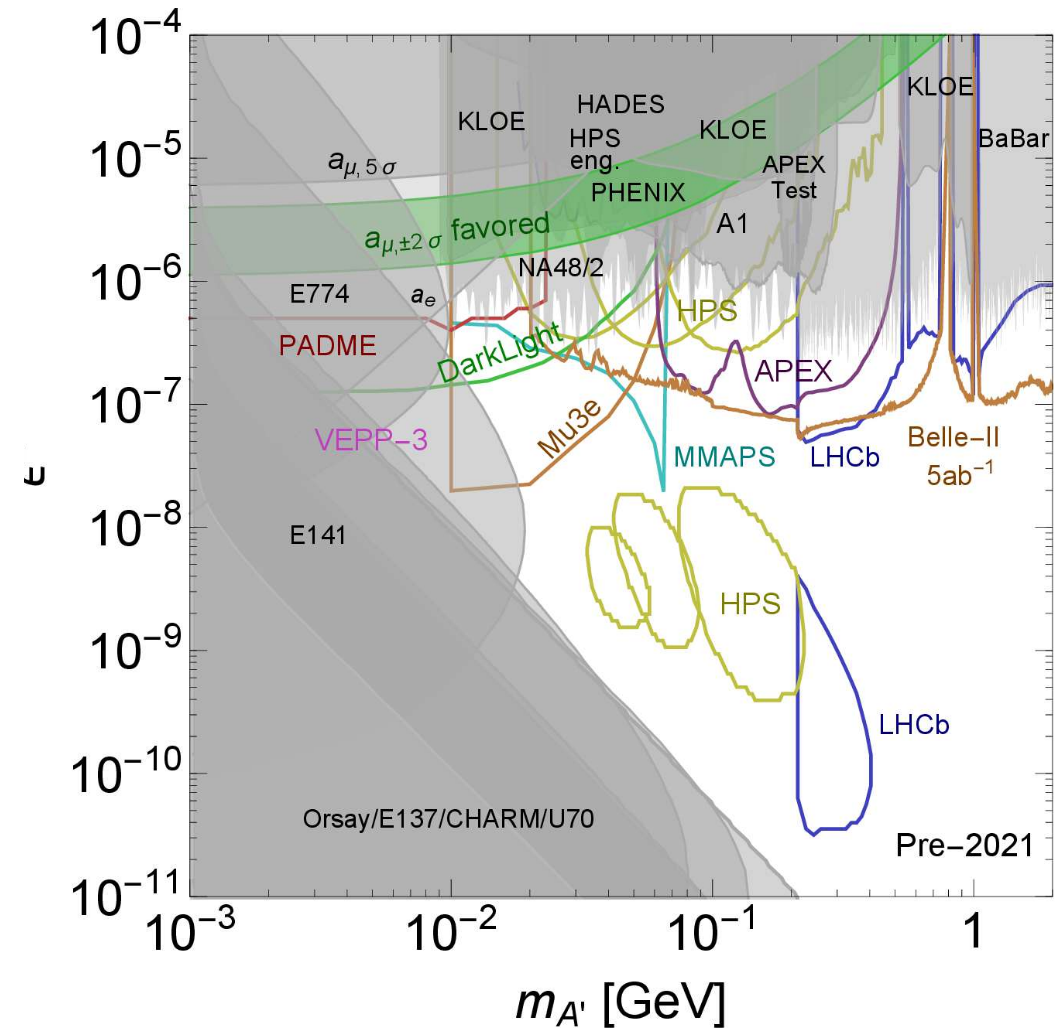
Remains a great hint of possible new physics

Soon FNAL g-2 experiment will shrink error bars

Many popular new physics *models* are now ruled out…



BABAR:1702.03327
Cosmic Visions 1707.04591

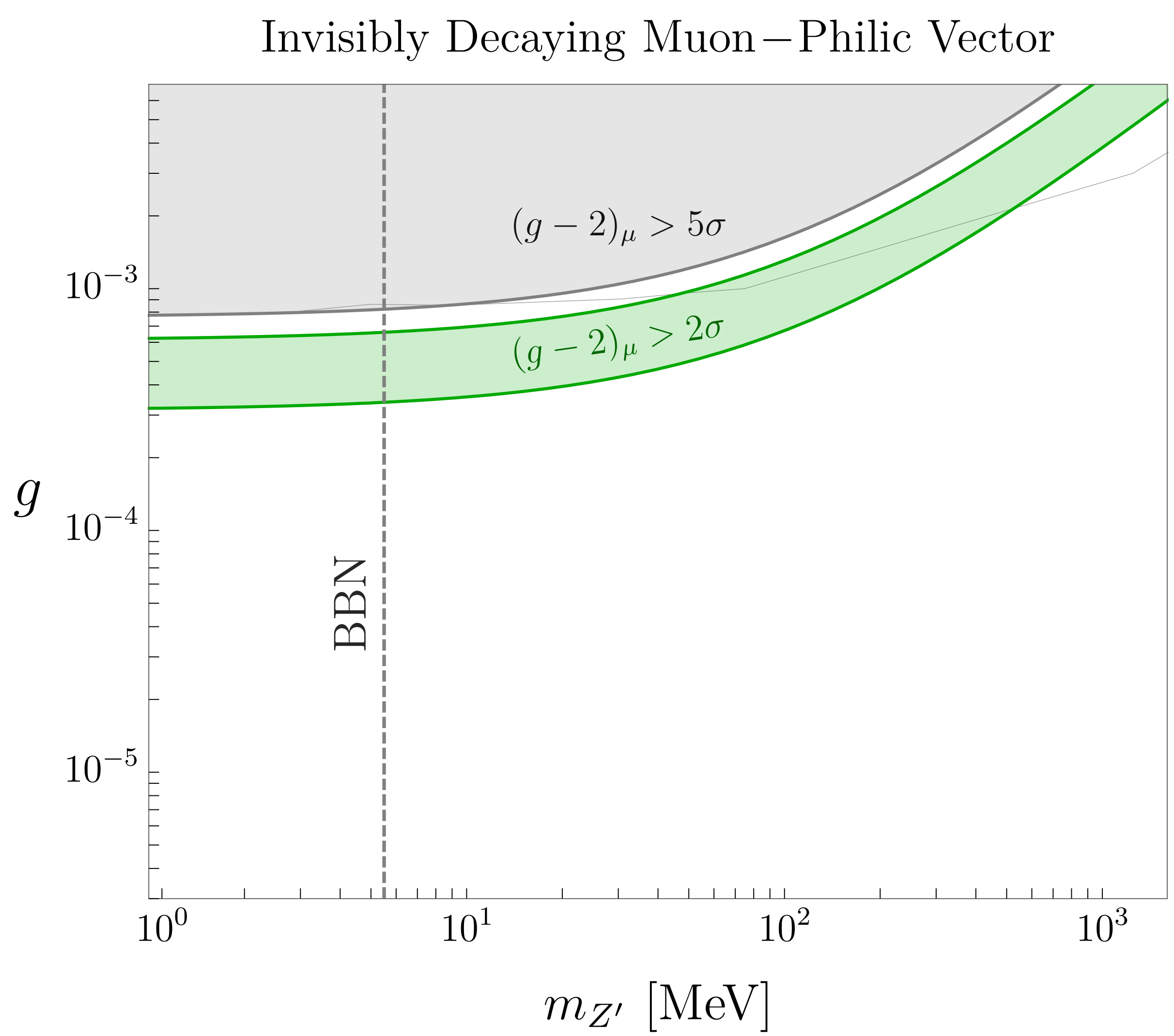


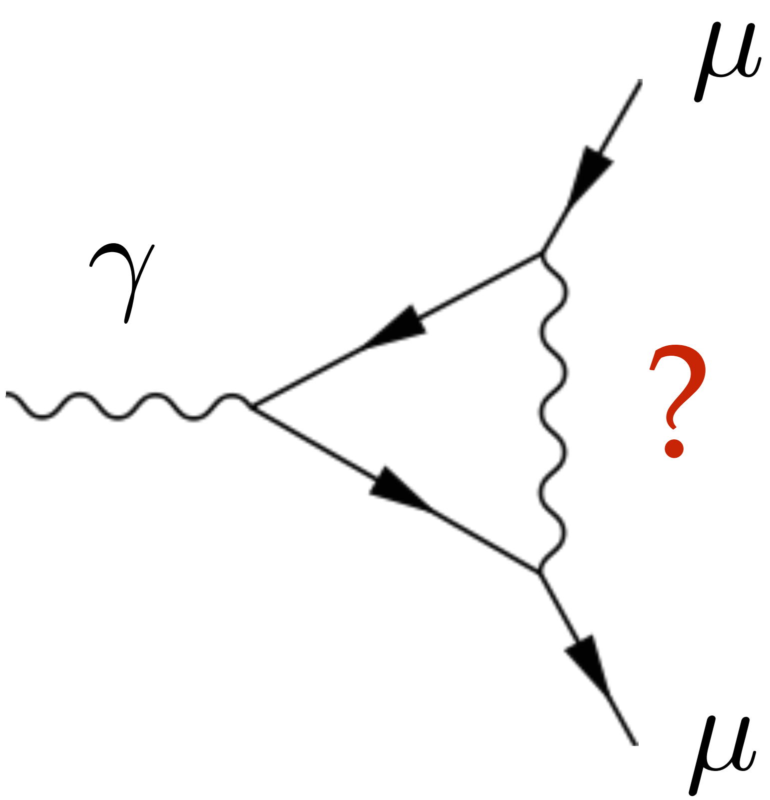
Weak scale models also under tension (e.g. MSSM)

Conclusions based on **first-generation** measurements

Motivates better understanding muon-philic interactions

Best viable BSM explanation: new muon-philic particles

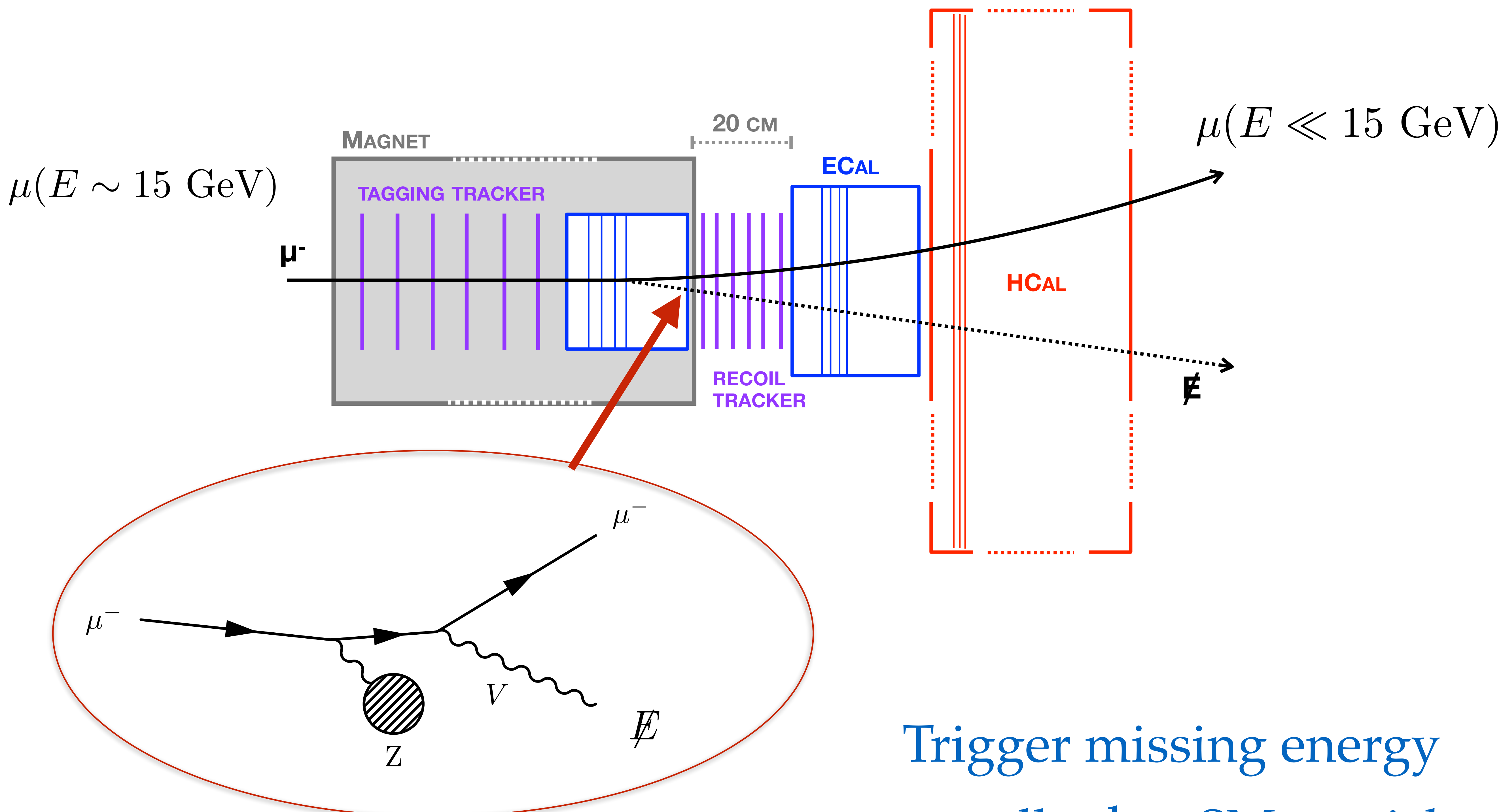




New particle couples to muons & decays invisibly

How do we directly test this scenario?

Basic Setup: muon beam incident on fixed target



Trigger missing energy

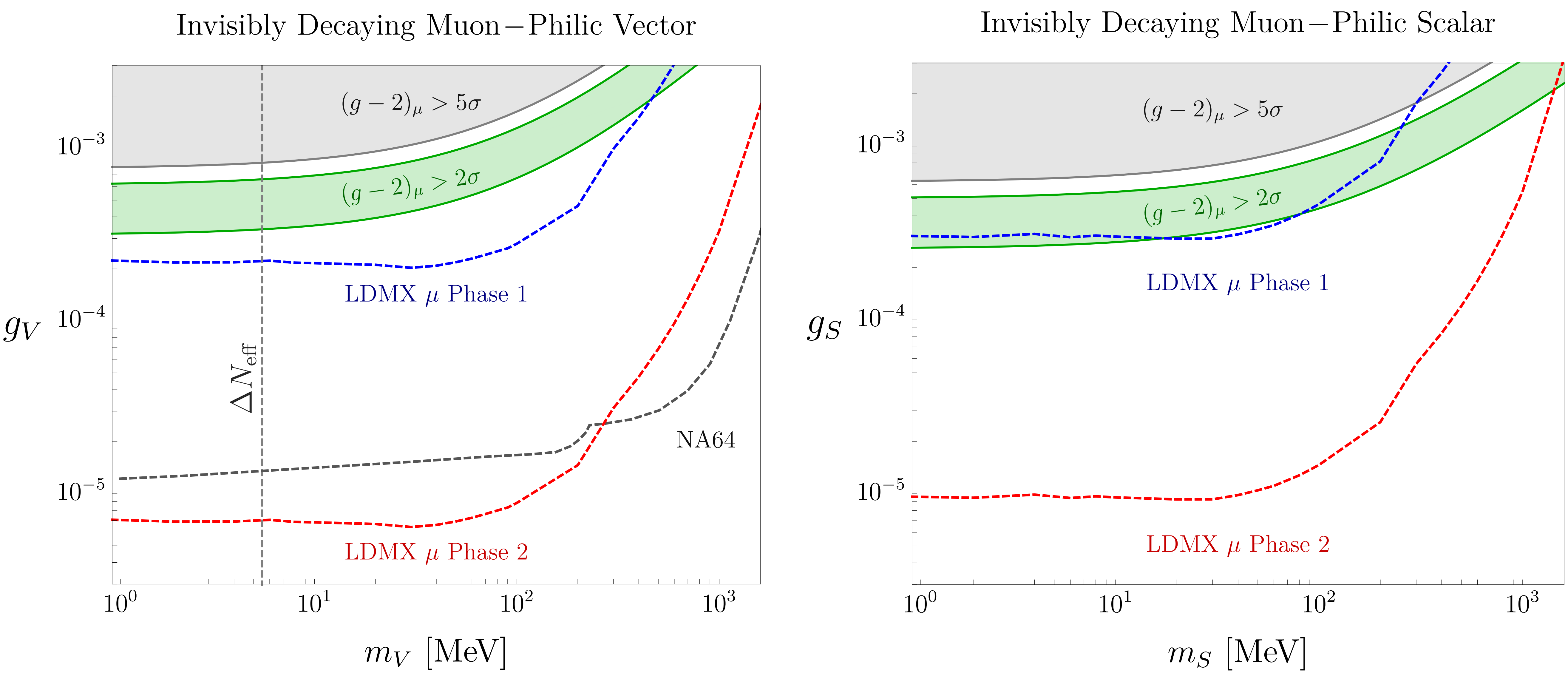
veto on all other SM particles

Kahn, GK, Tran, Whitbeck 1803.XXXX

Gninenko, Krasnikov, Matveev 1412.1400

Chen, Pospelov, Zhong 1701.07437

Generic test of light new particles in $(g-2)_\mu$



Phase 1 $\sim 10^{10}$ MOT

Phase 2 $\sim 10^{13}$ MOT

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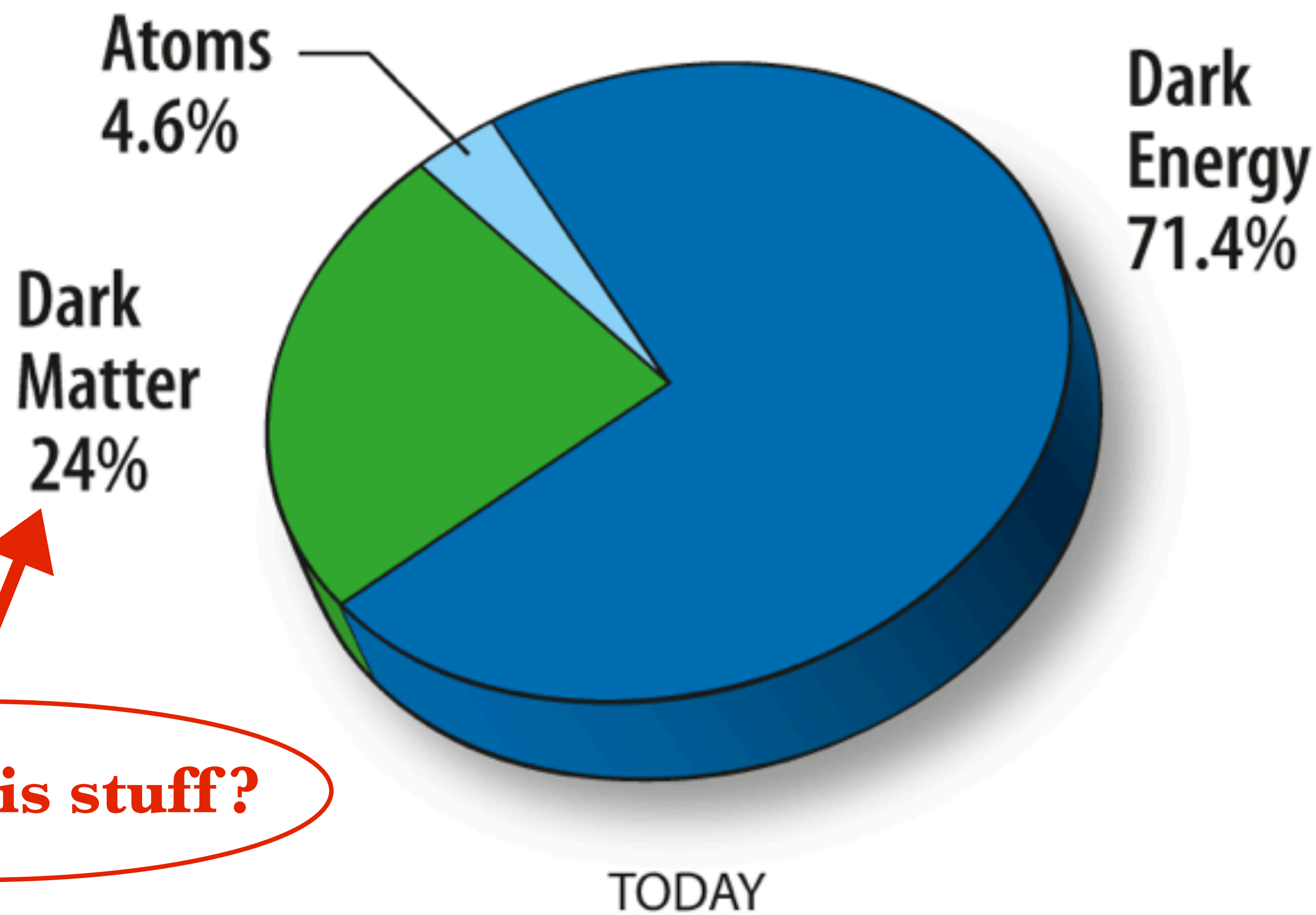
Zeroth Order Outstanding Problems

Matter Asymmetry
Inflation
Neutrino Masses

Accelerated
Cosmic
Expansion



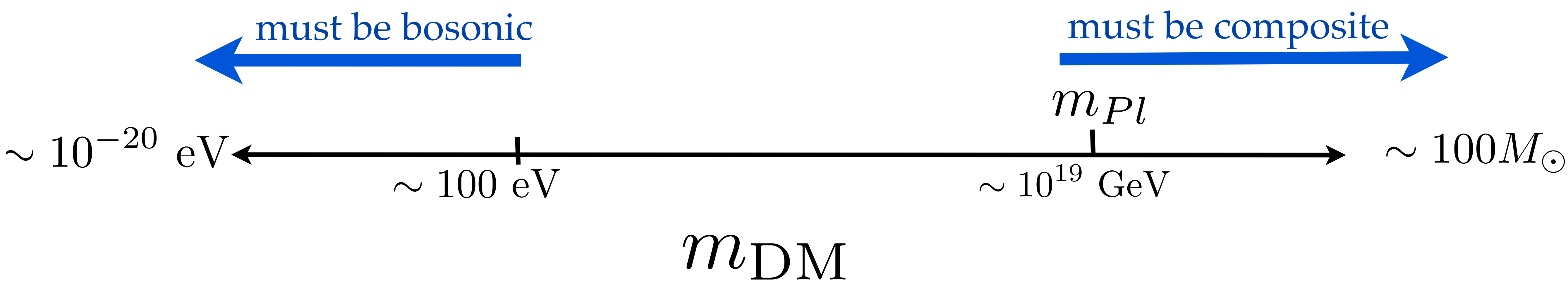
What is this stuff?

Also Quantum Gravity

DM Prognosis?

Bad news: DM-SM interactions are not obligatory

If nature is unkind, we may never know the right scale



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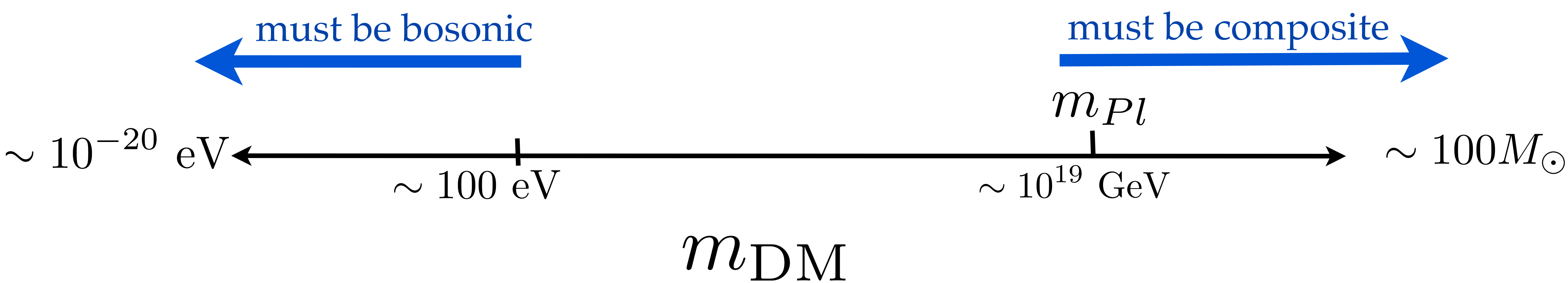


Good news: most *discoverable* DM candidates are in thermal equilibrium with us in the early universe

Why is this good news?

Thermal Equilibrium
Advantage #0: Hard to avoid

If interaction rate exceeds Hubble expansion

$$\mathcal{L}_{\text{eff}} = \frac{g^2}{\Lambda^2}(\bar{\chi}\gamma^\mu\chi)(\bar{f}\gamma_\mu f)$$

$$H \sim n\sigma v \quad \Longrightarrow \quad \frac{T^2}{m_{Pl}} \sim \frac{g^2 T^5}{\Lambda^4}\bigg|_{T=m_\chi}$$

Equilibrium is easily achieved in the early universe if

$$g \gtrsim 10^{-8}\left(\frac{\Lambda}{10\,\text{GeV}}\right)^2\left(\frac{\text{GeV}}{m_\chi}\right)^{3/2}$$

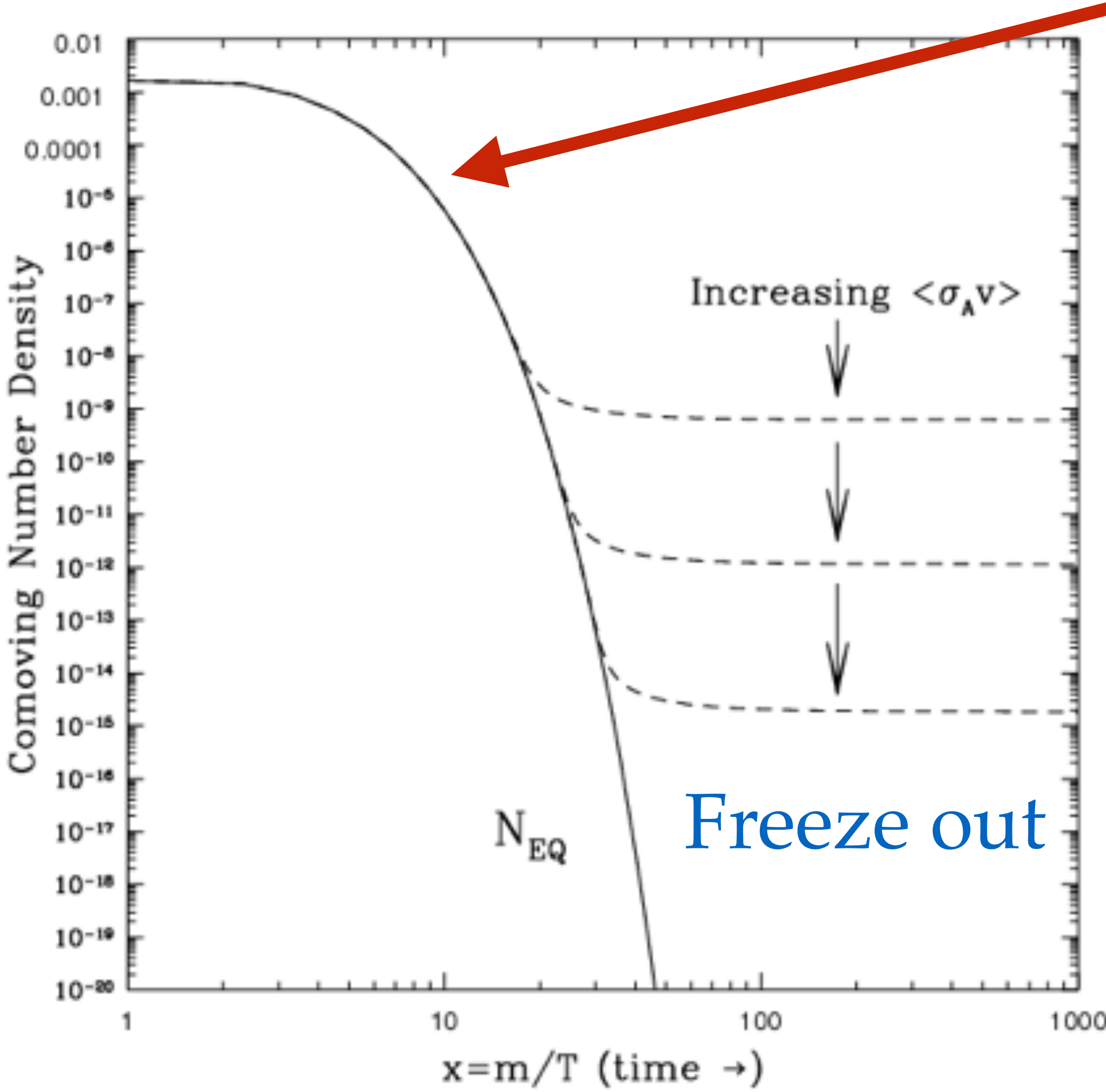
Applies to nearly all discoverable models (except axions)

Thermal Equilibrium
Advantage #1: Minimum Annihilation Rate

DM is overproduced, need to annihilate away the excess!

$$\Omega_\chi \sim \langle \sigma v \rangle^{-1}$$

$$n_{\rm DM}^{\rm (eq.)} = \int \frac{d^3p}{(2\pi)^3} \frac{g_i}{e^{E/T} \pm 1} \sim T^3$$



Griest et. al. 1992

Observed density requires

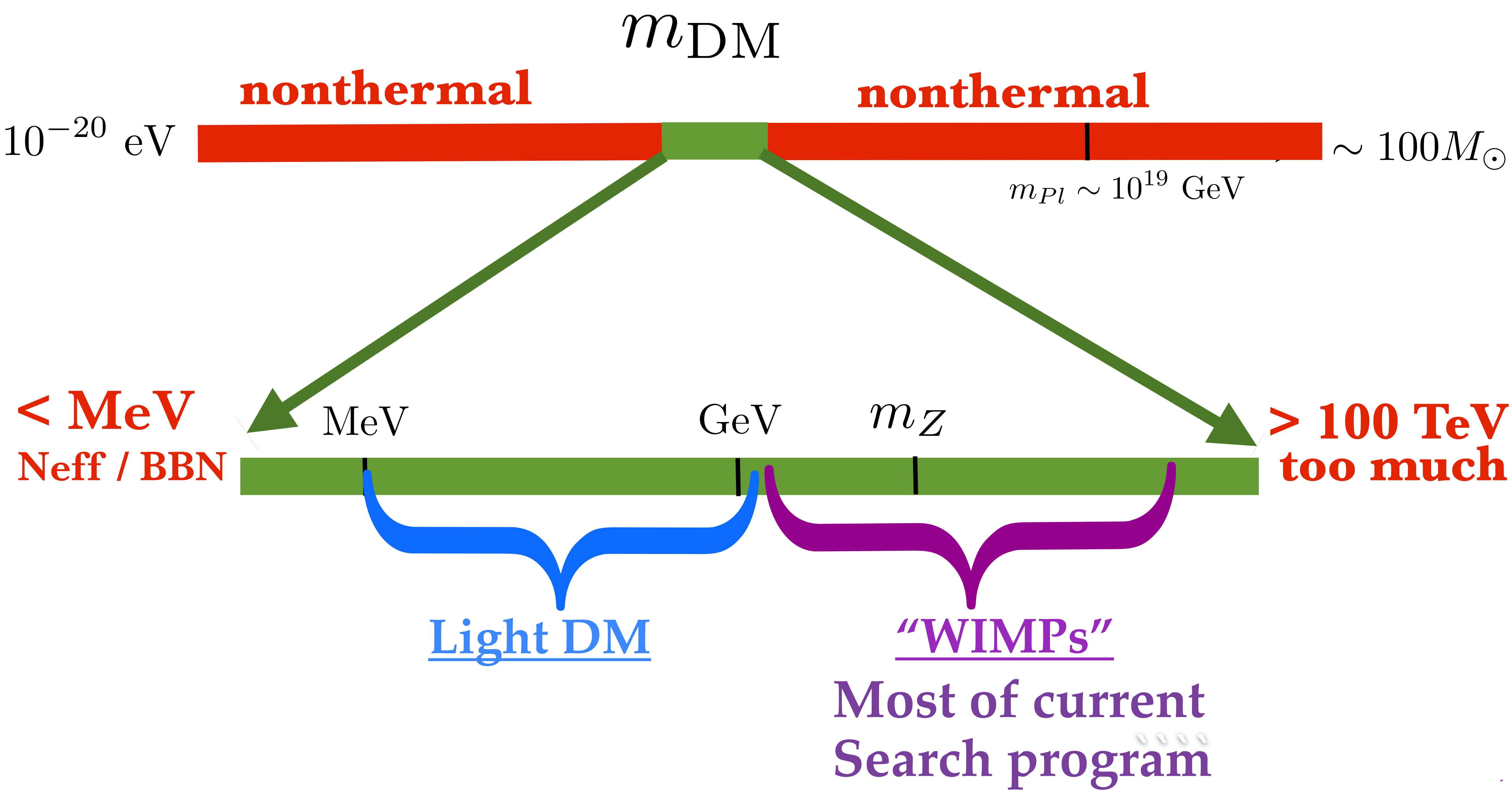
$$\sigma v_{\rm sym} \sim 3 \times 10^{-26} {\rm cm}^3 {\rm s}^{-1}$$

*Predictive rate

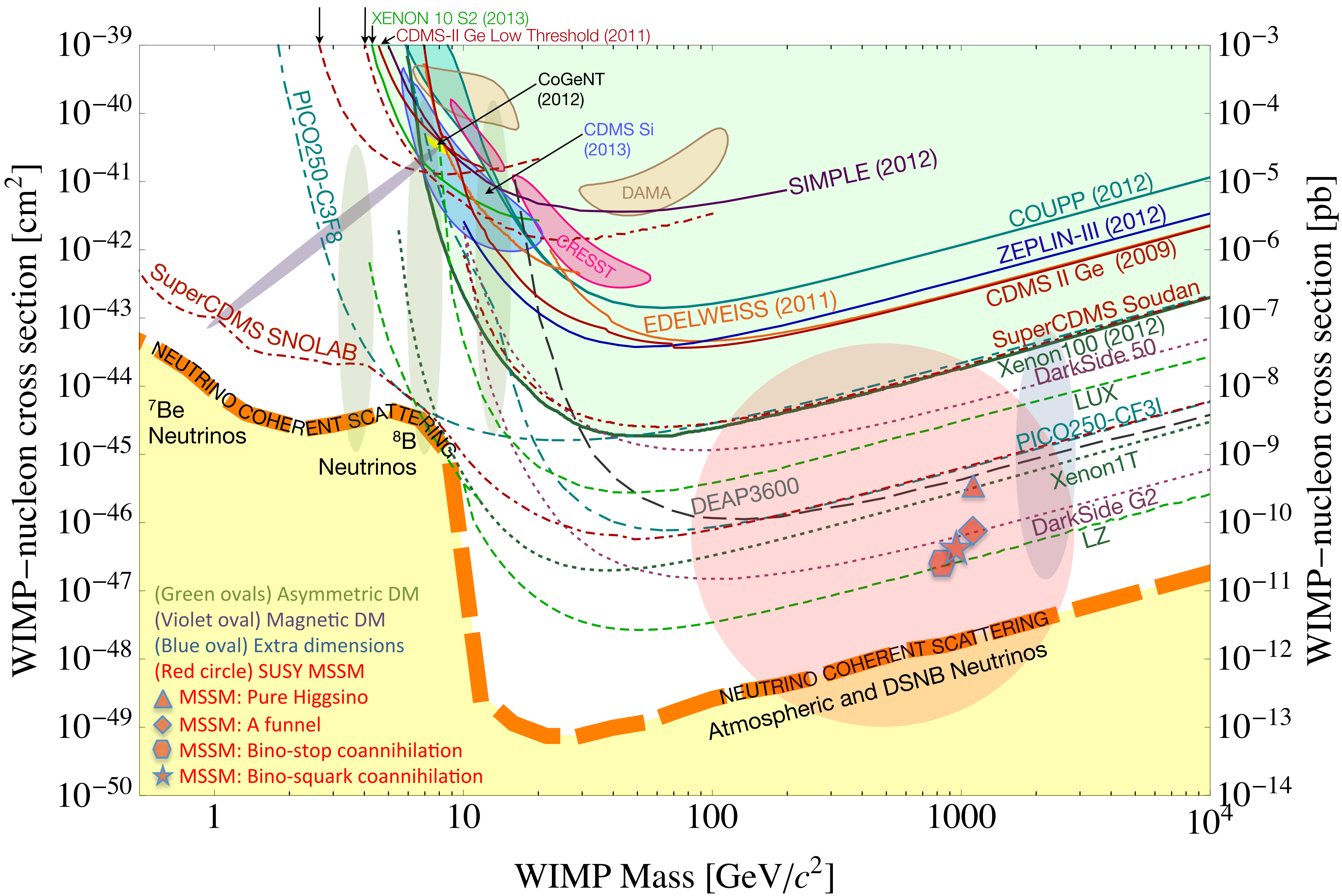
*Known initial condition

*Insensitive to high scales

Thermal Equilibrium
Advantage #2: Narrows Viable Mass Range

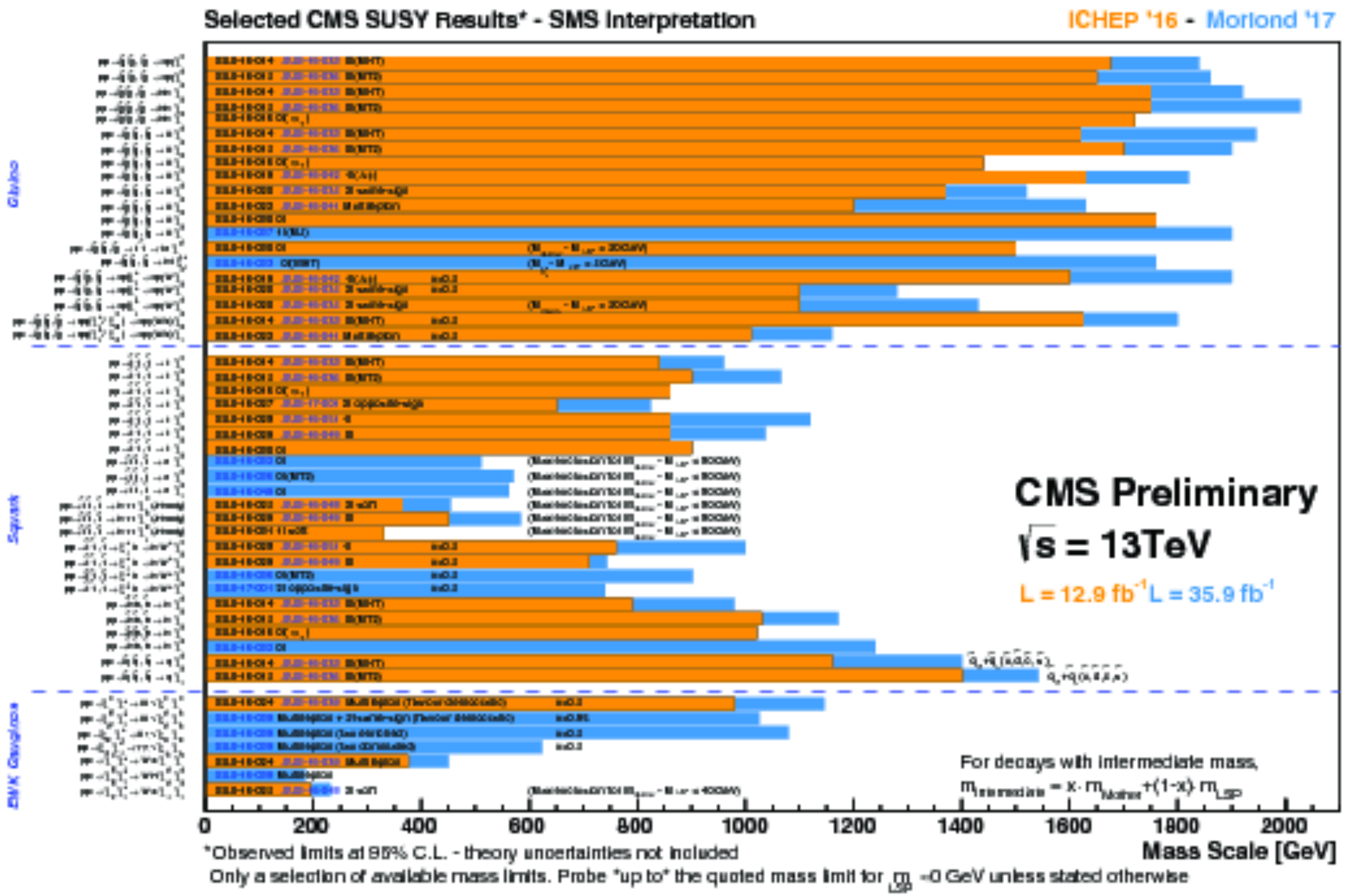


Decades of direct detection: null results



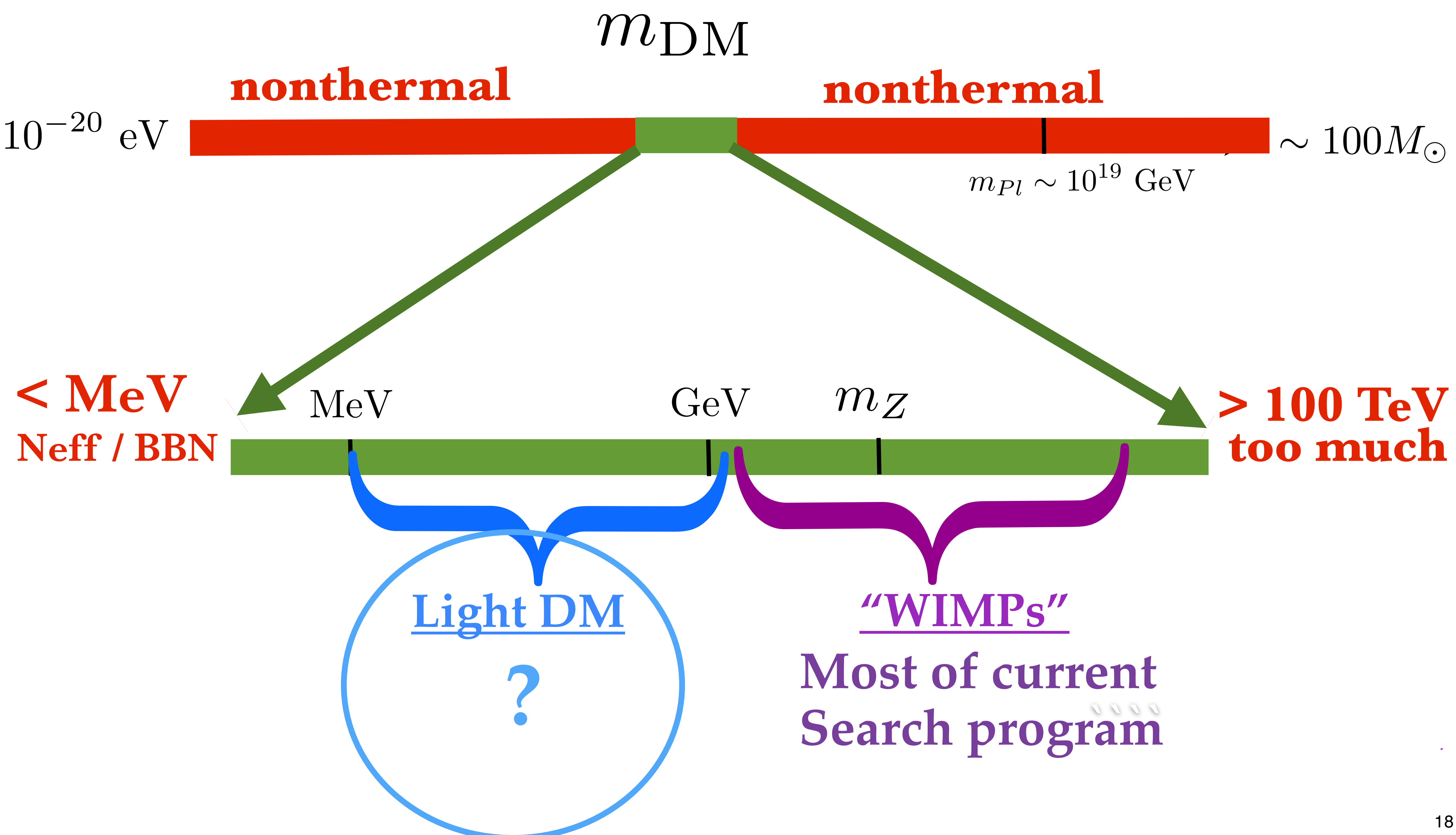
Cushman et al. arXiv:1310.8327

Null LHC results cast doubt on weak scale SUSY



Where else should we look?

How to test most elusive light DM models?



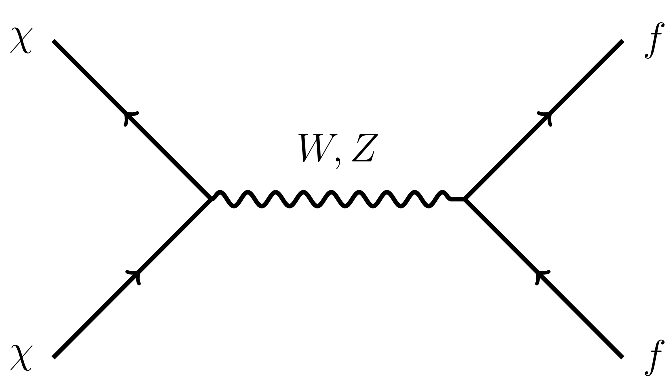
Light DM is different!

LDM must be a SM singlet

Otherwise would have been discovered (LEP etc.)

LDM needs new forces

Would be overproduced without light "mediators"

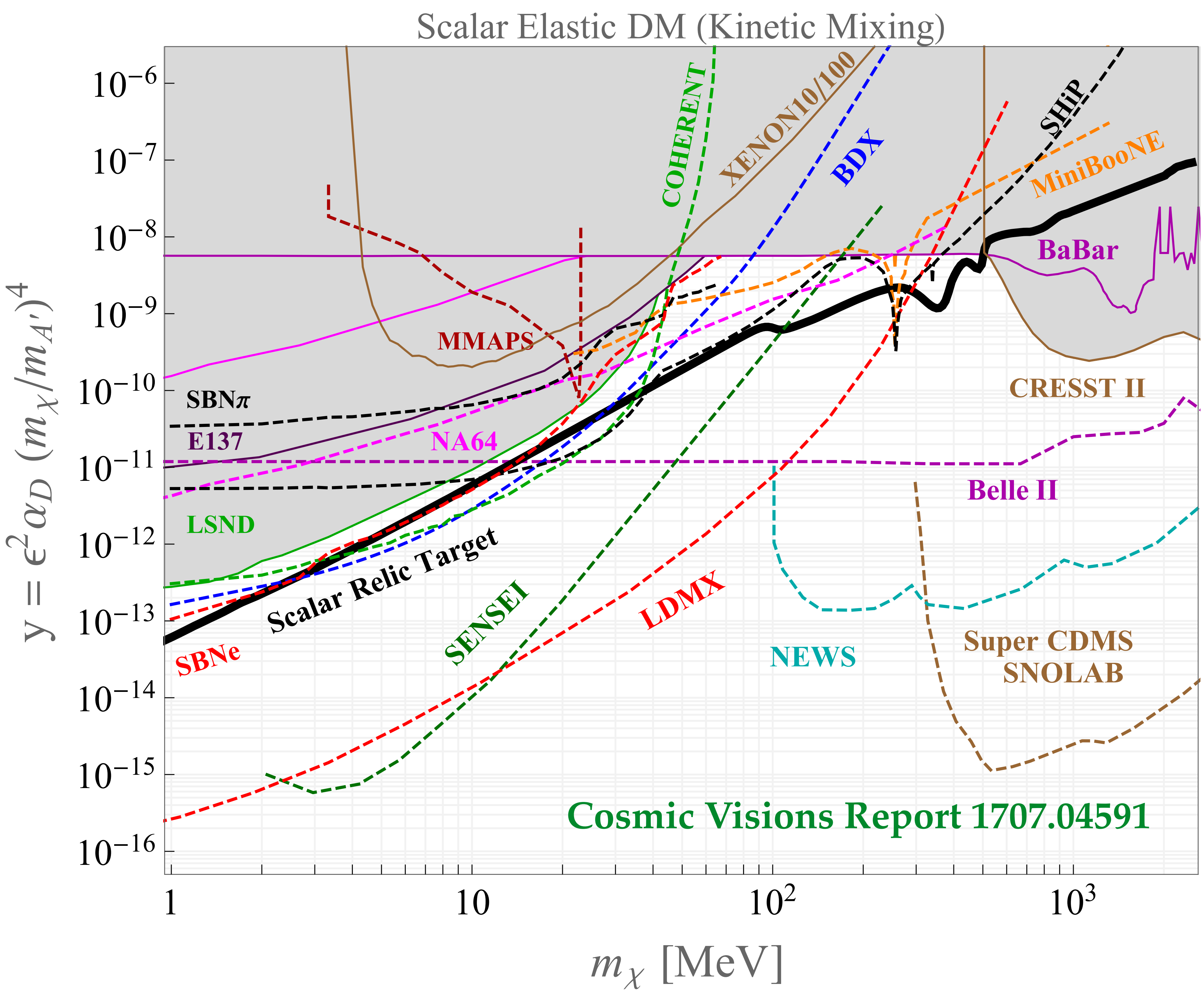


$$\sigma v \sim \frac{\alpha^2 m_\chi^2}{m_Z^4} \sim 10^{-29} \mathrm{cm}^3 \mathrm{s}^{-1} \left(\frac{m_\chi}{\mathrm{GeV}}\right)^2$$

Lee / Weinberg '79

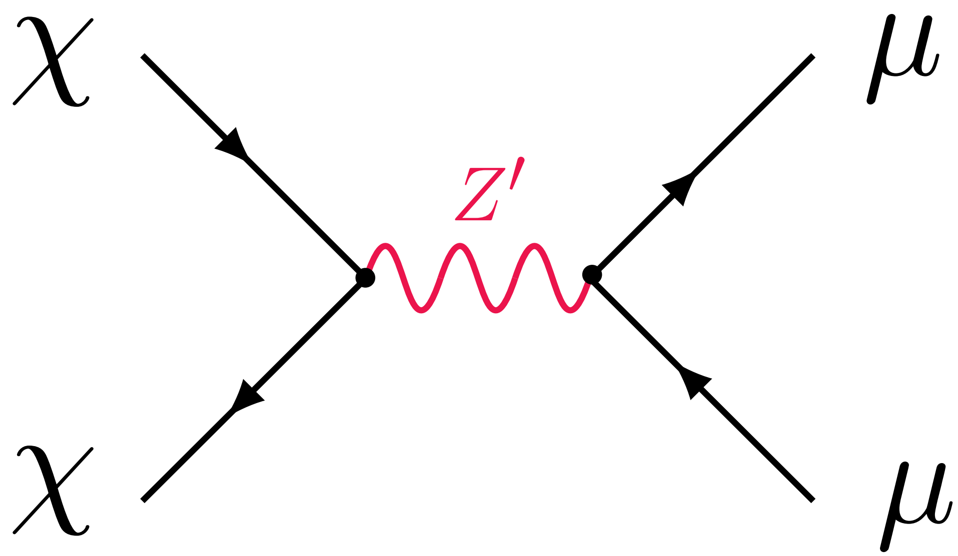
How do we look for new forces?

Emerging New Program of Light DM Experiments



… but all probe electron & proton couplings!

Major Blind Spot: Muon-Philic Dark "Mediators"



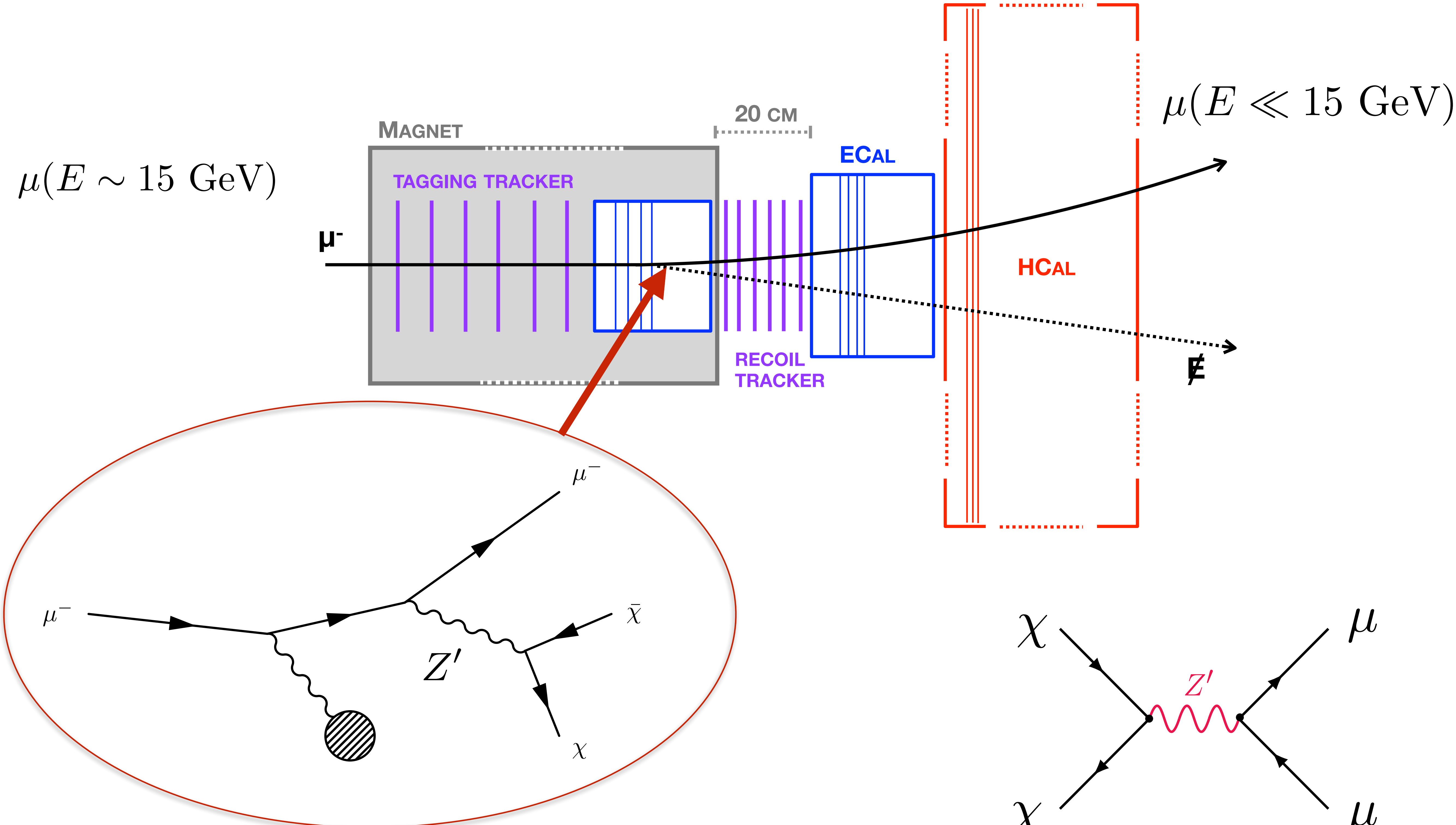
New force couple DM to muons, sets relic abundance

$$\mathcal{L} \supset Z'_\nu \left(g_\mu \bar{\mu} \gamma^\nu \mu + g_\chi \bar{\chi} \gamma^\nu \chi \right)$$

e.g. — gauged U(1) muon-tau number, no electron coupling

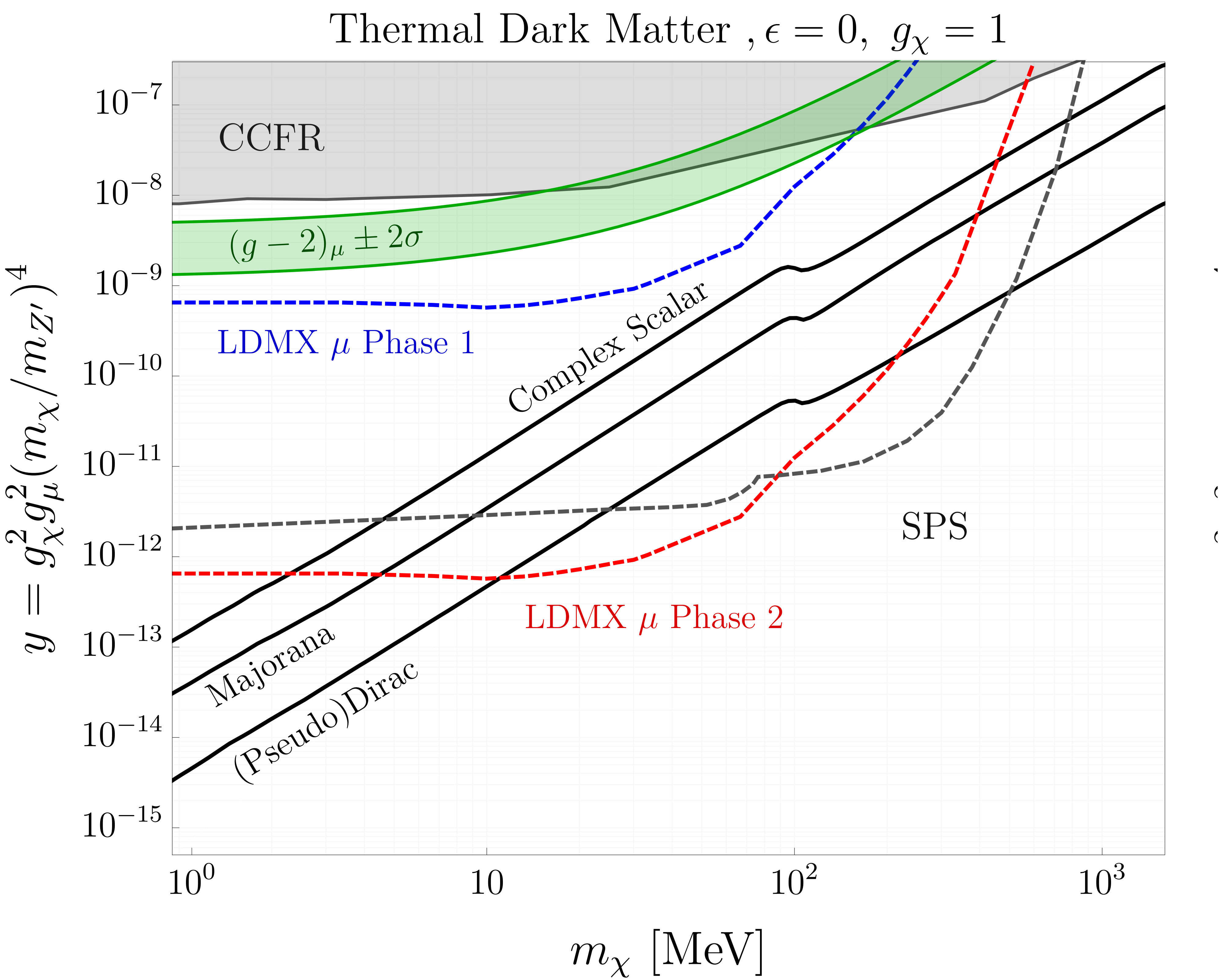
(mediator can be same Z′ responsible for g-2 anomaly)

Same setup as before: radiate missing energy



Tests same interaction that sets relic abundance

Cover nearly all predictive thermal DM models



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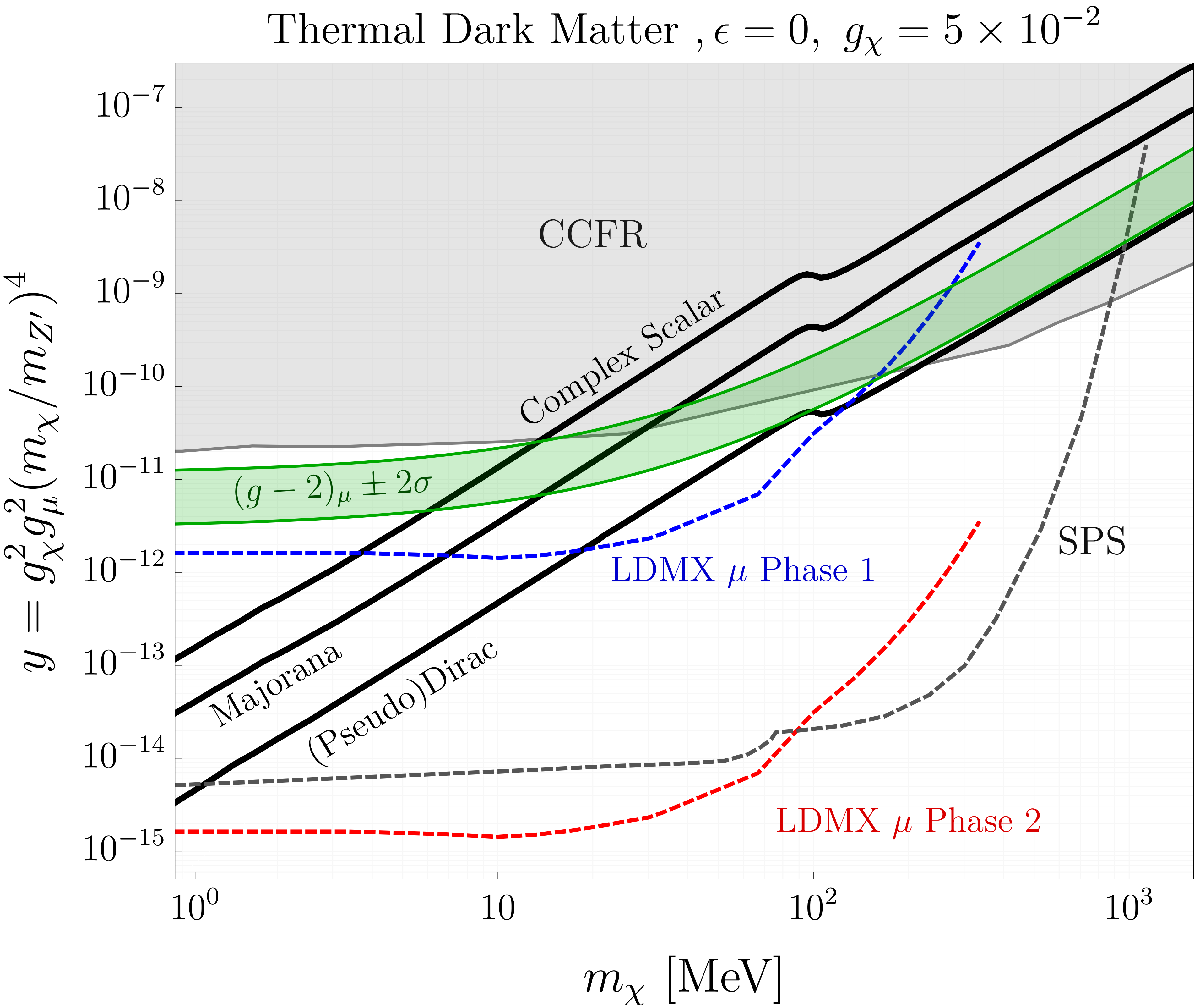

Including common g-2 regions

Summary

Muonic forces poorly constrained

New fixed-target missing momentum experiment

Trigger on large missing energy, veto SM particles

Utilize existing muon sources beams at Fermilab

Phase 1: 1e10 MOT robustly test g-2 BSM

Phase 2: 1e13 MOT cover thermal dark matter