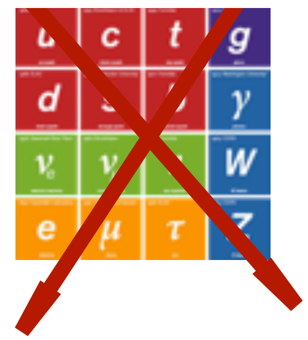
Dark Sectors & Portal Interactions Overview

Gordan Krnjaic

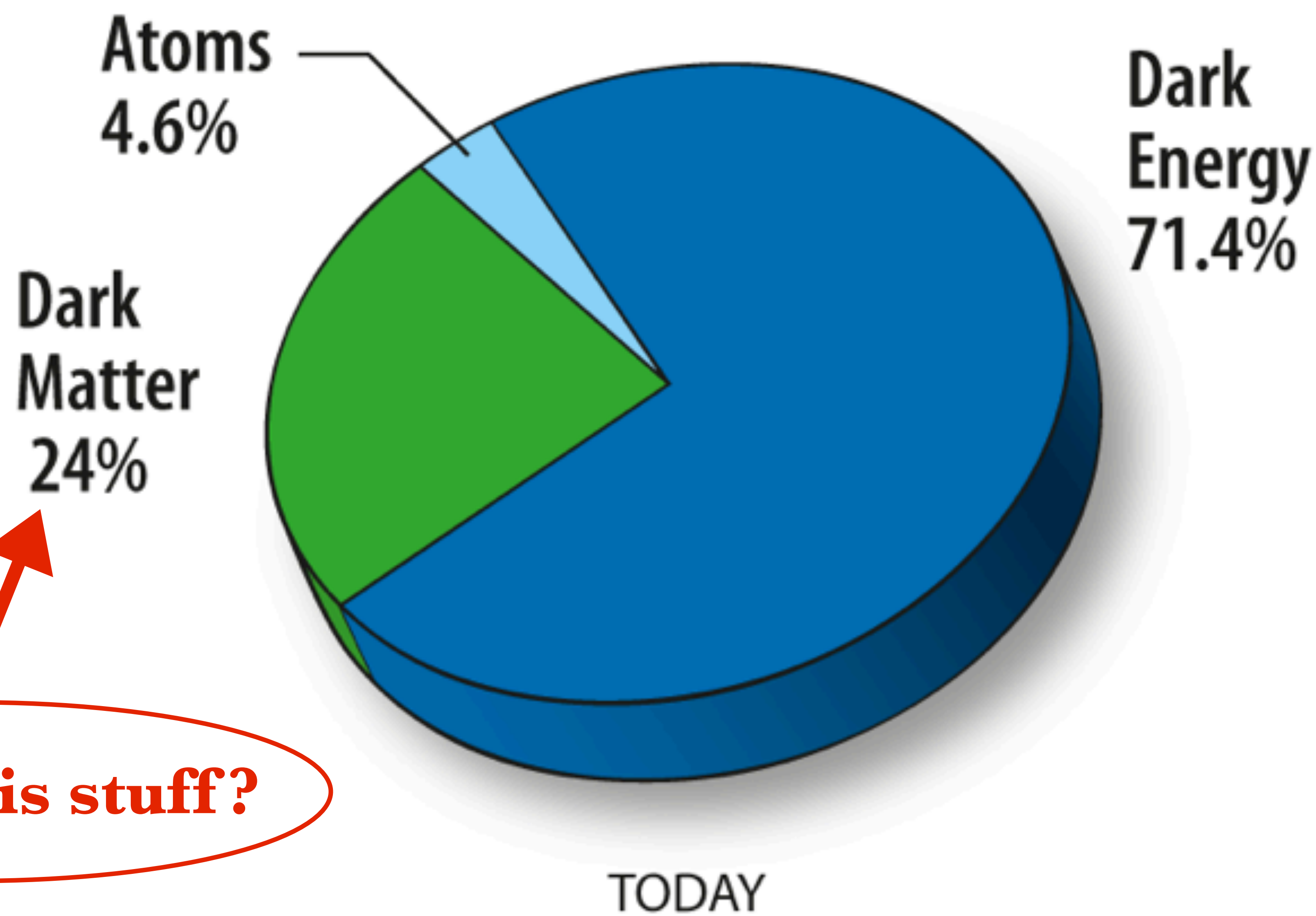
CERN Forward Spectrometer Meeting, April 16, 2020

Open Questions in Fundamental Physics & Cosmology

Neutrino Masses
Matter Asymmetry
Inflation



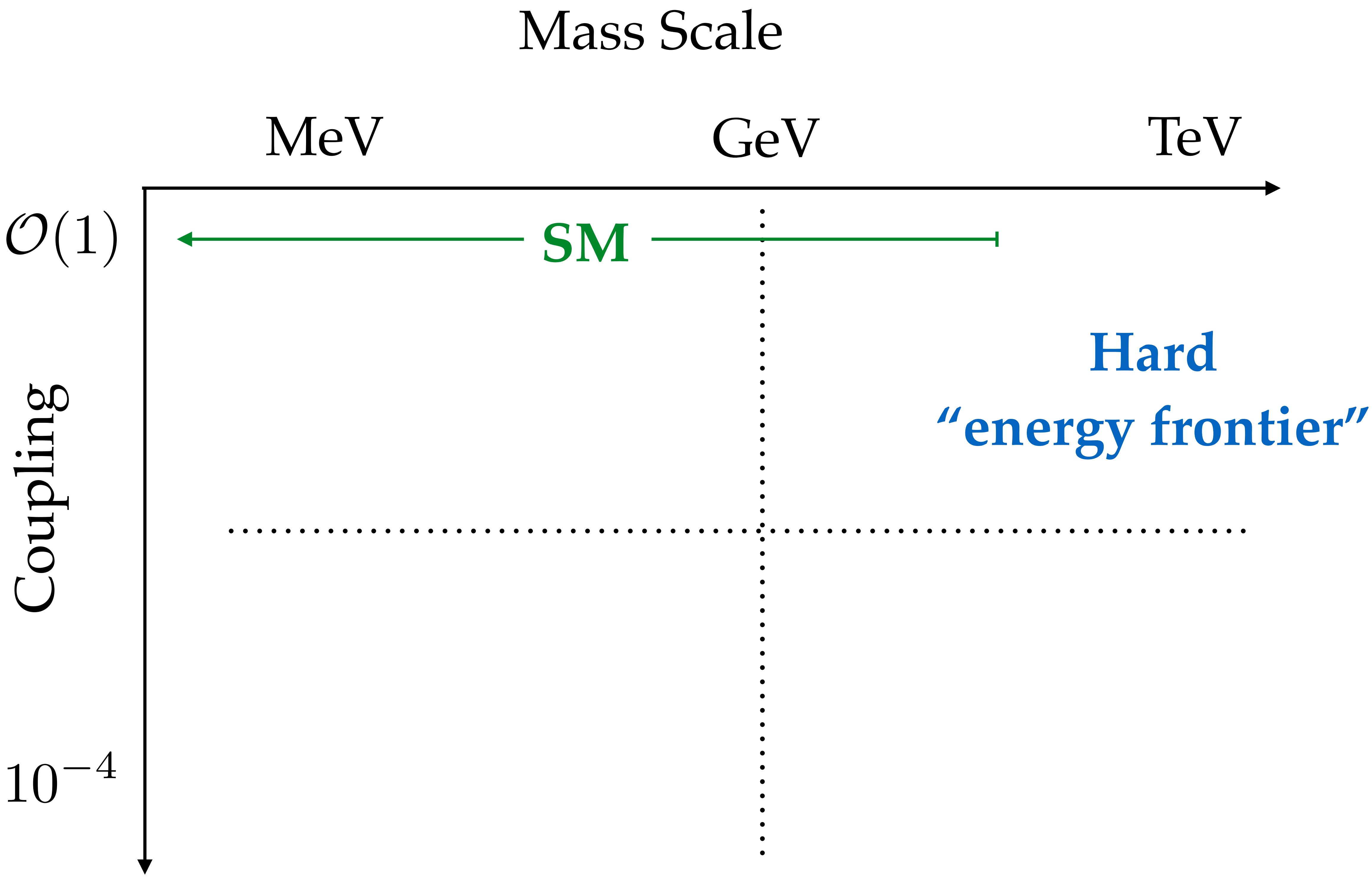
Accelerated Cosmic Expansion



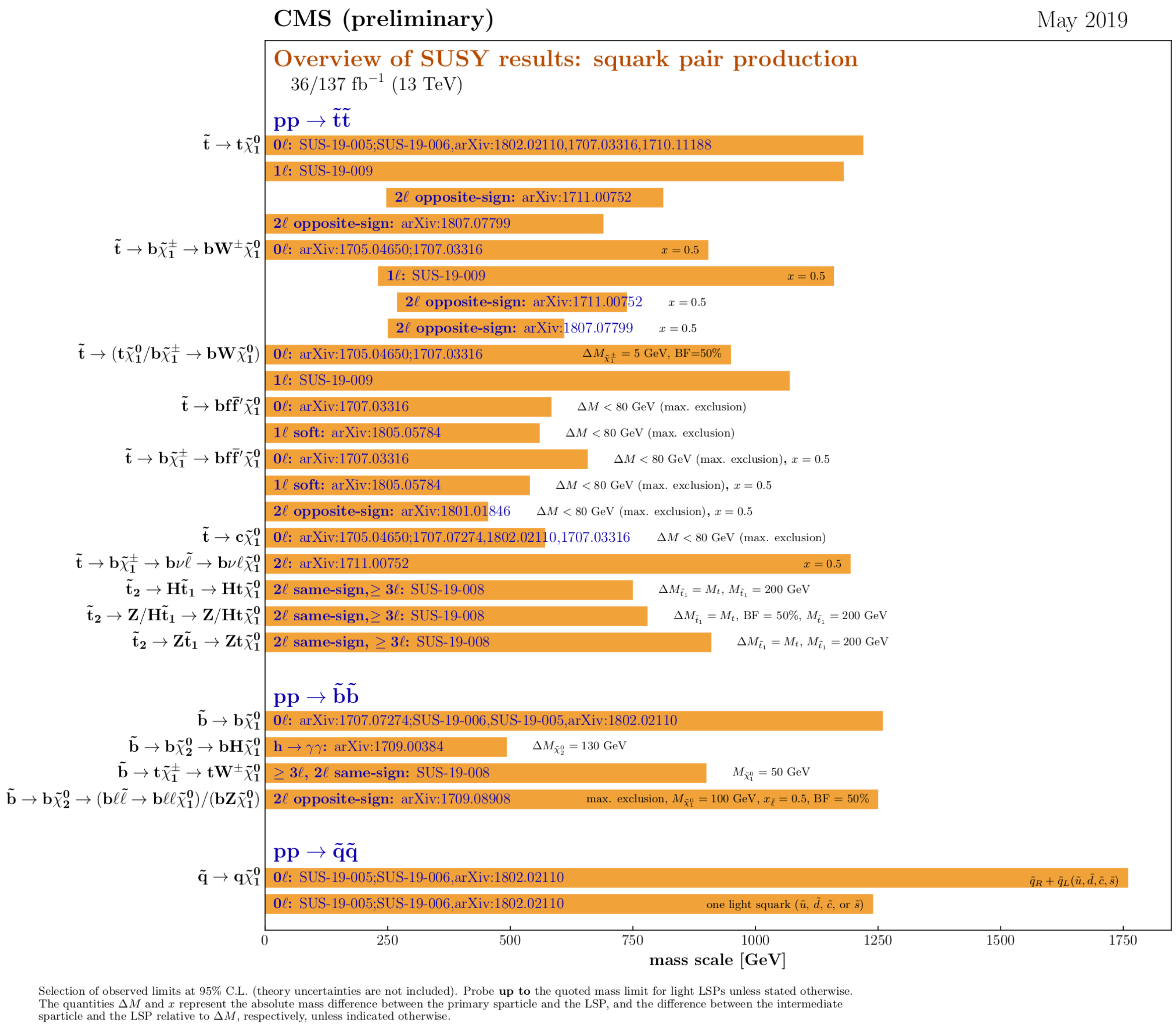
What is this stuff?

Also Quantum Gravity

How to look for new physics?

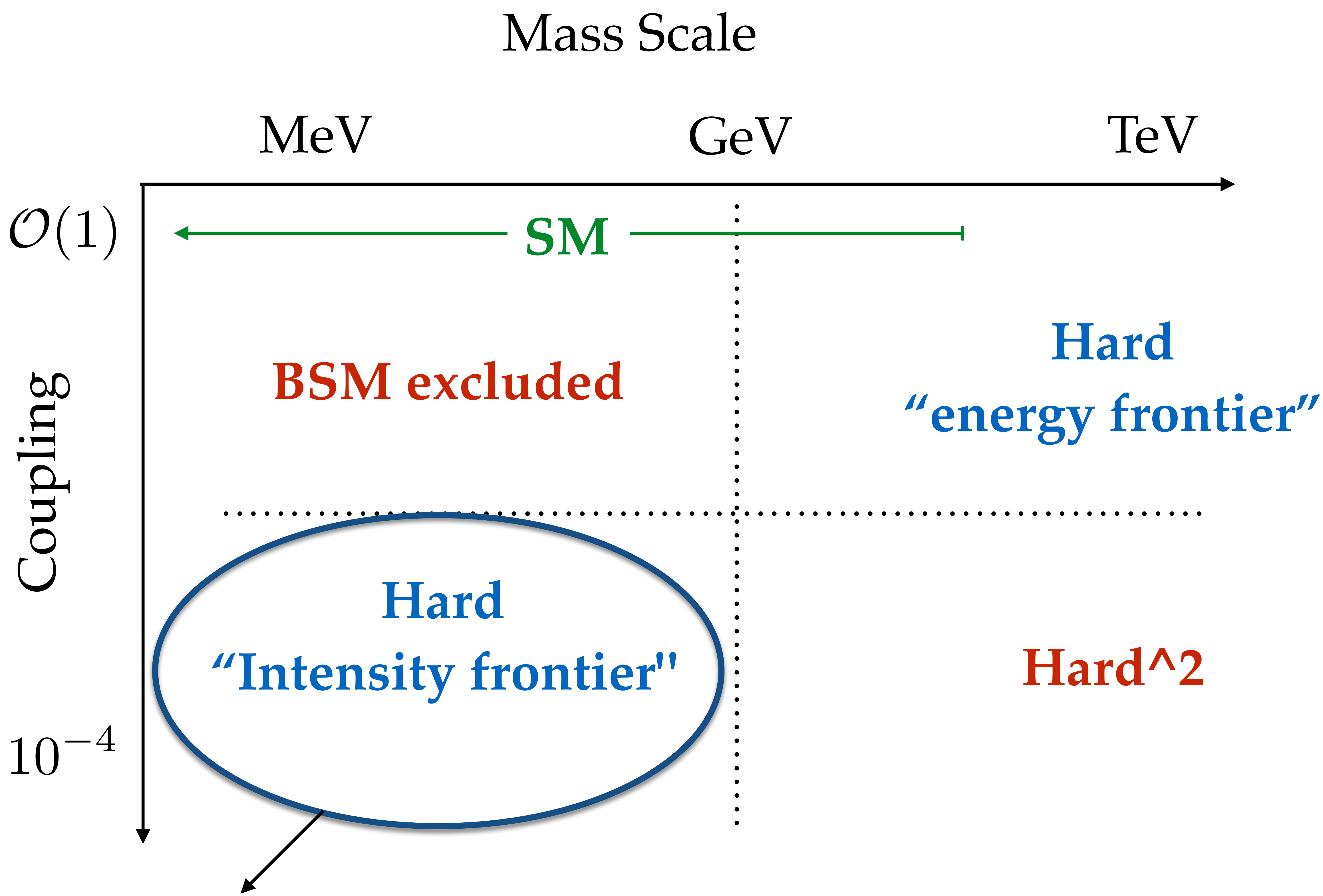


What have we learned on the "energy frontier"?



Null LHC results: no evidence yet of new SM charged particles

How to look for new physics?



BSM: Smaller coupling, lower mass, **SM neutral**

Overview

Part 1) Minimal Single Particle SM Extensions

Part 2) Add Light ~ GeV Dark Matter

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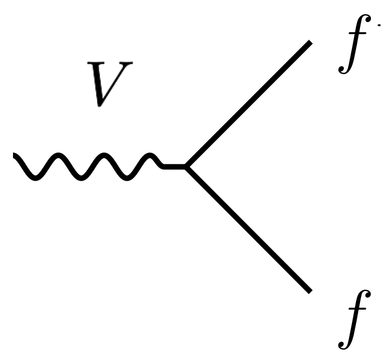
Part 2) Add Light ~ GeV Dark Matter

How to couple single neutral particle to the SM?

Option 1: New gauge force directly coupled to SM currer

$$\mathcal{L} \supset g V_\mu J^\mu_{\rm SM} \quad , \quad J^\mu_{\rm SM} \equiv \sum_f Q_f \bar{f} \gamma^\mu f$$



Only anomaly free possibilities:

$$U(1)_{B-L} \; , \; U(1)_{L_i - L_j} \; , \; U(1)_{B-3L_i}$$

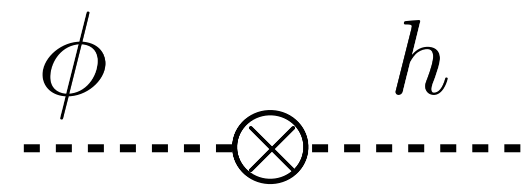
Qualitatively similar, but some differences in bounds

Two parameter family of models: $\{g, m_V\}$

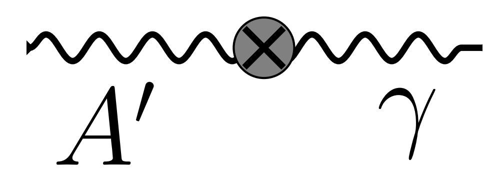
How to couple single neutral particle to the SM?

Option 2: Mass or kinetic mixing with neutral SM particles

Scalar / Higgs mixing $\phi H^\dagger H \to \phi h$

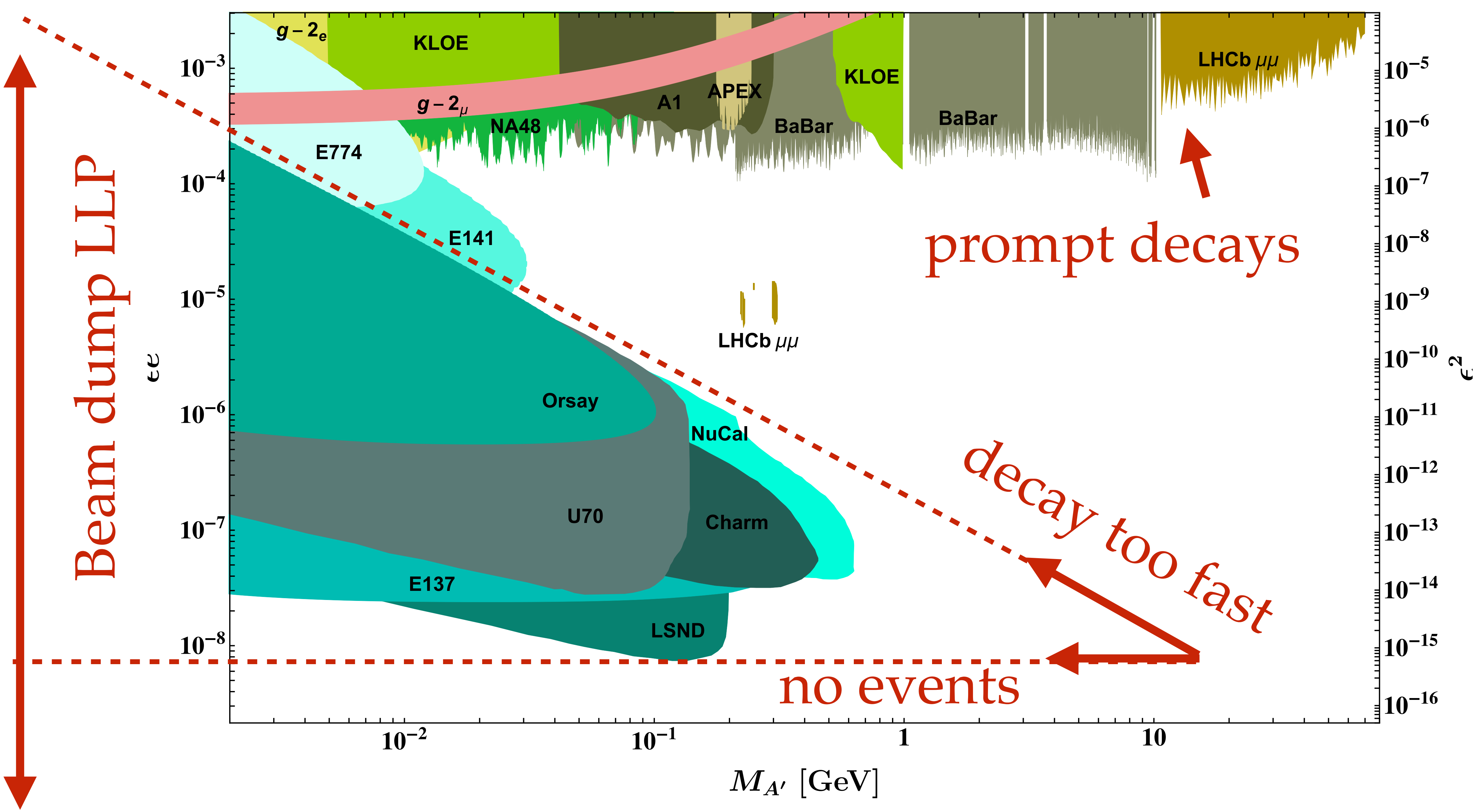


Dark / visible photon mixing $F'_{\mu\nu} F^{\mu\nu}$



Sterile / active neutrino mixing LHN

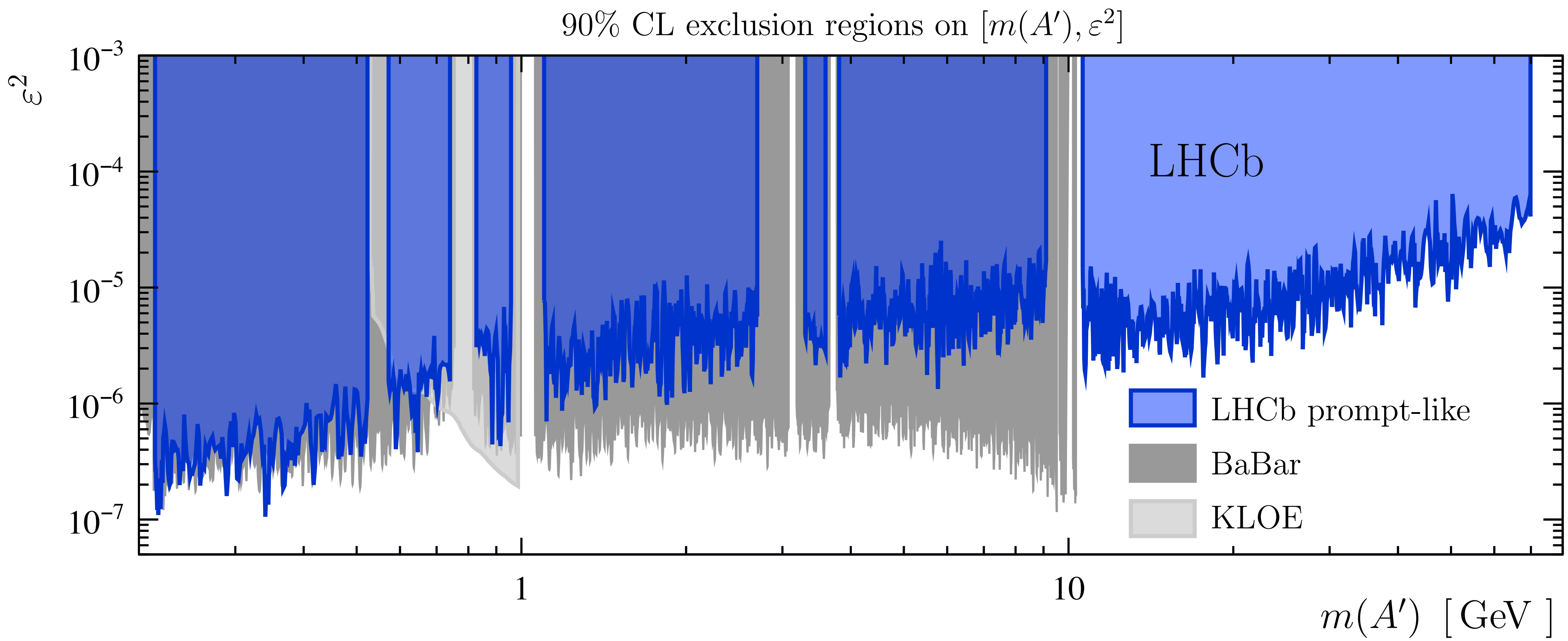
Minimal Kinetically Mixed Dark Photon $\epsilon F'_{\mu\nu} F^{\mu\nu}$



Bauer, Foldenauer, Jaeckel, 1803.05466

Collider strategy: prompt decays

Resonance searches for visible daughters: BABAR, Belle II, LHCb…



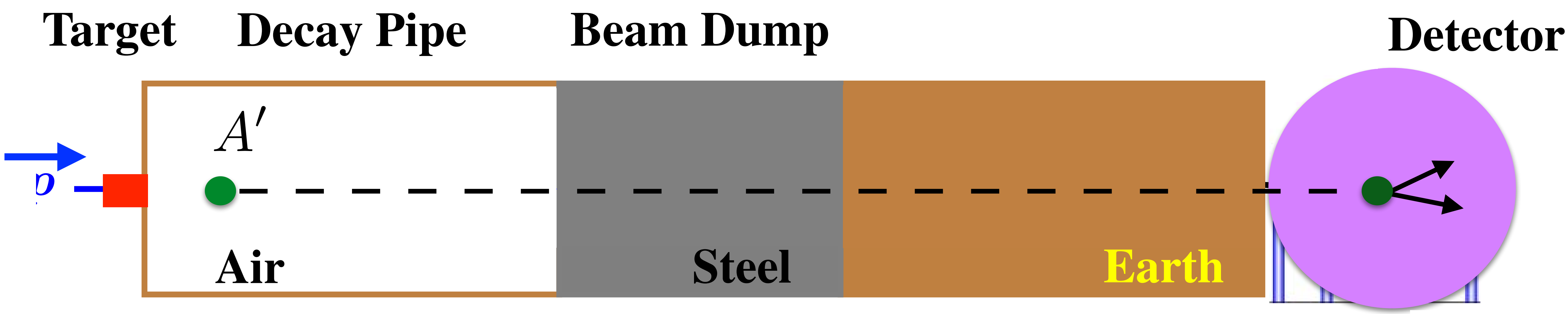
B-factories: continuum production $e^+e^- \to \gamma A' \to \gamma(e^+e^-)$

Colliders (also short-er baseline fixed targets) $K^+ \to \pi^+ A' \to \pi^+(e^+e^-)$

and many other channels / mesons etc.

LHCb Collaboration 1710.02867

Beam Dumps: LLP searches



1) LLP produced in target

2) Passes through shielding

3) Decays in detector

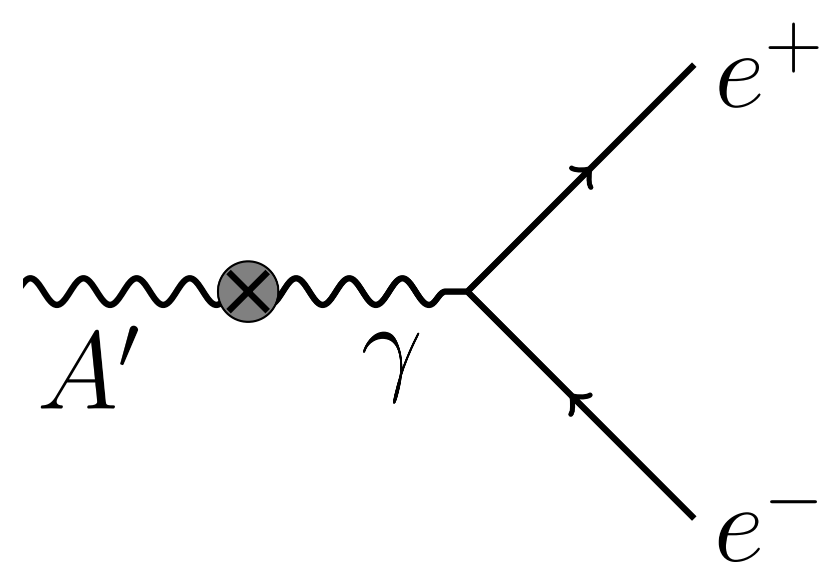
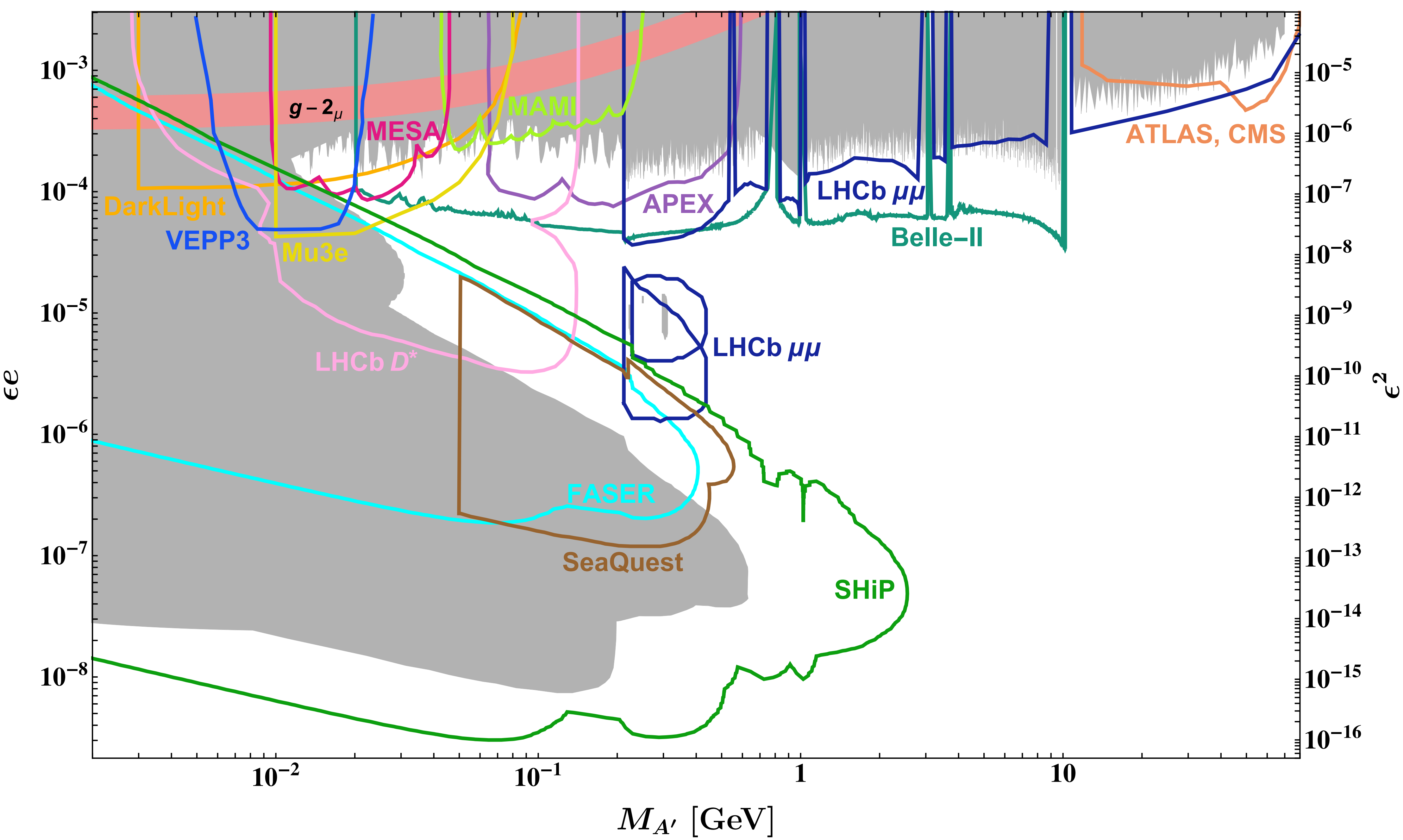


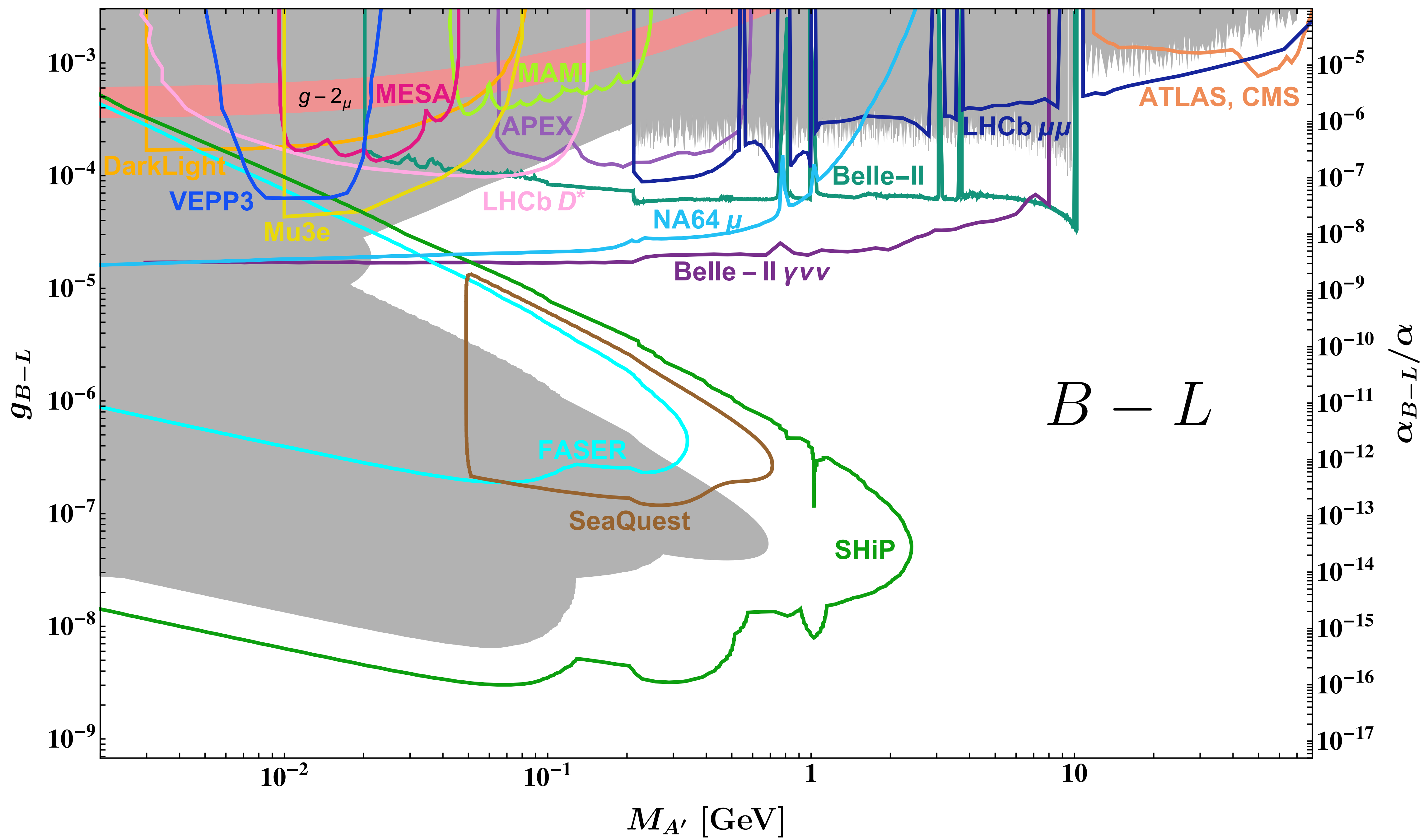
Image: MiniBooNE Collab. Phys. Rev. Lett. 118 (2017)

Minimal Kinetically Mixed Dark Photon $F'_{\mu\nu}F^{\mu\nu}$



Bauer, Foldenauer, Jaeckel, 1803.05466

Gauged 5th force U(1)



Bauer, Foldenauer, Jaeckel, 1803.05466

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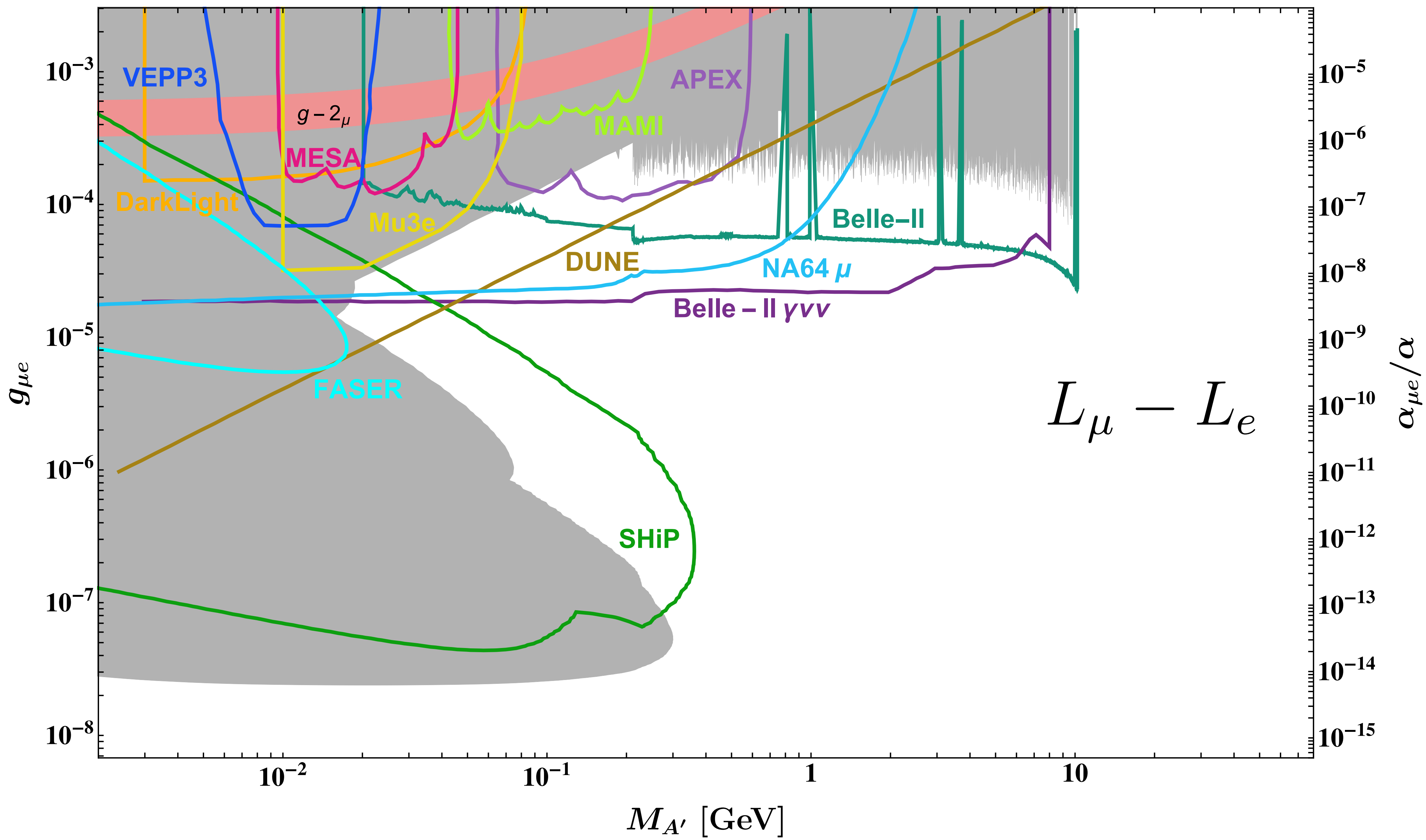
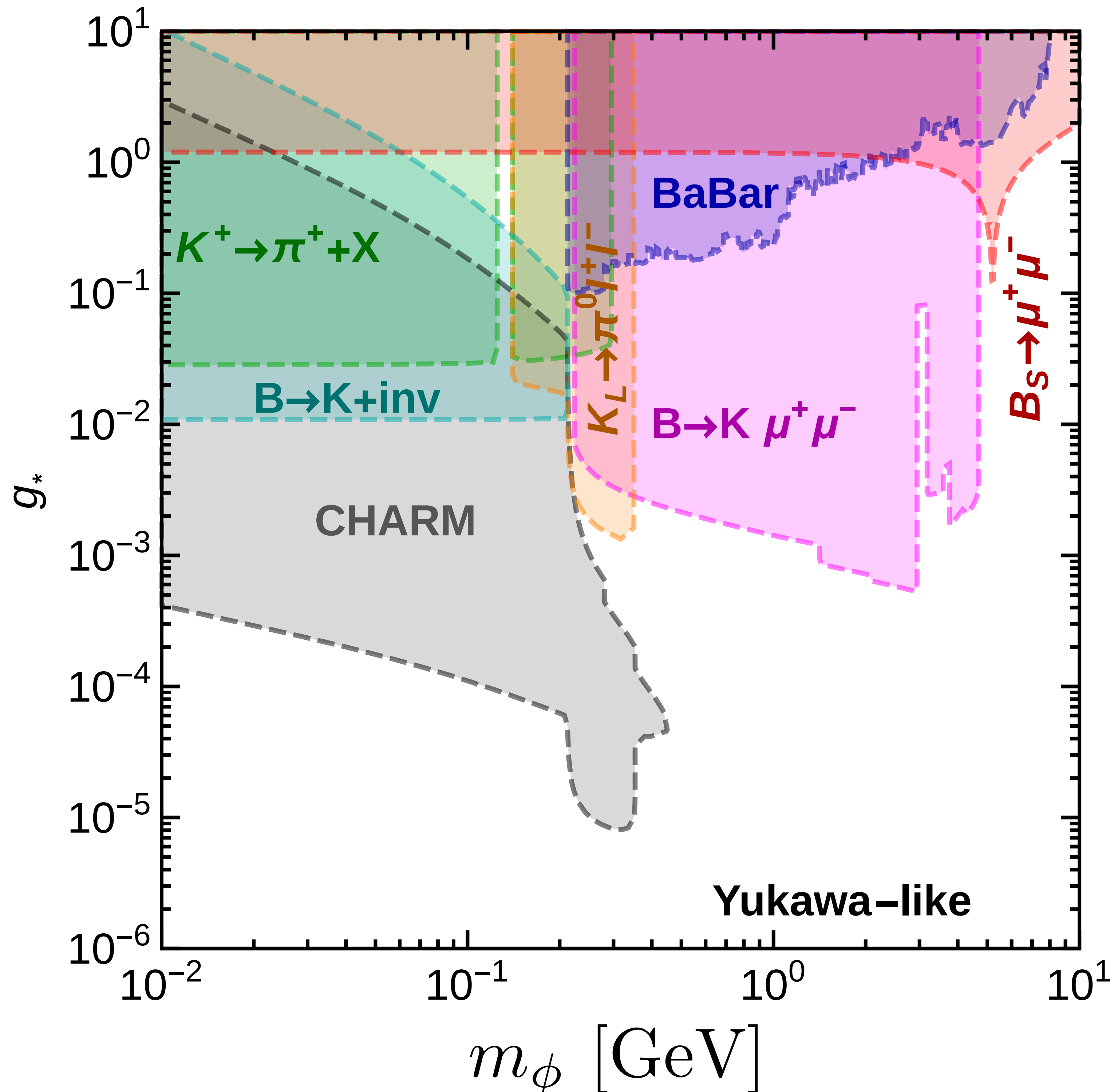
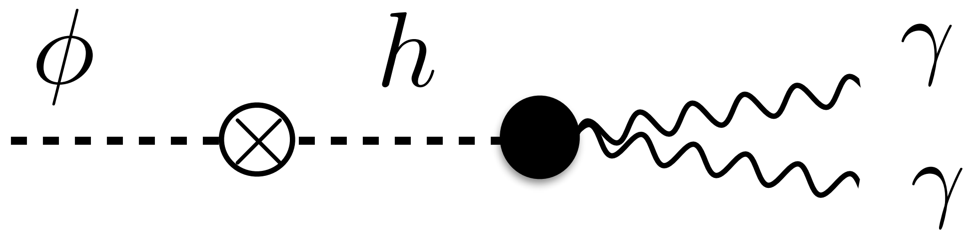


Only scenario that mainly couples to 2nd and 3rd generations

Bauer, Foldenauer, Jaeckel, 1803.05466

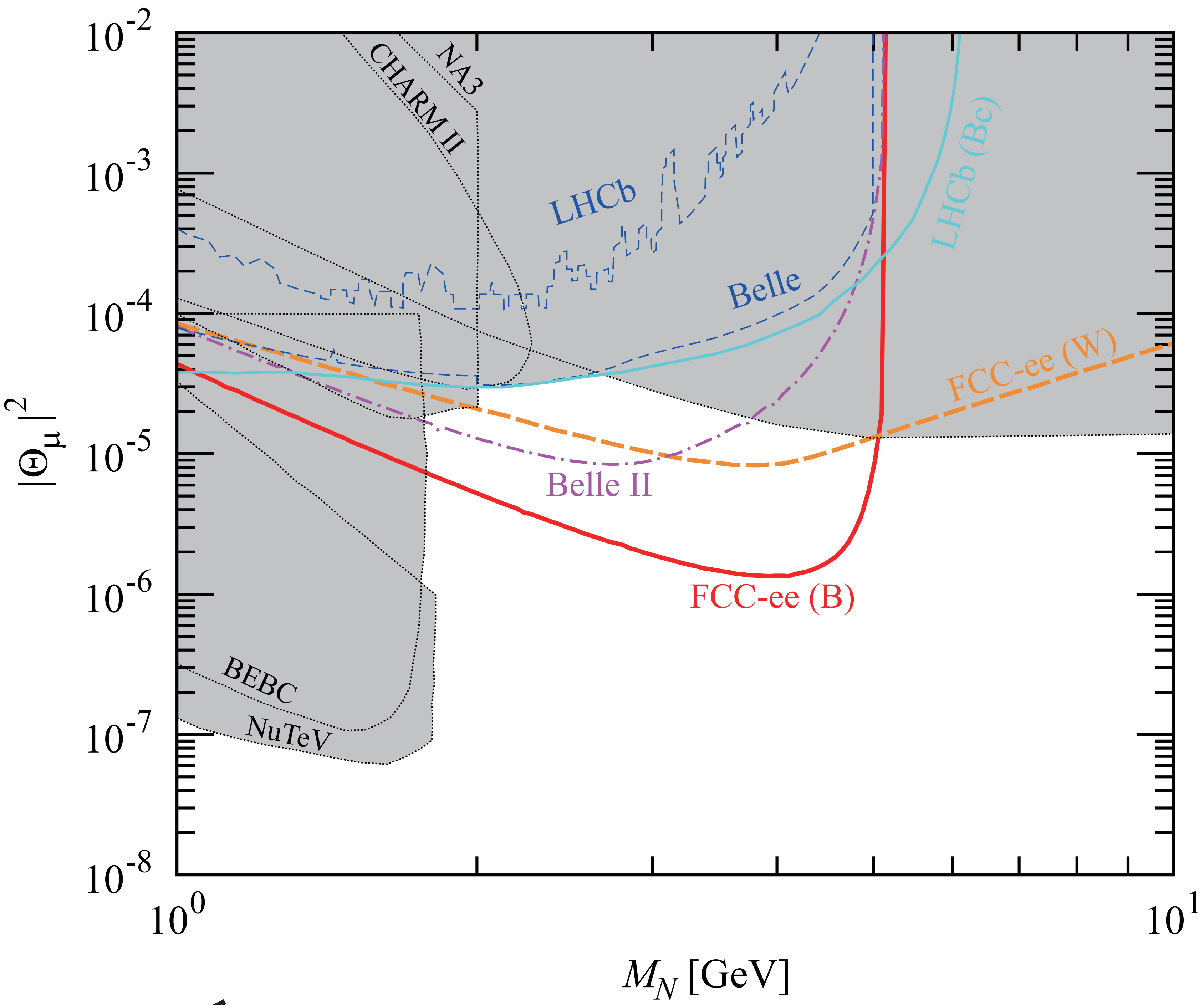
Scalar/Higgs Mixing $\phi H^\dagger H$

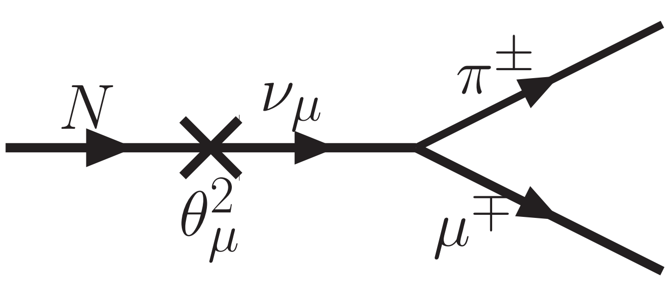




Alekhin et. al. 1504.04855

Sterile / Active Neutrino Mixing LHN





Asaka, Ishida 1609.06113

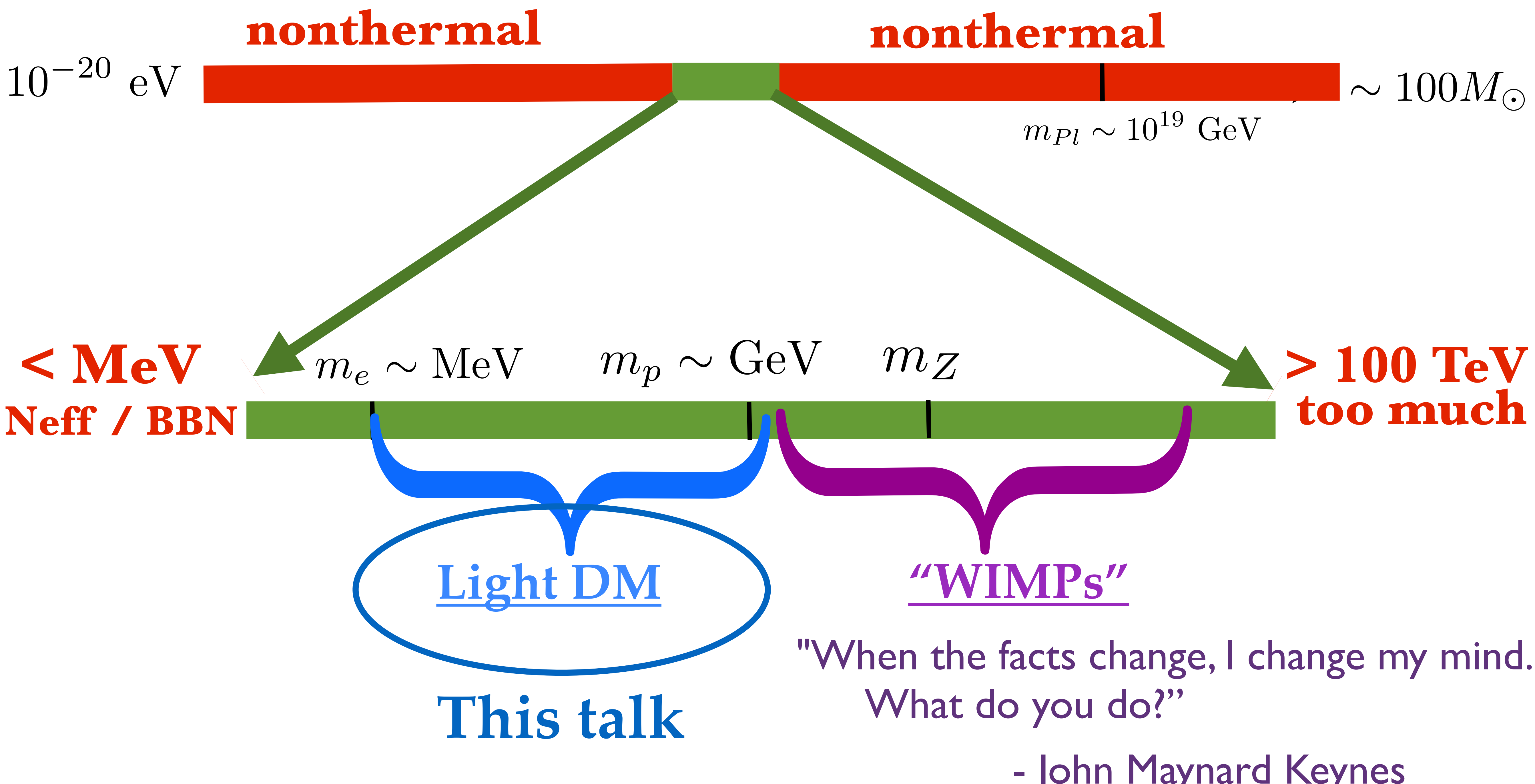
Overview

Part 1) Minimal Single Particle SM Extensions

Part 2) Add Light ~ GeV Dark Matter

Q: What's so great about equilibrium?

A: Narrows Viable Mass Range (!)



Light DM vs. WIMPs

Light DM must be SM neutral

Otherwise would have been discovered at earlier colliders

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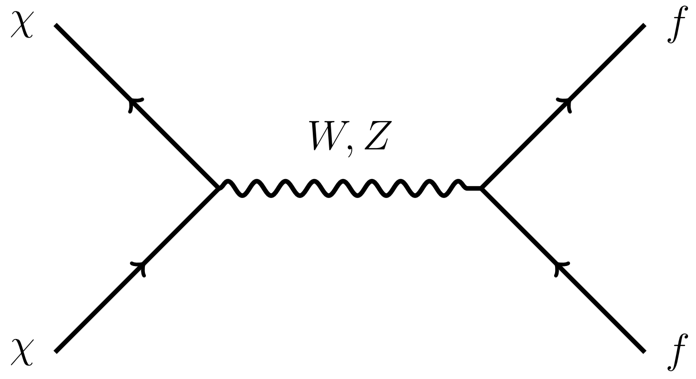
Light DM requires light new force carriers

Overproduced without comparably light, neutral "mediators"



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

Always too small if mediator at weak scale

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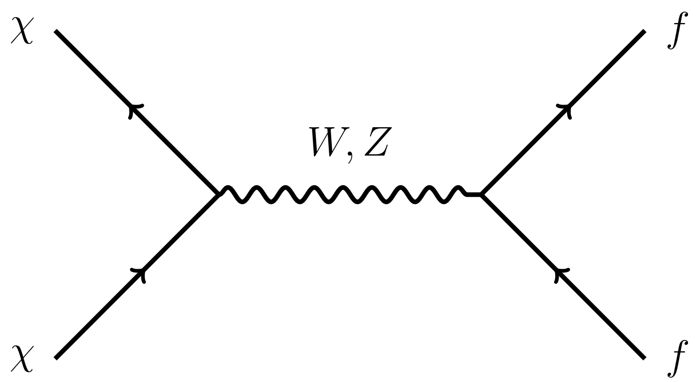

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Always too small if mediator at weak scale

Annihilation through renormalizable interactions

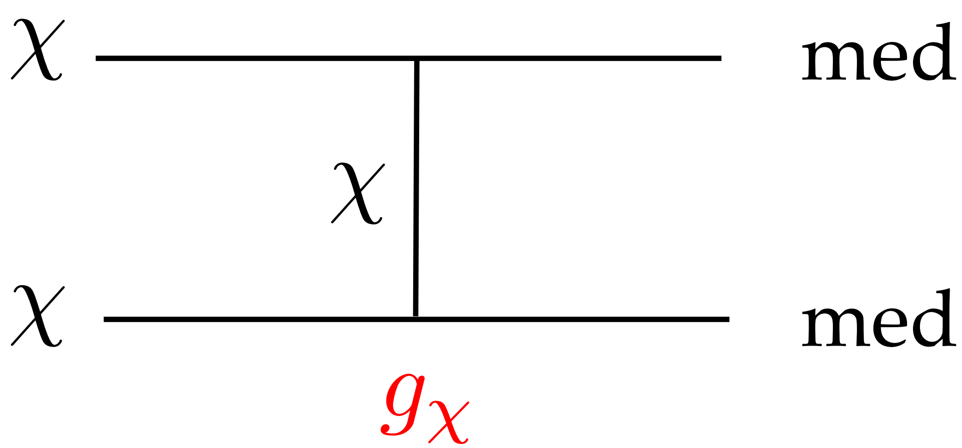
Higher dimension operators have same problem as electroweak forces

Light mediators are not optional!

Who's Heavier: DM or Mediator?

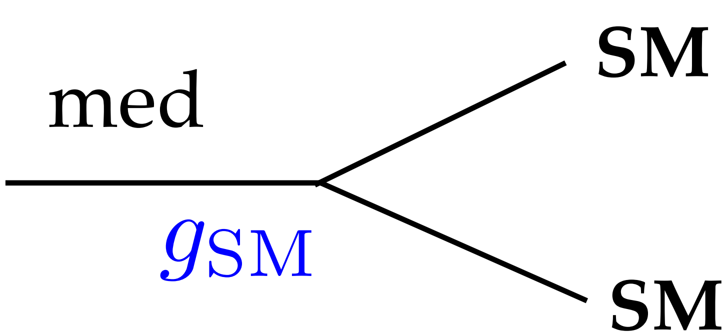
Hidden Annihilation

$$m_\chi > m_{\rm med}$$



No clear experimental target

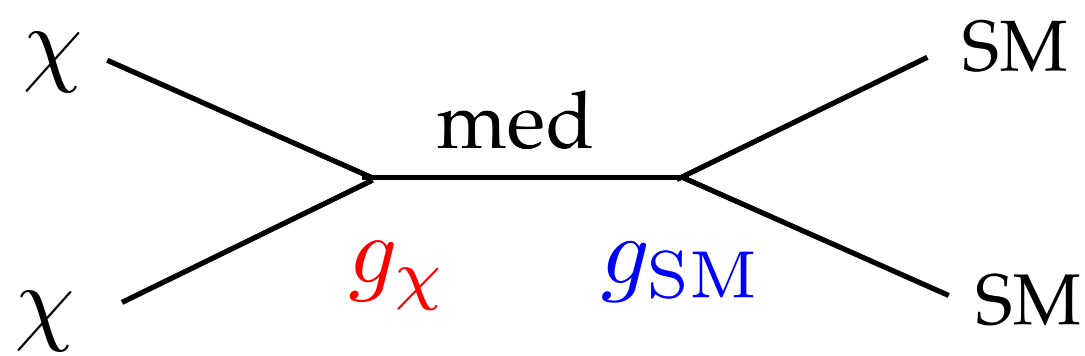
Abundance set by g_χ



Mediator decays **visibly**

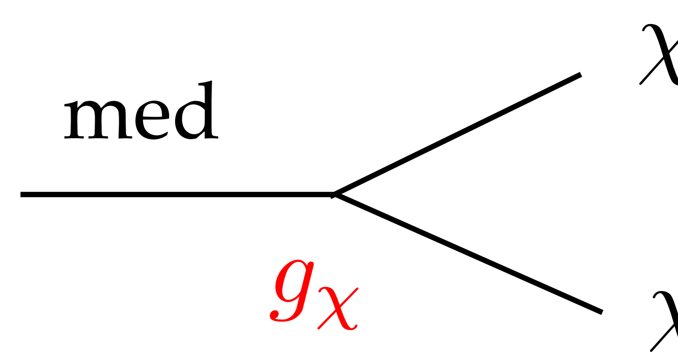
Direct Annihilation

$$m_\chi < m_{\rm med}$$



Predictive thermal targets

Abundance depends on $g_{\rm SM}$



Mediator decays **invisibly***

Who’s Heavier: DM or Mediator?

Hidden Annihilation

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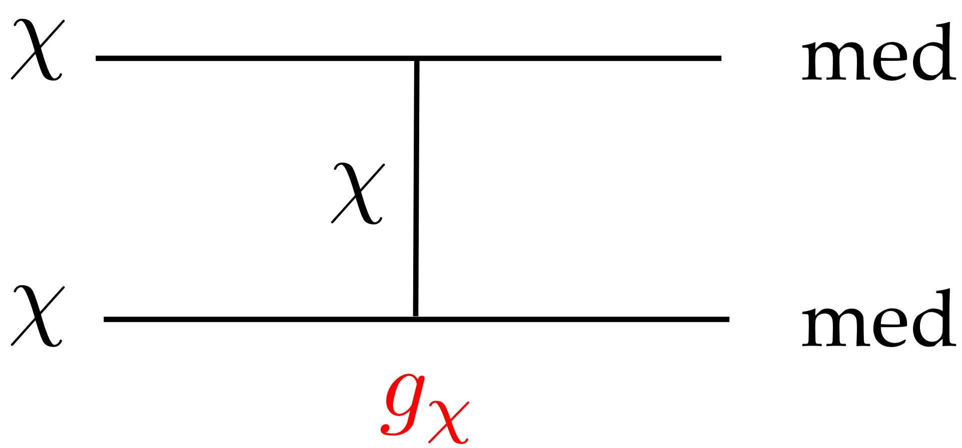

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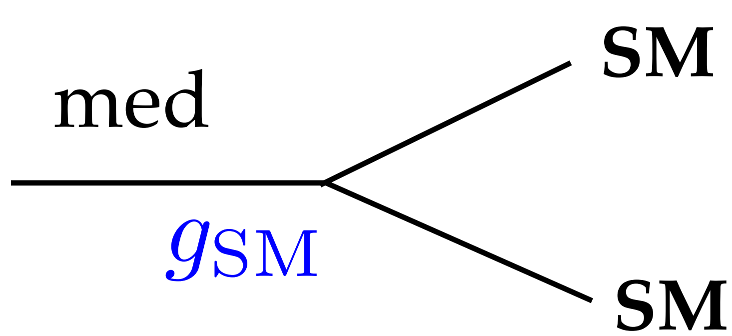

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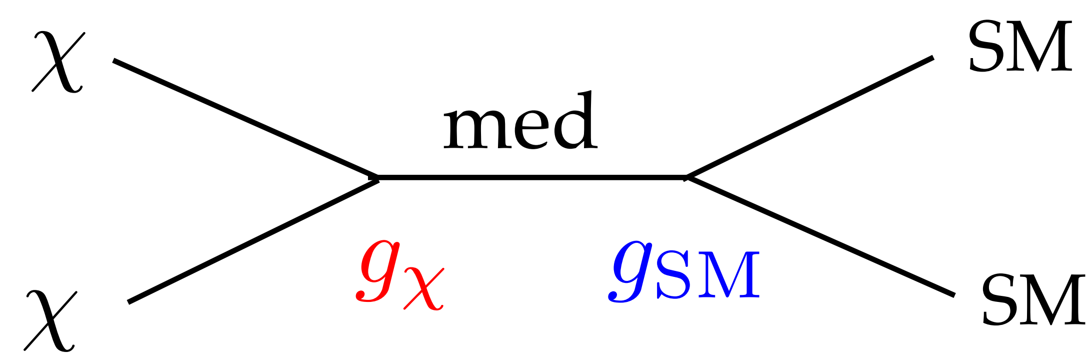
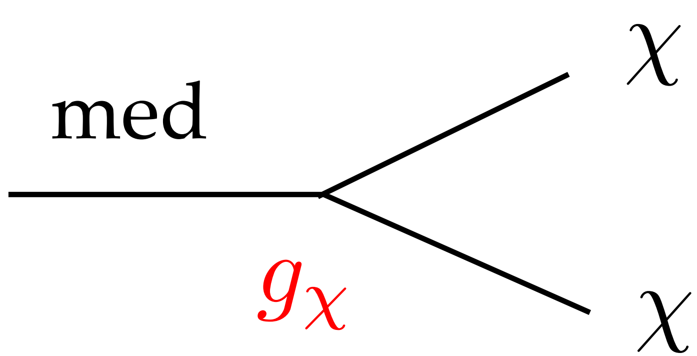


Predictive thermal targets

Abundance depends on g_{SM}



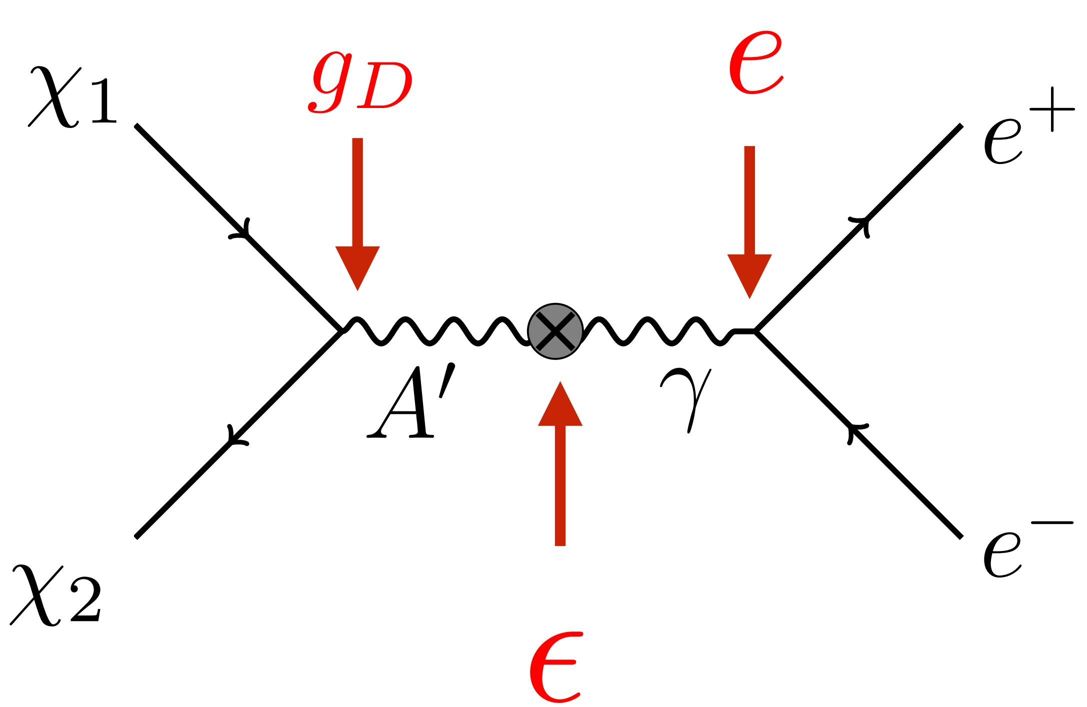
Mediator decays **invisibly***

Representative Model

Dark photon + "pseudo-Dirac" DM current

$$\mathcal{L} \supset g_D A'_\mu \bar{\chi}_2 \gamma^\mu \chi_1 + h.c.$$

Dominant process for relic abundance

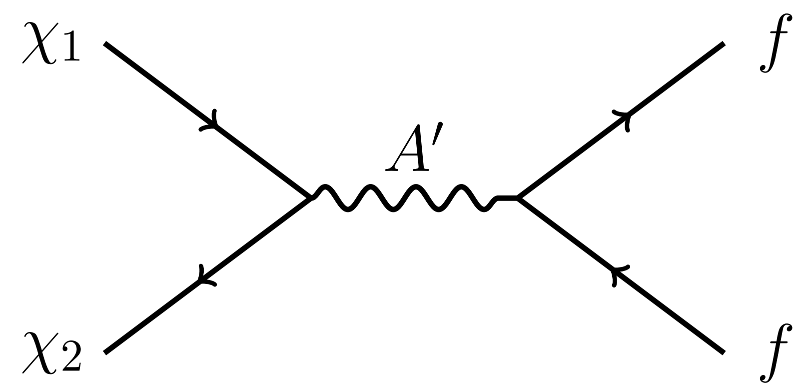


Direct annihilation

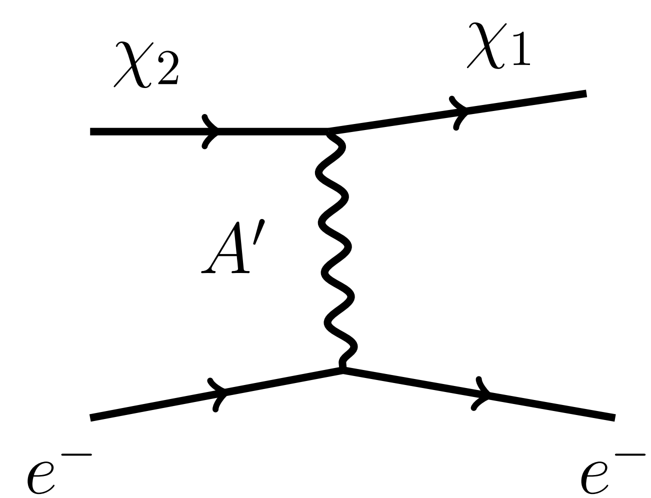
$$m_{A'} > m_1 + m_2$$

Representative Model: Inelastic Dark Matter

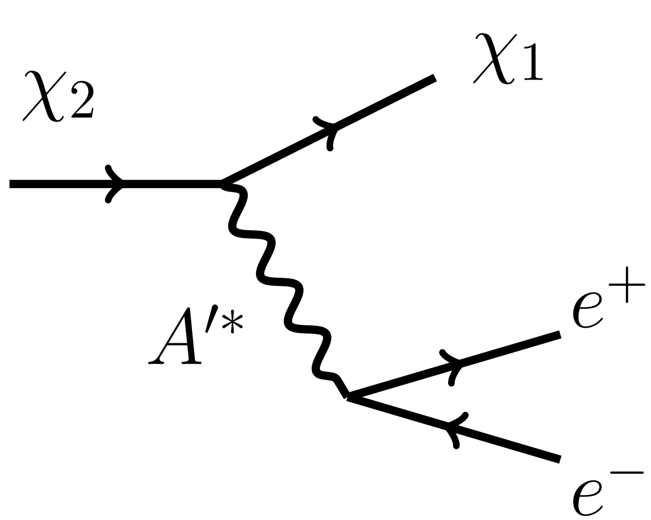
Coannihilation



Upscattering +
Downscattering

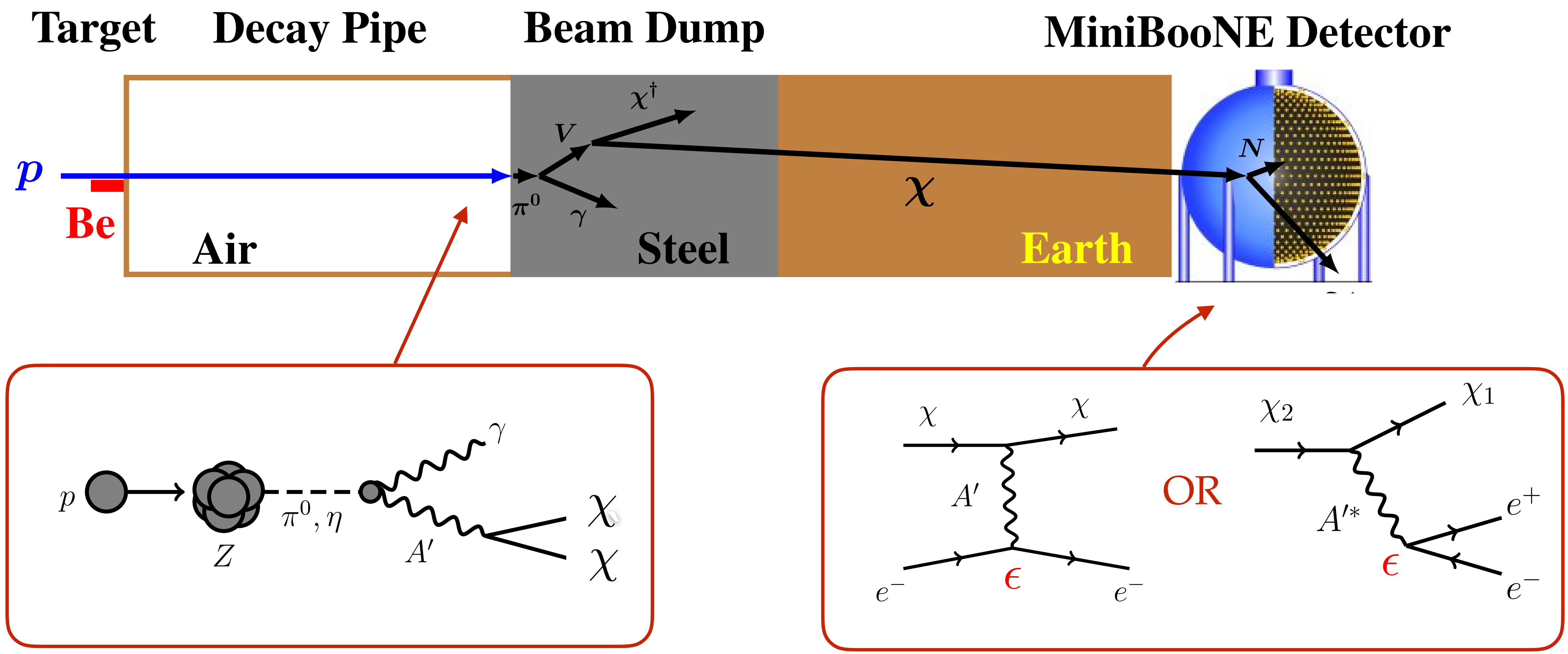


Excited State Decays



$$\Gamma(\chi_2 \to \chi_1 \; e^+ e^-) = \frac{4\epsilon^2 \alpha \alpha_D \Delta^5}{15\pi m_{A'}^4}$$

Beam Dump Strategy



$$N_p \sim 10^{20}$$

$$E_{\rm beam} \sim 10\,{\rm GeV}$$

$$[\text{production}] \times [\text{detection}] \propto \epsilon^4$$

Existing proton beam & neutrino detector

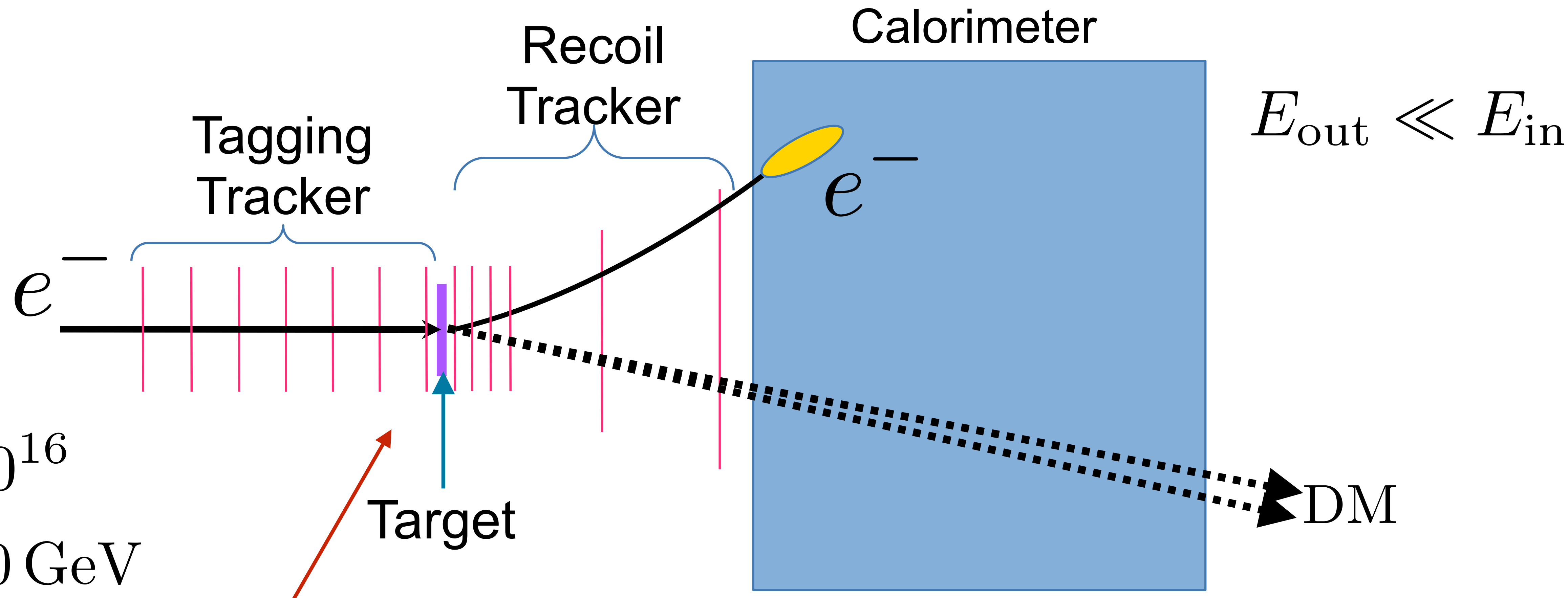
Relativistic direct detection (no halo)

Batell, Pospelov, Ritz 0903.0363

deNiverville, Pospelov, Ritz 1107.4580

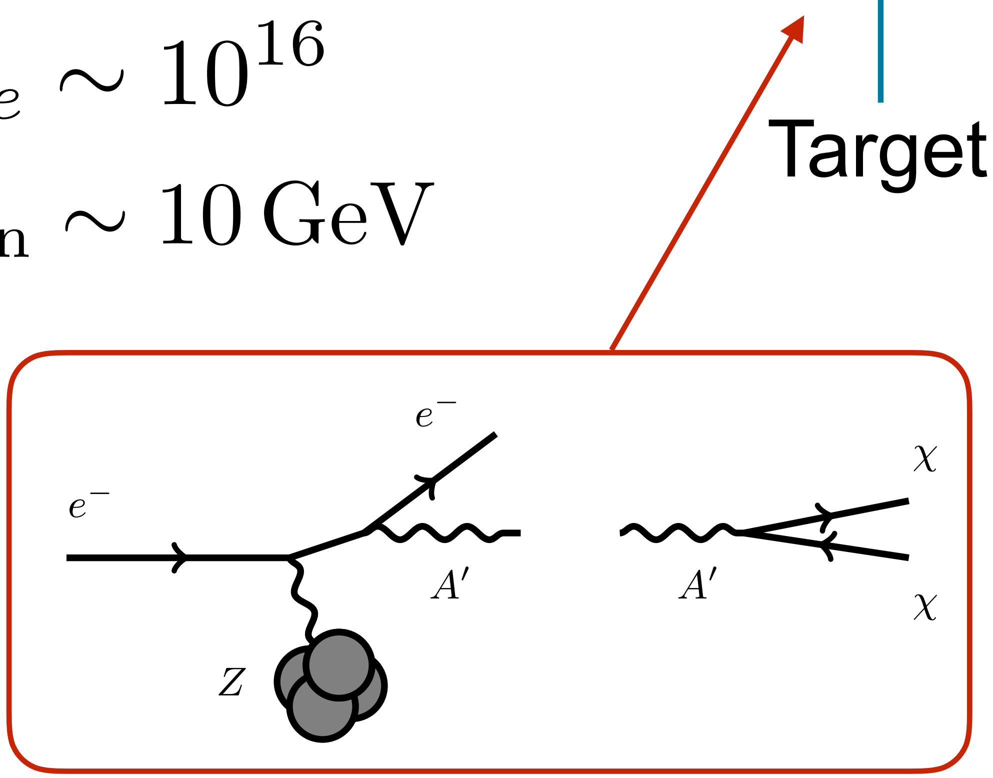
MiniBooNE Collaboration Phys. Rev. Lett. 118 (2017)

Missing Momentum Concept



$N_e \sim 10^{16}$

$E_{\text{in}} \sim 10\,\text{GeV}$



1) Measure **each** e- energy in/out
2) Trigger on missing momentum
3) Veto additional SM activity

Only measure electron beam — don't require DM to scatter

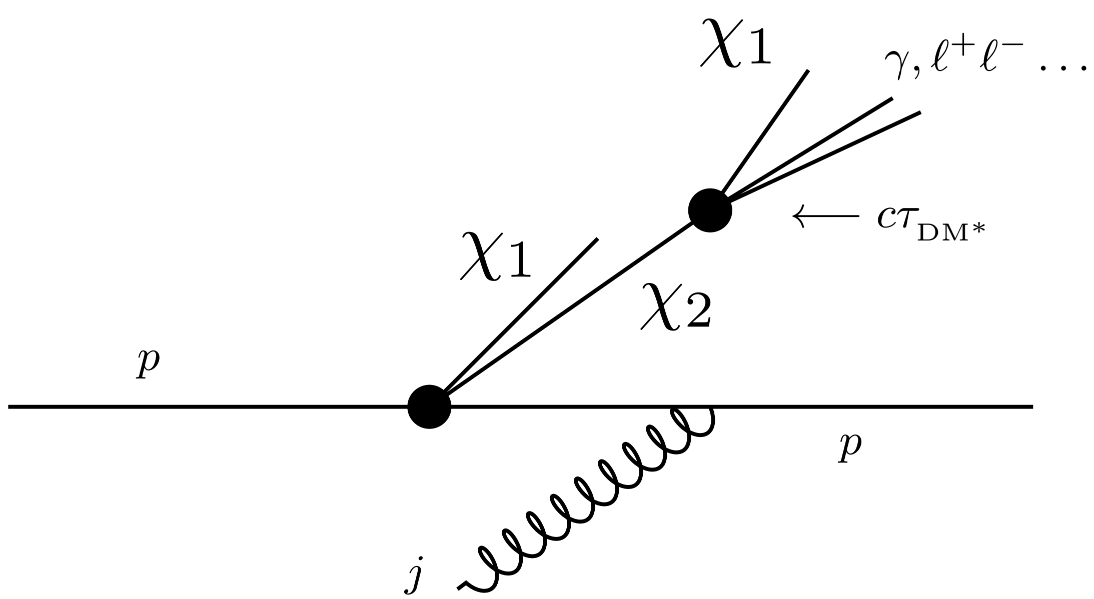
Signal $\propto \epsilon^2$

Izaguirre, GK, Schuster, Toro 1411.1404, LDMX 1808.05219, NA641906.00176

Colliders and LLP Displaced Vertices

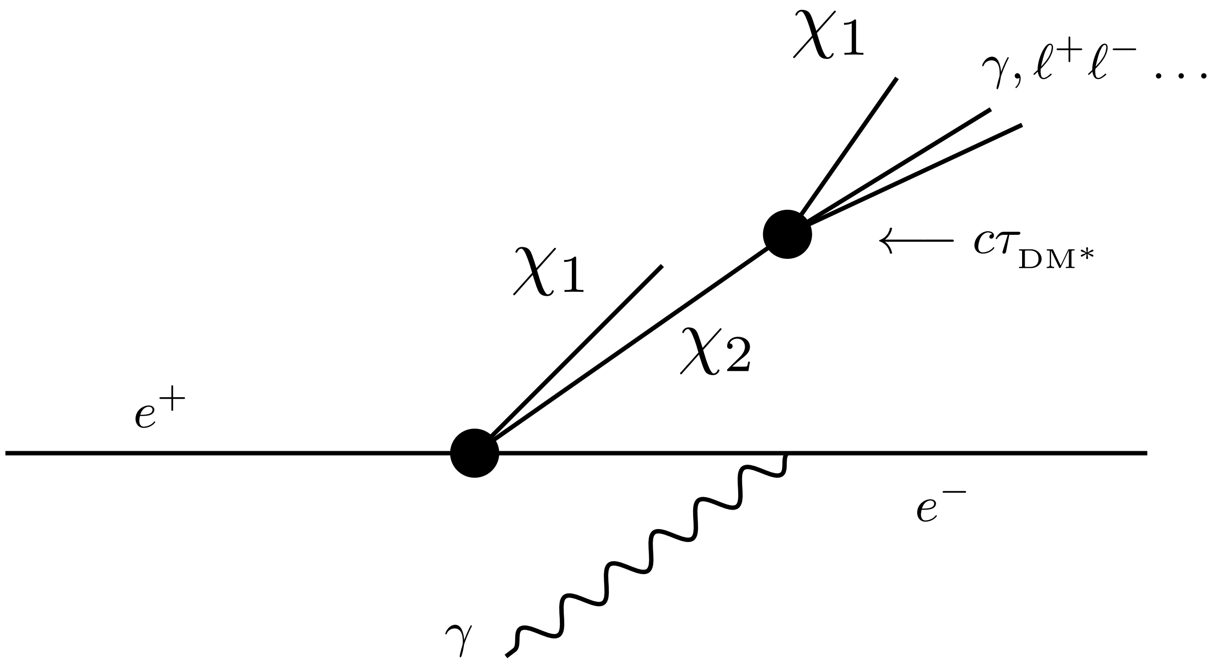
Hadron Collider

$$J + \not{E}_T + \ell^+\ell^-$$



Lepton Collider

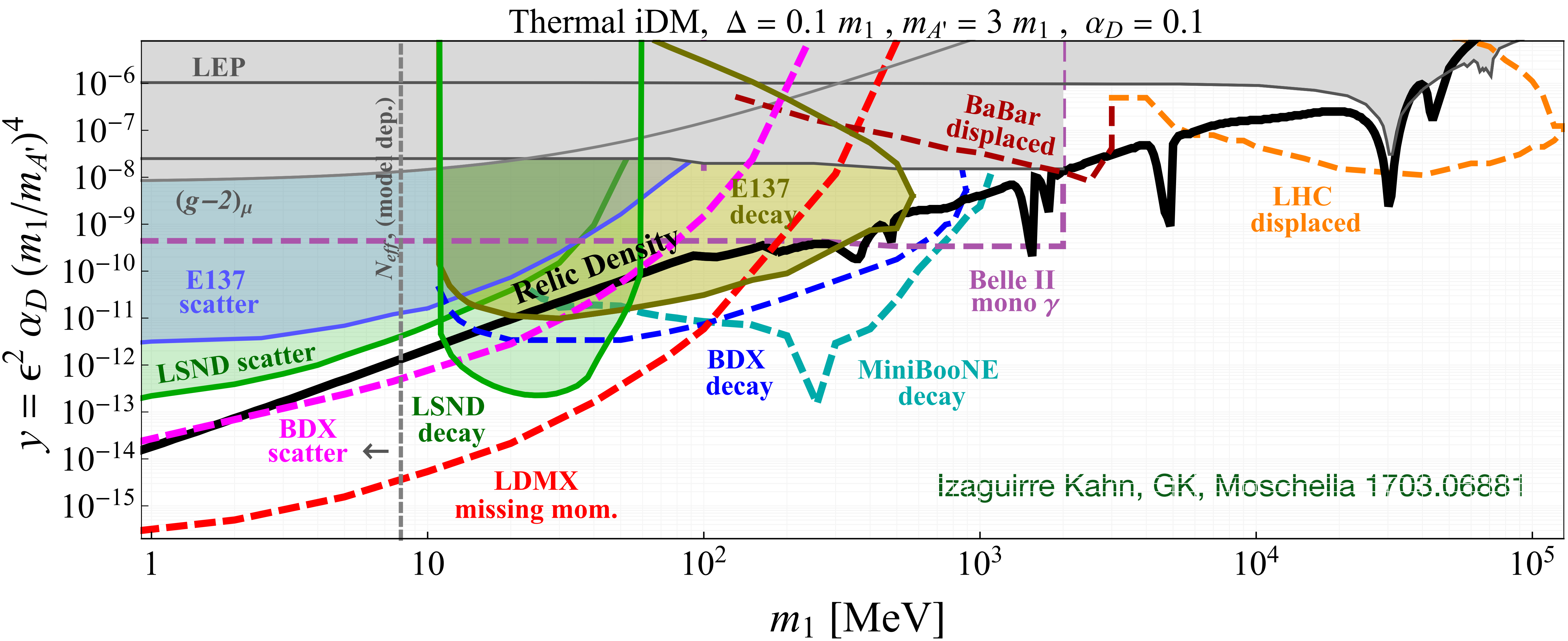
$$\gamma + \not{E} + \ell^+\ell^-$$



Fortin, Tait 1103.3289

Izaguirre, GK, Shuve 1508.03050

Testing Thermal DM Production Targets

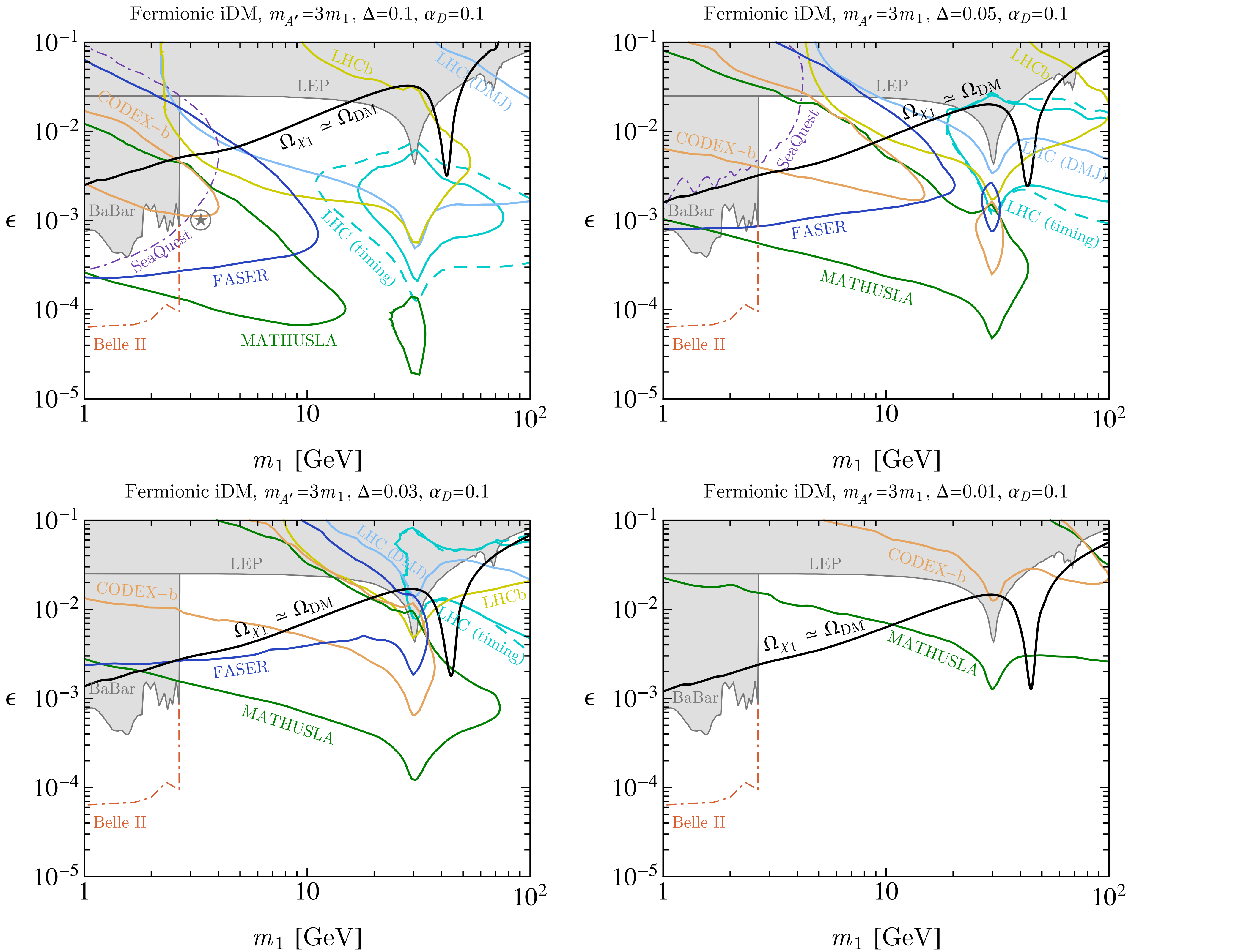


Broad variety of search strategies required to cover "thermal target"

See also Mohlabeng 1902.05075
deNiverville, Tsai, Liu 1908.07525
Berlin, Kling 1810.01879

and… Yu-Dai Tsai and Felix Kling's talks

Testing Thermal DM Production Targets



Updated studies: LLP only searches “lifetime frontier”

Berlin, Kling 1810.01879

Concluding Remarks

Broader priors on BSM physics: light weakly coupled states

Minimal single-particle SM extensions

New U(1) forces (e.g. B-L gauge boson)

Mixing with neutral SM states (e.g. sterile neutrino)

Search strategies

Prompt decays at colliders + B-factories

Displaced LLP searches at beam dumps

Adding < GeV Dark Matter

LLP signatures at colliders from inelastic DM decays

Comprehensively test thermal freeze out via coannihilation