Title: Testing Light Dark Matter Co-Annihilation Signatures with Fixed Target Experiments

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Abstract:

Light DM at Fixed Target Experiments

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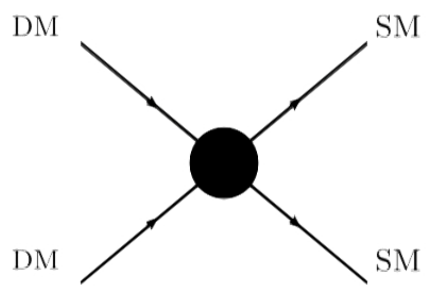
Based on 1703.06881

New Directions in Dark Matter and Neutrinos, July 21 2017

A Thermal Origin

Suppose DM was in thermal equilibrium with SM



$$\Gamma = n\sigma v$$

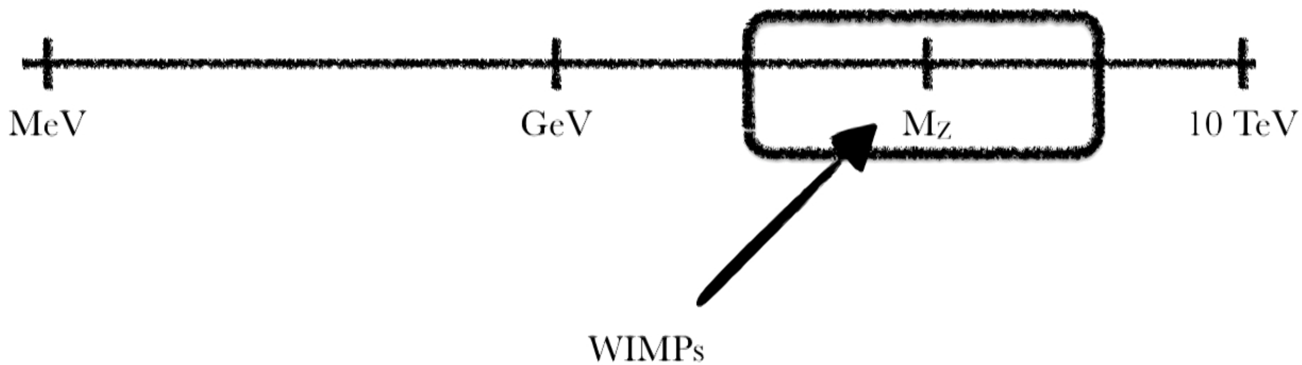
Thermal equilibrium will cease when

$$\Gamma < \Gamma_H$$

After this point, DM is "frozen out"

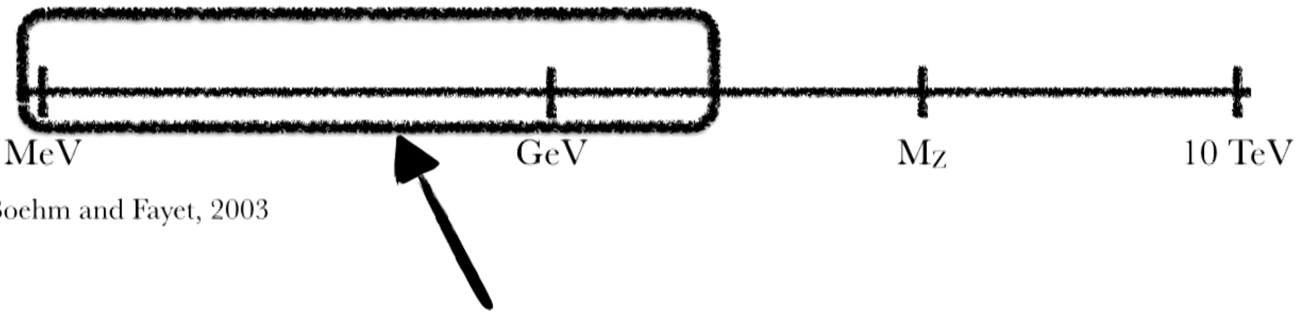
A Thermal Origin

A thermal origin gives us a restricted sharp target to aim for



Light DM

A thermal origin gives us a restricted sharp target to aim for



c.f. Boehm and Fayet, 2003

Light thermal DM in contact with SM necessarily requires a new force to avoid over closure

Can look for new SM-DM interaction and its mediator

Benchmarks/Models of Light DM

Must have light mediator
Need SM feebly coupled to mediator

Focus on marginal operators

Vector Portal (spin 1) $\epsilon_Y B^{\mu\nu} F'_{\mu\nu}$

Scalar Portal (spin 0) $\epsilon_h |h|^2 |\phi|^2$

Fermion Portal (spin 1/2) $\epsilon_\nu L h \psi$

Benchmarks/Models of Light DM

Must have light mediator
Need SM feebly coupled to mediator

Focus on marginal operators

This talk: $\epsilon_Y B^{\mu\nu} F'_{\mu\nu}$

Also can be seen as simplified model
e.g., very similar phenomenology to gauged B - L models

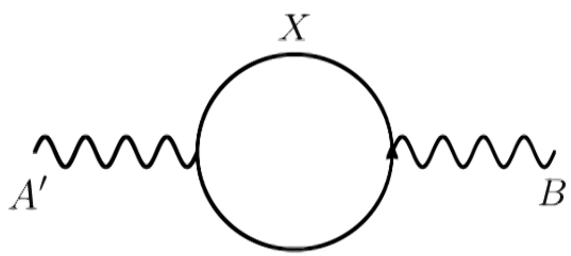
The Vector Portal

Holdom - 1985

Minimal Lagrangian = SM Lagrangian + Dark QED + "Kinetic Mixing"

$$\mathcal{L} \supset -\frac{1}{4}B^{\mu\nu}B_{\mu\nu} - \frac{1}{4}F'^{\mu\nu}F'_{\mu\nu} - \frac{\kappa}{2}B^{\mu\nu}F'_{\mu\nu} + \frac{1}{2}m^2_{A'}A'^{\mu}A'_{\mu}$$

Even if absent from fundamental theory the "kinetic mixing term" can be generated through virtual effects of massive particles



$$B^{\mu\nu} \equiv \partial^\mu B^\nu - \partial^\nu B^\mu$$

$$B^\mu = \cos\theta_W \gamma^\mu - \sin\theta_W Z^\mu$$

$$F'^{\mu\nu} \equiv \partial^\mu A'^\nu - \partial^\nu A'^\mu$$

Induce $\kappa \sim \frac{g_D g_Y}{16\pi^2} \sim 10^{-3}$

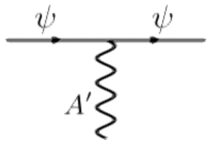
Matter in the Dark Sector

Can expect DS matter states to be split (inelastic)

Start with a Dirac fermion $\psi = \begin{pmatrix} \eta & \xi^\dagger \end{pmatrix}$ charged under a $U(1)_D$ symmetry

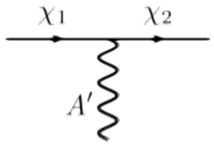
The vector current is diagonal

$$\mathcal{J}^\mu = \overline{\psi}\gamma^\mu\psi = \eta^\dagger\overline{\sigma}^\mu\eta - \xi^\dagger\overline{\sigma}^\mu\xi$$



Gauge invariance only allows a Dirac mass
But if dark symmetry spontaneously broken can also get

$$-\mathcal{L} \supset m\bar{\psi}\psi + y\langle v_D\rangle\bar{\psi}^c\psi + h.c.$$



Split States

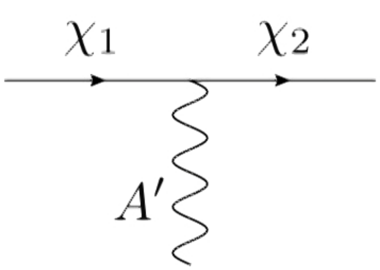
The mass eigenstates

$$\chi_1 = i(\eta - \xi)/\sqrt{2}\ ,\ \ \chi_2 = (\eta + \xi)/\sqrt{2}$$

c.f. Tucker-Smith and Weiner, 2001

now have (dominantly) off-diagonal interactions

$$\mathcal{J}^\mu = i(\chi_1^\dagger \overline{\sigma}^\mu \chi_2 - \chi_2^\dagger \overline{\sigma}^\mu \chi_1)$$



Kinetic Mixing Portal Model

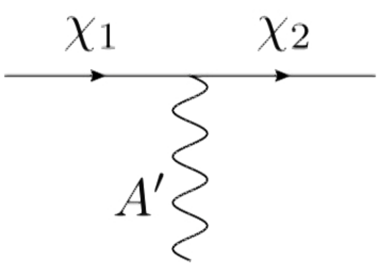
The mass eigenstates

$$\chi_1 = i(\eta - \xi)/\sqrt{2}\ ,\ \ \chi_2 = (\eta + \xi)/\sqrt{2}$$

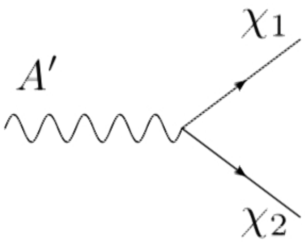
now have (dominantly) off-diagonal interactions

$$\mathcal{J}^\mu = i(\chi_1^\dagger \overline{\sigma}^\mu \chi_2 - \chi_2^\dagger \overline{\sigma}^\mu \chi_1)$$

Will focus on decay to DS hierarchy



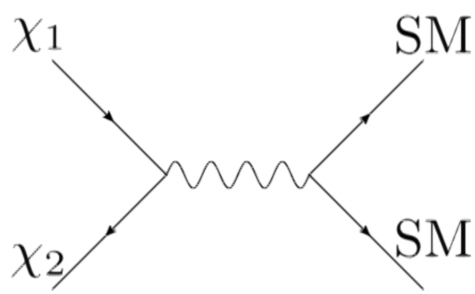
$$m_{A'} > m_1 + m_2$$



A Viable DM Candidate?

DM could have obtained its present abundance from thermal freeze-out

In the early universe, in thermal contact with SM predominantly through



$$m'_A \gg m_1 \gg \Delta \to \quad \langle \sigma v \rangle \approx \frac{y}{m_1^2}$$

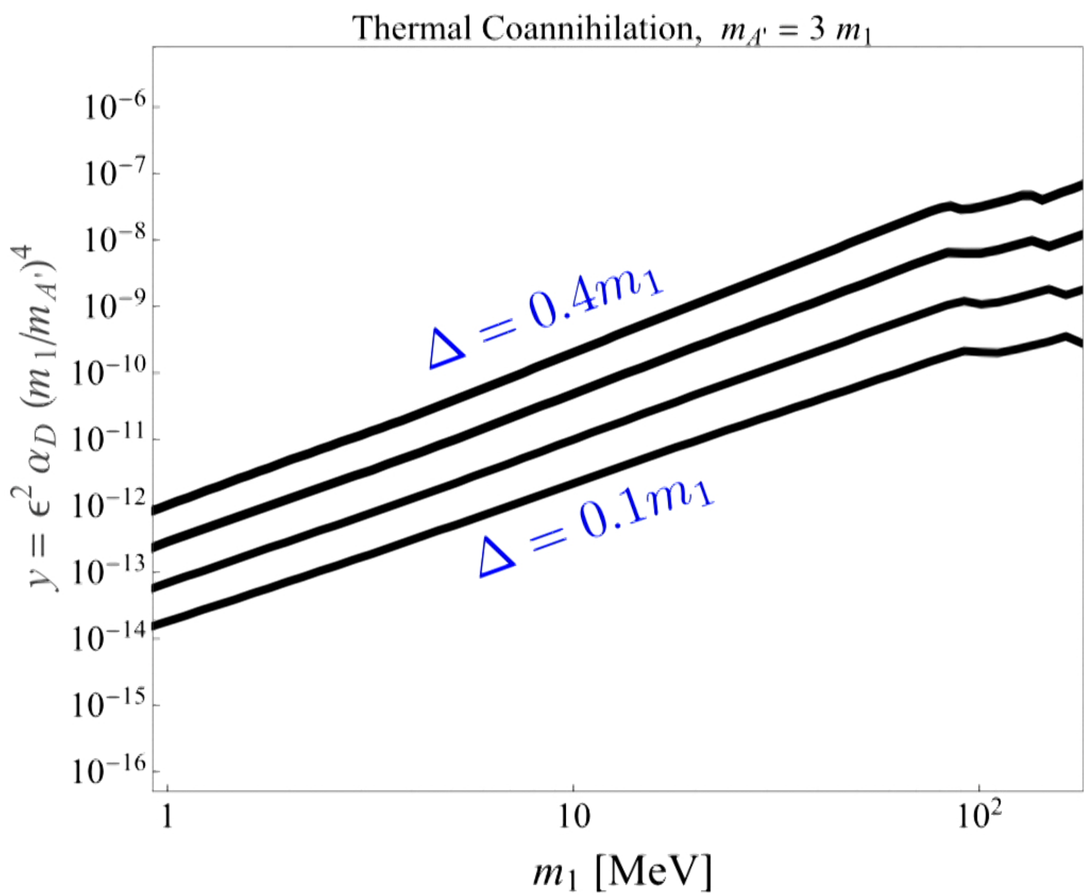
$$y = \alpha_D \epsilon^2 (m_1/m_{A'})^4$$

Co-annihilation most efficient when

$$\Delta = m_2 - m_1 \ll m_1$$

In this talk: Will focus on unexplored territory of MeV - GeV GeV

Thermal Target



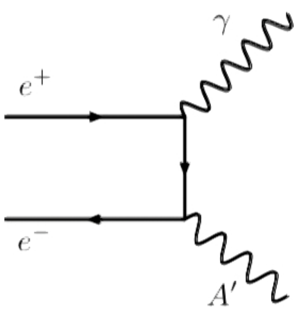
What We Need is Tons of Collisions

Want to probe tiny couplings
Need to increase N_{signal}

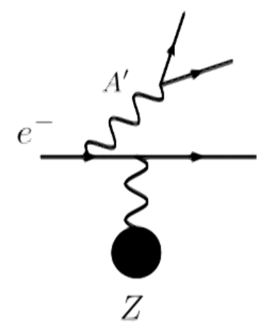
$$N_{\text{signal}} = \text{Lum} \times \sigma_{\text{prod}} \times \text{P}_{\text{det}}$$

Two possibilities: collider or fixed-target

Collider



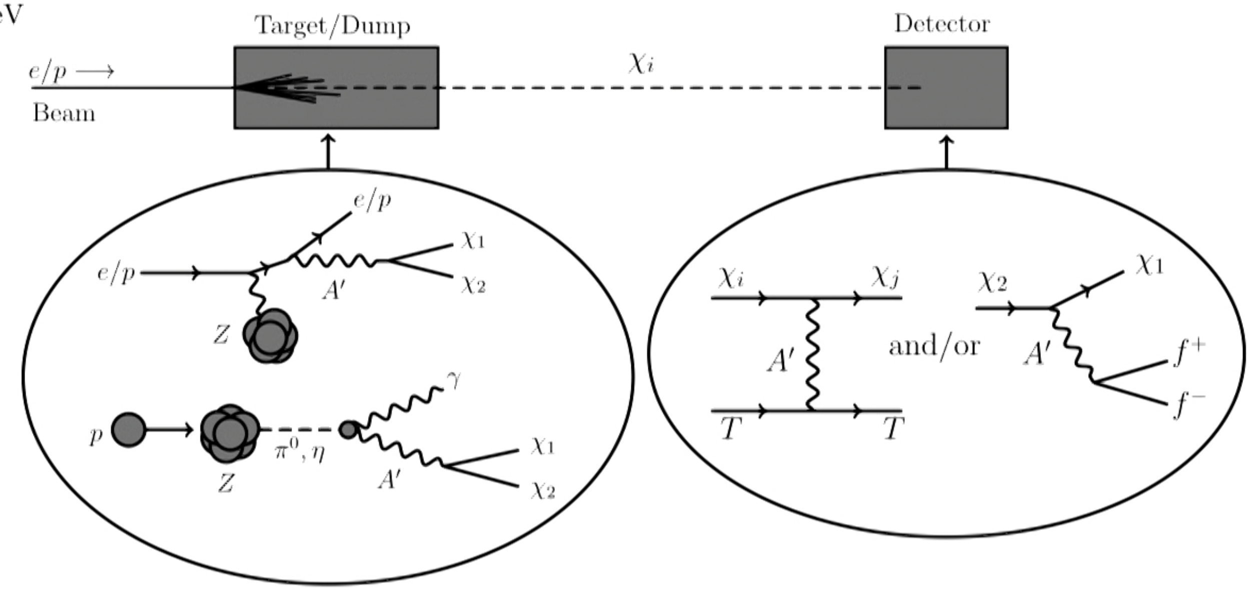
Fixed-Target



Approach 1: Beam-Dump Signatures

$N_{e/p} \sim 10^{20-22}$

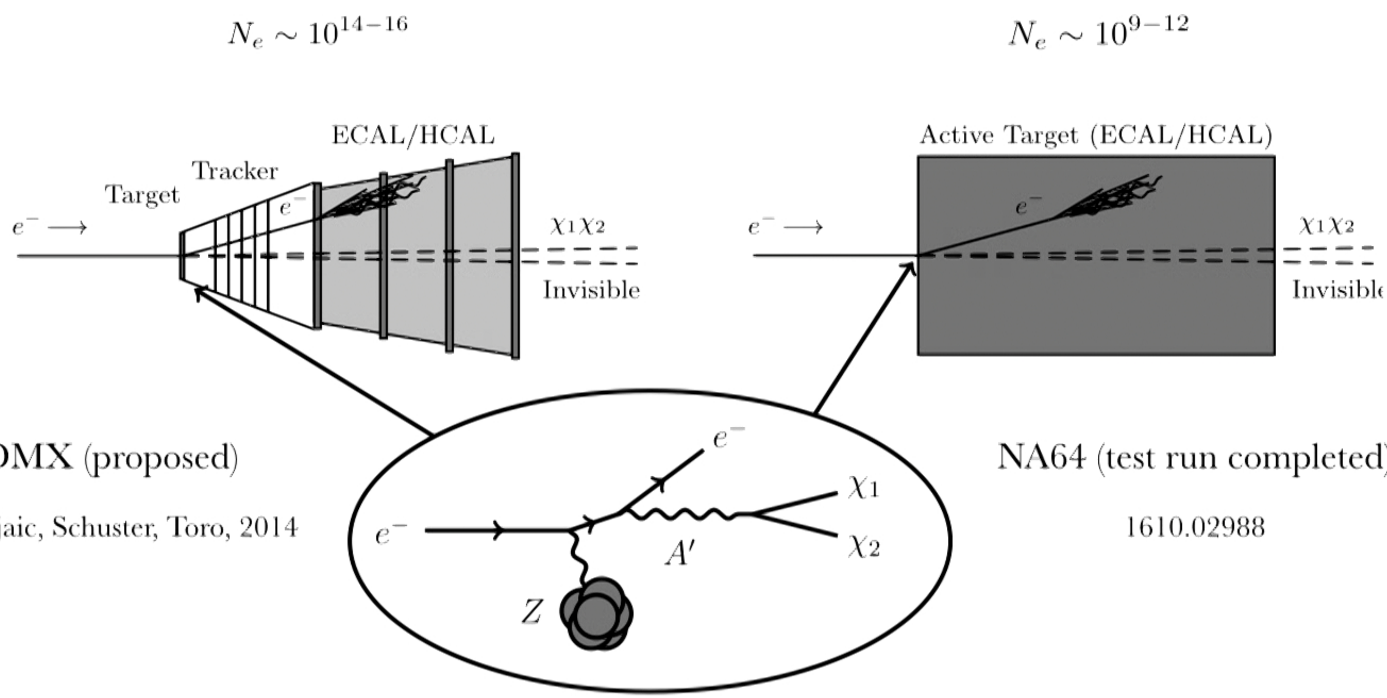
$E_{e/p} \sim 10$ GeV



Approach 1: Beam-Dump Signatures

Proton facilities	
LSND (past)	deNiverville, Pospelov, Ritz, 2011
MiniBoone (present near future)	MiniBoone cn 1702.02688
SBN (future)	
Electron facilities	
E137 (past)	Batell, Essig, Surujon, 2014
BDX (proposed)	1607.0390

Approach 2: Missing Energy Signatures



LDMX (proposed)

EI, Krnjaic, Schuster, Toro, 2014

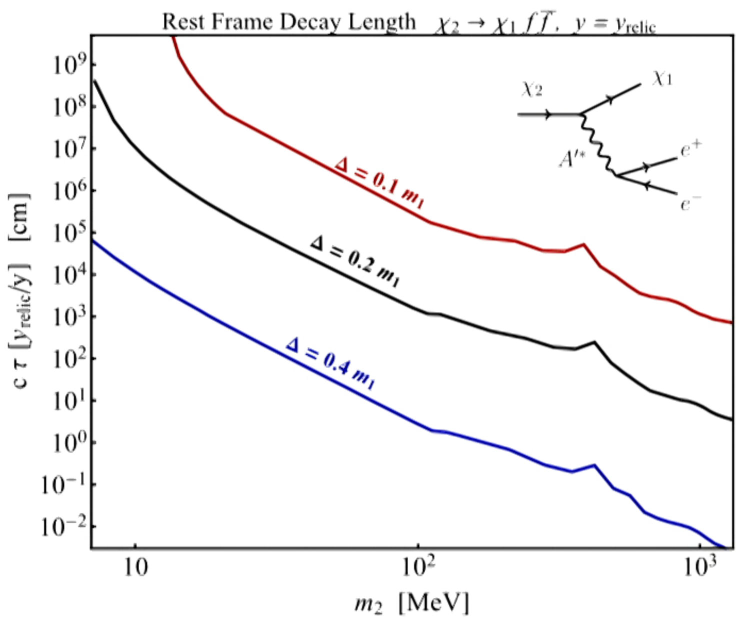
NA64 (test run completed)

1610.02988

Decay vs Scattering Signals

$$R \equiv \frac{P_{\rm decay}}{P_{\rm scatter}} \simeq \frac{\Delta^5}{60\pi^2\gamma E_\chi m_e n_e}$$

$$R \simeq 3\left(\frac{m_1}{20\,{\rm MeV}}\right)\left(\frac{\Delta}{0.1 m_1}\right)^5\left(\frac{10\,{\rm GeV}}{E_\chi}\right)^2$$



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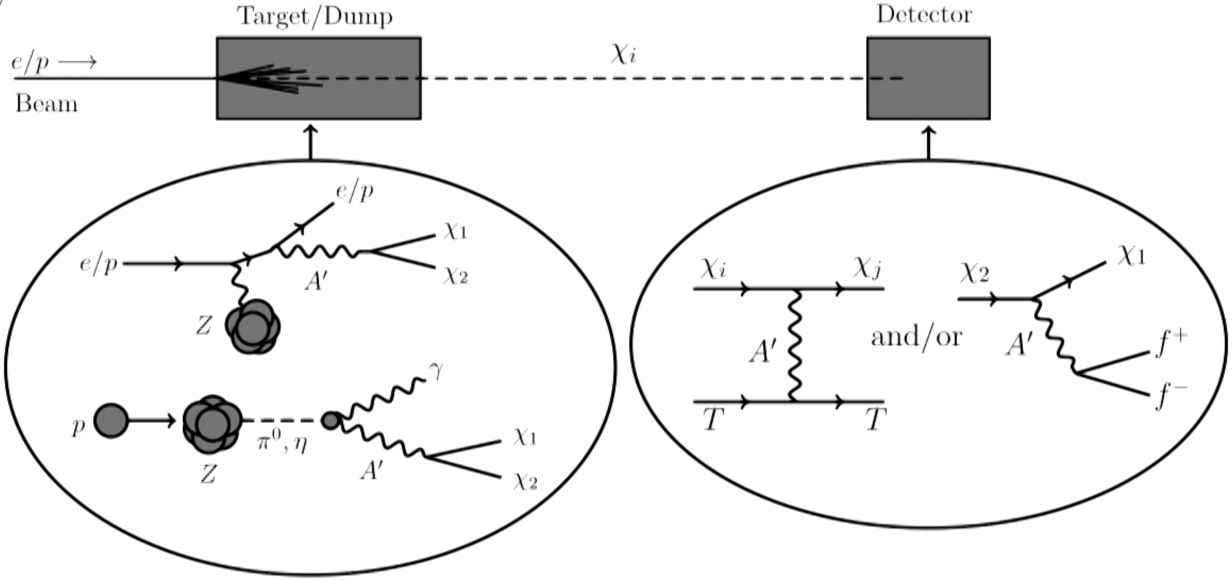
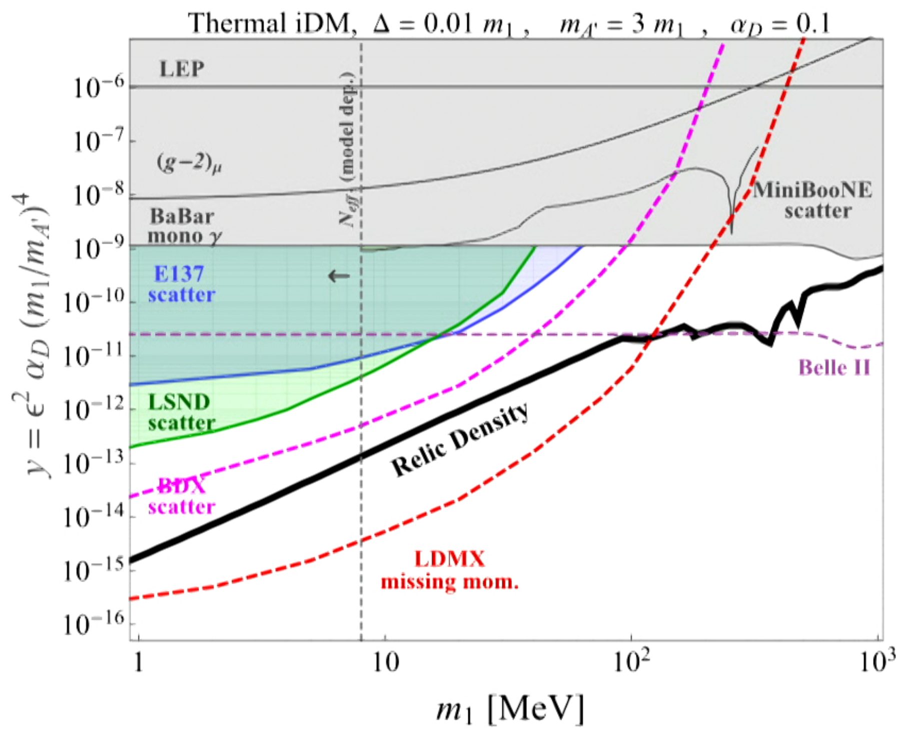


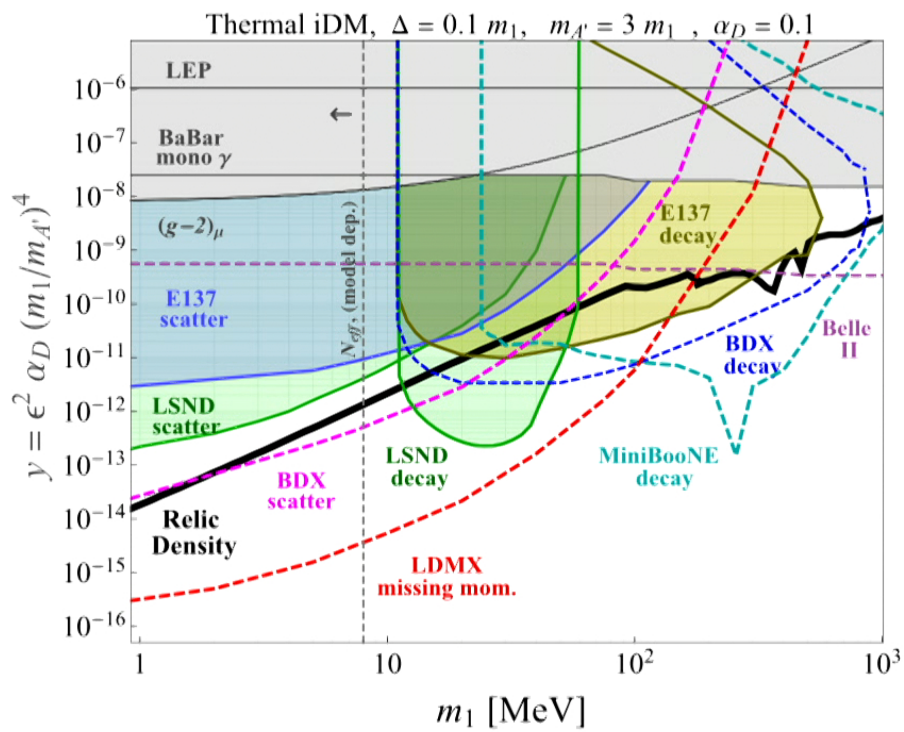
Small Splittings: 1%

Only scattering allowed



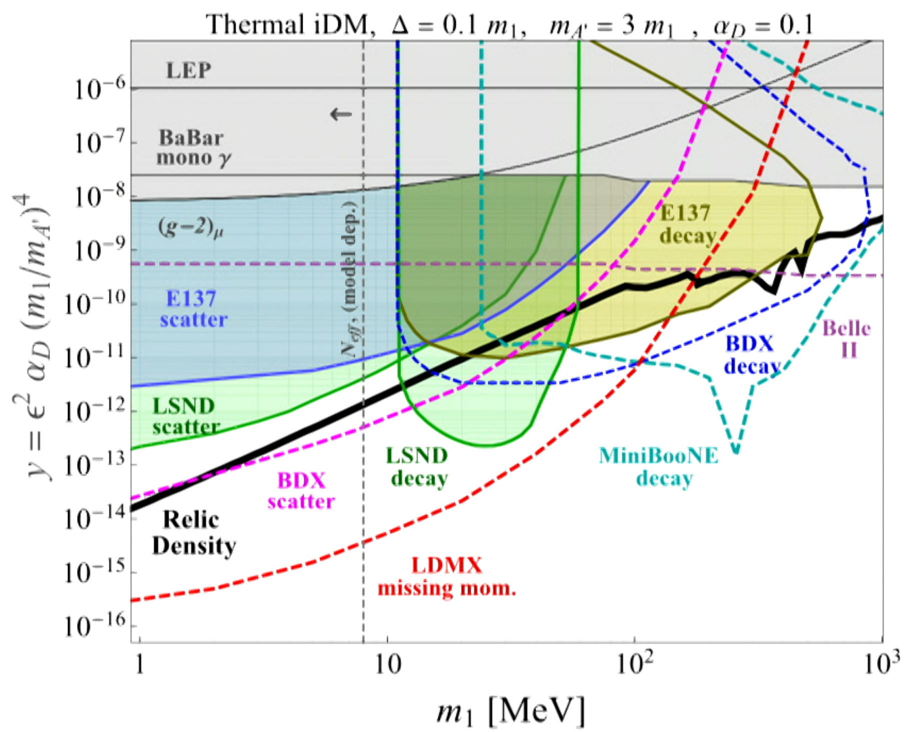
Moderate Splittings: 10%

Scattering and decays allowed

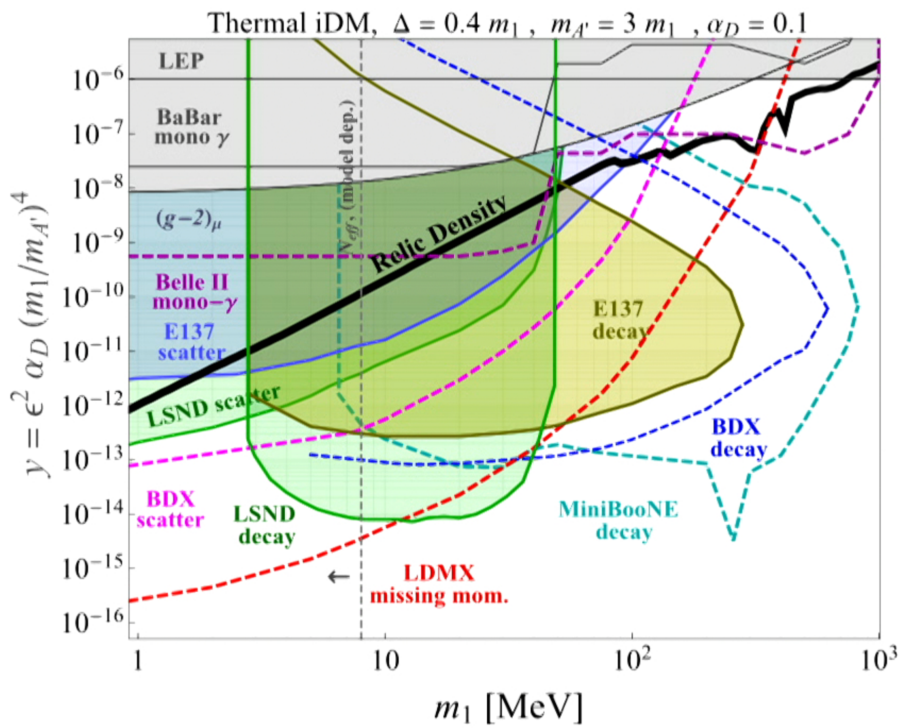


Moderate Splittings: 10%

Scattering and decays allowed



Moderate Splittings: 40%



Conclusions

Fixed-target experiments are awesome